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DEVELOPMENT OF FABRICATION PROCEDURES
FOR CORE B FUEL ELEMENTS FOR THE ENRICO
FERMI FAST BREEDER REACTOR

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

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JULY 1964

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ABSTRACT

The work described in this report is the result of a program at the Oak Ridge National Laboratory to develop procedures for fabricating the proposed Core B fuel element of the Enrico Fermi Fast Breeder Reactor. The element consists of fourteen 0.112-in.-thick fuel plates spaced 0.054-in. apart to form a rigid bundle 2.270-in. high $\times$ 2.386-in. wide $\times$ 20 3/32-in. long fabricated to extremely close tolerances. The attachment of a multiplicity of additional components, such as spacers, bushings, wear balls, and seal strips, was also required.

A total of six dummy solid stainless steel and seven prototype elements containing depleted UO_2 was fabricated by furnace brazing. Over 100 individual parts were joined for each fuel element in a single brazing operation. The nickel-chromium-silicon brazing alloy chosen for this application met all brazing, corrosion, strength, and nuclear requirements. Special fixtures and techniques were developed for the complex and close tolerance machining work, and special procedures were developed for inspecting the various critical dimensions of the element. A detailed description of all procedures used is presented, and, with one exception, it is believed that these procedures can produce fuel elements meeting the specifications. The exception is the inability to consistently maintain the coolant-channel width within 2.246 ± 0.002 in.

INTRODUCTION

In the fall of 1960, a program was initiated at ORNL to develop methods and procedures for the fabrication of fuel elements intended for use as Core B of the Enrico Fermi Fast Breeder Reactor. Atomic Power Development Associates, an affiliate of the Power Reactor Development Company, was responsible for the engineering design of the core. Fabrication of axial and radial blanket subassemblies was not considered in this program.

Core B uses UO_2 -stainless steel cermet fuel to obtain longer fuel life, high reactor power level, and, consequently, more economical power production than was possible with Core A. Core B is designed for a core loading of 130 fuel subassemblies (greater than 500 kg ^{235}U) and a reactor power level of 300 Mw. The inlet temperature of the sodium coolant is 550°F and the exit temperature is 812°F . Coolant pressure drop across the subassemblies is about 90 psi. Burnup is expected to average about 21% of the ^{235}U throughput.

The fuel element consists of fourteen 0.112-in.-thick fuel plates¹ spaced at 0.054-in. intervals to form a rigid bundle 2.270-in. high $\times$ 2.386-in. wide $\times$ about 20-in. long as shown in Fig. 1. The fuel plates consist of a UO_2 dispersion of 35 wt % (about 27.5 vol %) in stainless steel with a 0.005-in.-thick stainless steel cladding. The attachment of a number of additional components such as spacers, bushings, wear balls, and seal strips was also required. Two fuel elements, one upper and one lower, are incorporated in a stainless steel wrapper can to form a core subassembly.

Because of the rigorous operating conditions in this high performance reactor, extremely close tolerance requirements were mandatory in this assembly as typified by the plate spacing requirements of 0.054 ± 0.002 in. on the average with a maximum local deviation of ± 0.005 in. A similarly rigid requirement was placed on the element height (2.270 ± 0.005 in.). The height tolerance is obviously difficult to maintain since the bundle is to be built up of 14 individual plates and 13 layers of spacers, each fabricated with a thickness tolerance of ± 0.001 in. The conventional grooved side plate design generally used for other flat plate fuel elements was not used since it was felt that the ± 0.002 -in. average tolerance on the plate spacing would be difficult to meet by this method.

¹J. H. Cherubini et al., Fabrication Development of UO_2 -Stainless Steel Composite Fuel Plates for Core B of the Enrico Fermi Fast Breeder Reactor, ORNL-3077 (April 4, 1961).

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ORNL-LR-DWG 53039AR3

Fig. 1. Enrico Fermi Core B Fuel Element.

Because it was necessary for the Core B fuel elements to fit the existing core grid work of the reactor, the design of the fuel elements was basically fixed. The method of attachment of the various components was open for development, but the geometries and dimensions were not. Thus, few changes from the original drawings were permitted, and these were primarily in the method of dimensioning.

The fuel element assemblies generated as part of this program were destined for specific tests as determined by Atomic Power Development Associates. To fulfill the testing needs, many of the elements were fabricated in sets of two. The APDA testing program is presented in Table 1.

In addition to the fabrication development performed at ORNL, three solid stainless steel and one fuel-containing prototype fuel element were assembled and vacuum brazed by a commercial brazing company.² This permitted determination of some of the assembly and brazing difficulties that a commercial fabricator might encounter and also permitted a comparison between vacuum and dry-hydrogen brazing.

The major endeavor in the assembly development program was to determine fabrication techniques which, when transferred to industrial practice, could consistently achieve design requirements. The construction of the necessary test hardware during the course of the fabrication development served to provide a wealth of useful information for the development of satisfactory procedures.

DESCRIPTION OF COMPONENTS

Each of the components which make up the fuel element is described in this section. Engineering drawings of all components are presented in Appendix A-1. The names of each of the parts and the quantity required are listed below and it is suggested that cross reference to Fig. 1 will be helpful.

²UCNC Purchase Order No. 93X24566 with Vac-Hyd Processing, Inc., Detroit, Michigan, Nov. 14, 1960.

Table 1. APDA Fuel Element Testing Program

Test	Fuel Elements	Comments
<u>Hydraulics</u>		
Total Pressure Drop	ORNL-1, ORNL-2	Solid stainless steel plates
Annulus Flow Rate	—	Required no elements
Flow Distribution Between Plates	ORNL-3, Vac-Hyd-3	Solid stainless steel plates with pressure tap holes
Annulus Flow Variation	ORNL-3, Vac-Hyd-3	Solid stainless steel plates with pressure tap holes
<u>Endurance</u>		
Core Subassembly Sodium Endurance	ORNL-P-1, ORNL-P-2	Fueled plates
<u>Structural</u>		
Material Properties	—	Required no elements
Plate Thermal Cycle	—	Required no elements
Plate-Rib Joint Mechanical Test	—	Required no elements
Plate-Rib Joint Thermal Cycle	Special assembly	Three-plate assemblies with fuel
Plate Assembly Thermal Shock	ORNL-P-1	Fueled plates
Core Subassembly Bowing	Undesignated	Element with fueled plates
Core Subassembly Distortion	Undesignated	Element with fueled plates

<u>Components</u>	<u>Fuel Element</u>	
	<u>Upper</u>	<u>Lower</u>
Top Fuel Plate	1	1
Inner Fuel Plates	10	10
Notched Fuel Plates	2	2
Bottom Fuel Plate	1	1
Long Edge Spacers	20	20
Short Edge Spacers (Front)	6	6
Short Edge Spacers (Rear)	6	6
Center Spacers	13	13
Center Spacer Stubs	10	13
Round Center Bushings	2	2
Square Center Bushings	2	2
End Bushing	1	1
Spring Fingers	2	2
Wear Bearings	8	8
Long Seal Strips	16	16
Short Seal Strips	16	16
Bearing Bars	2	2
Interlock Lug	1	0

Fuel Plates

Each of the 14 plates in a fuel element contains a core of spherical UO_2 particles dispersed in a matrix of type 347 stainless steel.³ The core is fabricated by powder metallurgical techniques and is assembled with a picture frame for roll cladding into a composite fuel plate. After rolling to 0.112 ± 0.001 -in. total thickness, the plates have a 0.005-in.-thick cladding of type 347 stainless steel.

The core center line in each plate is determined from radiographs so that each plate can be machined accurately to the proper width and length. Gage pin and end bushing holes are also machined at this time. After machining radii on the leading and trailing edges of the plates, they are ready for assembly.

³J. H. Cherubini et al., Fabrication Development of UO_2 -Stainless Steel Composite Fuel Plates for Core B of the Enrico Fermi Fast Breeder Reactor, ORNL-3077 (April 4, 1961).

Spacers

Attempts were made to purchase spacers with both square and rectangular cross sections (a small radius on the spacer edges was acceptable). However, difficulty was experienced in obtaining bids for research quantities of these spacers from commercial vendors. The first vendor was unable to meet the fabrication tolerances which included, at that time, a ± 3 -mil tolerance on the width dimension and a ± 1 -mil tolerance on the thickness. The second vendor supplied acceptable, square cross-section center spacers but failed in two attempts to fabricate acceptable, rectangular cross-section edge spacers.

As a result, most of the spacers used throughout this study were fabricated at ORNL from type 347 stainless steel weld wire. The wires were annealed and drawn through a turk's-head die roll to provide the desired cross sections. After a subsequent anneal, the wires were deburred and stretch-straightened. No difficulty was encountered in fabricating either type of spacer to ± 0.001 -in. tolerances by this method.

Bushings

Each fuel element is contained in a stainless steel wrapper can which fixes its position in the reactor core and provides the main channel for sodium flow. Fuel elements are retained in this wrapper by pins protruding through the can wall and into bushings that contain accurately machined recesses as shown in Appendix A-4. Galling between the pins and bushings was expected to be a problem because of the expansion and bowing of the elements during operation. Consequently, a hard material was selected for both the pins and bushings (wrought Stellite 6B;⁴ nominal composition: Co-30 Cr-4 W-1 C). As will be seen later, this material can be brazed readily to the stainless steel fuel plates and presents no particular problem to the fuel element fabrication except in machining.

⁴Product of the Stellite Division of the Union Carbide Corporation.

Seal Strips and Bearing Bars

The seal strips, which, in effect, are 0.009-in.-thick leaf springs, are placed on the outer surfaces of the fuel element in such a manner that they form a double spiral path to channel the sodium coolant around the element. They must be metallurgically bonded to the top and bottom fuel plate surfaces over their full contact area to provide adequate heat transfer. This requirement does not exist for the strips on the sides of the bundle since there is no fuel close to the surface.

The material originally selected for these springs was type 347 stainless steel but later was changed to type 19-9-DL stainless steel (nominal composition: Fe-19 Cr-9 Ni-1.25 Mo-1.2 W-1.1 Mn-0.6 Si-0.4 Nb-0.3 Ti-0.3 C) which possesses better properties for this application. Because of the titanium oxide formed on the surface, type 19-9-DL stainless steel is not recommended if hydrogen brazing is to be used, but it can be used readily in vacuum brazing where the oxide does not form.

The bearing bars (see Appendix A-1) are attached to the fuel element sides, parallel to the seal strips at the bushing end (see Appendix A-2). Their function is to keep the element from contacting the wrapper can if the element bows during operation.

Spring Fingers and Wear Bearings

The spring fingers aid in positioning the element in the wrapper can. Since two of the four spring fingers are integral with top and bottom fuel plates (see Appendix A-1), only the two side spring fingers remain to be attached to an element. This is done as noted in the section on Spring Finger Attachment.

The wear bearings were a purchased item of Stellite No. 93 (nominal composition: Fe-17 Cr-16 Mo-6 Co-3 C-1.9 V).⁴ The wear bearings, which are attached to the spring fingers, bear on the inside of the wrapper can and provide sliding point contacts. The method of attachment is explained in the appropriate section on Wear Bearing Attachment.

INVESTIGATION OF WELDING AS A FABRICATION METHOD

In view of the general availability of welding equipment and high-quality welding procedures in most commercial fuel element manufacturing facilities, welding was initially considered as the primary process for fabricating the Core B element. Although the attachment of several bushings and spacers undoubtedly necessitated some brazing, welding appeared to be potentially attractive for the joining of the edge spacers and fuel plates into a rigid bundle. The main problem anticipated was the distortion reported by previous investigators on similar types of joints.⁵ The expected large thermal stresses required that the joints between these components be sound and that weld penetration be complete.

Weld samples were prepared and preliminary tungsten-arc experiments quickly revealed that the conditions necessary for complete penetration of the plate-spacer joint produced severe distortion of the assembly. Programing of the welding sequence failed to significantly counteract this effect. Figure 2 shows cross sections of two sample welds. It is obvious that only about 30% penetration was obtained using a current of 75 amp at 12 in./min. Increasing the current to 100 amp gave practically no improvement in penetration but merely increased the width of the weld and the distortion.

Electron-beam welding would have undoubtedly minimized the distortion since the heat produced is much more concentrated. However, the process was not investigated in this study since other investigators had encountered difficulties in consistently obtaining uniform penetration⁶ and since the equipment is not available in many fuel element fabricating shops. Weld spatter on the fuel plates which can be incurred in the production of full-penetration welds was also considered to be objectionable from the standpoint of operating requirements.

Fusion welding studies were, therefore, discontinued early in the fabrication development and the emphasis placed on brazing.

⁵C. T. Armenoff and M. H. Binstock, Fuel Elements for the Organic Moderated Experiment, NAA-SR-1934 (Dec. 15, 1957).

⁶G. Burton and W. L. Frankhouser, Welding J. 38(10): 401s-409s (1959).

Fig. 2. Cross Sections of Plate-to-Spacer Test Welds Showing That Very Little Difference in Penetration is Produced with Welding Currents of 75 and 100 amp. Etched in glyceric regia. 19X.

INVESTIGATION OF BRAZING AS A FABRICATION METHOD

The following section describes the problems encountered and techniques used in the fabrication of brazed prototype Core B elements. As noted previously, each element includes a variety of components (about 120) which must be rigidly attached to make a complete assembly. The goal of the fabrication program was to effect all of the required joints in a single brazing cycle with high assurance of joint integrity. An assembly flow chart is shown in Fig. 3.

Brazing Alloy Selection

Of the many alloys available for brazing stainless steel components for high-temperature service, four were selected for further study on the basis of extensive past experience at ORNL and other installations.^{7,8,9} These alloys, listed in Table 2, were chosen for testing because of their high melting temperatures and their excellent resistance to sodium corrosion.¹⁰ Tests of joints brazed with these alloys were made using Miller-Peaslee shear test specimens¹¹ of the design shown in Fig. 4. The joints were brazed in a dry-hydrogen atmosphere for 30 min. The specimens were then machined to leave a 1/8-in. length of joint which would be loaded initially in shear as the specimen is pulled in tension. No specimens were tested with the nickel-phosphorus alloy since these were so brittle that they fractured upon machining. The alloy was accordingly eliminated from further testing.

Because of the high thermal gradients across each fuel plate during reactor service, the design requires that the base metal must yield before the joint fails. From the photographs of typical specimens in Fig. 5, it

⁷P. Patriarca, G. M. Slaughter, and W. D. Manly, Welding J. 36, 1172-78 (1957).

⁸P. Patriarca, G. M. Slaughter, and W. D. Manly, Electroless-Plated Brazing Alloys, ORNL-2243 (March 1957).

⁹Engineering Data Sheet J-8100, "Vacuum Melted High Temperature Brazing Alloys," Metallurgical Products Dept., General Electric Co., Detroit 23, Mich.

¹⁰G. M. Slaughter et al., Welding J. 36(5), 217-s-25-s (1957).

¹¹R. L. Peaslee and F. M. Miller, Welding J. 37(4), 144-s-50-s (1958).

Fig. 3. Enrico Fermi Core B Fuel Element Fabrication Sequence.

Table 2. List of Brazing Alloys Investigated

Alloy	Nominal Composition (wt %)	Brazing Temperature (°F)
Ni-Cr-Si	(66 Ni-19 Cr-10 Si-4 Fe-1 Mn)	2150
Ni-Si-B	(89 Ni-5 Si-4 B-2 Fe)	1925
Ni-Cr-P	(77 Ni-13 Cr-10 P)	1850
Ni-P	(89 Ni-11 P)	1850

can be seen that, with a joint overlap of $1/8$ in., those specimens brazed with both the nickel-chromium-silicon and nickel-silicon-boron alloys did not fail through the brazed joint until after the base metal adjacent to the joint had yielded. However, the specimen brazed with the nickel-chromium-phosphorus alloy sheared before reaching the yield point of the base metal. The results of all the shear tests are listed in Table 3. Since considerable bending occurred in the joint area, the data for the nickel-chromium-silicon and nickel-silicon-boron specimens are not pure shear values. Nevertheless, they give a good indication of the joint strength.

Since the yield strength of type 347 stainless steel is about 30,000 psi at 1000°F, it appears that both the nickel-chromium-silicon and nickel-silicon-boron alloys should be suitable for brazing the elements from a structural standpoint. However, since boron (^{10}B) transmutes to helium under irradiation, the nickel-silicon-boron alloy was eliminated. It was felt that helium bubble precipitation would tend to weaken joints brazed with this alloy. Thus, all dummy (solid stainless steel) and prototype (containing depleted UO_2) fuel elements fabricated during this program were brazed with the nickel-chromium-silicon alloy. This alloy did not erode or dissolve the base metal to any measurable extent during brazing. This feature is important because there is only a 5-mil cladding of stainless steel over the core of the fuel plates.

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Y-45508BRAZING ALLOY SHEAR TEST SPECIMENS
(Miller-Peaslee Type)

Base Metal	Type 347 SS
Testing Temperature	1000°F
Time at Brazing Temperature	30 min

Ni-Cr-Si

Ni-Si-B

Ni-Cr-P

Fig. 5. Miller-Peaslee Shear Specimens After Testing.

Table 3. Results of Brazed Joint Shear Tests at 1000°F

Specimen Number	Brazing Alloy	Visual Determination of Base-Metal Yielding	Shear Strength of Joint (psi)
1	Ni-Cr-Si	Yielding	44,800
2	Ni-Cr-Si	Yielding	42,900
3	Ni-Cr-Si	Yielding	35,900
4	Ni-Cr-Si	Yielding	38,400
5	Ni-Cr-Si	Yielding	38,400
6	Ni-Cr-Si	Yielding	41,300
7	Ni-Cr-Si	Yielding	42,300
8	Ni-Cr-Si	Yielding	44,600
9	Ni-Cr-Si	Yielding	44,600
10	Ni-Cr-P	No Yielding	15,400
11	Ni-Cr-P	No Yielding	21,500
12	Ni-Si-B	Yielding	36,600
13	Ni-Si-B	Yielding	45,600
14	Ni-Si-B	Yielding	43,600
15	Ni-Si-B	Yielding	44,800
16	Ni-Si-B	Yielding	45,200
17	Ni-Si-B	Yielding	44,200

Base Metal: type 347 stainless steel; Brazing Temperature: Ni-Cr-Si = 2150°F, Ni-Cr-P = 1850°F, Ni-Si-B = 1925°F; Time at Brazing Temperature: 30 min.

Brazing Alloy Placement

Early tests with subsized elements showed that the amount of brazing alloy used was critical. An insufficient amount would result in only a partially brazed joint; such a condition is shown in Fig. 6. At the other extreme, an excessive amount of alloy resulted in very large fillets or even partial constriction of the coolant channels. Since the edge of the fuel plate core could be located immediately adjacent to the inside edge of the edge spacers, any large fillet along this edge would cover the fueled area of the plate. This, in turn, would impair thermal performance. Thus, the optimum amount of brazing alloy is that required to braze the joint fully while leaving essentially no fillet in the spacer-to-plate joint.

Fig. 6. Edge Spacer-to-Dummy Fuel Plate Joints Incompletely Brazed as a Result of an Insufficient Amount of Alloy. Etched in glyceria regia.

A second reason why large fillets are not desired is shown in Fig. 7. A characteristic of the nickel-chromium-silicon alloy is that it forms a brittle, silicon-rich, intermetallic compound in large fillets, and the stresses induced by the surrounding material during cooling from brazing temperature tend to cause cracking in this region. Further examination of the structure reveals that these cracks are arrested by the more ductile phase adjacent to the stainless steel. However, since the resistance to propagation of the cracks during service is not well known and since the ductile phase may lose some of its crack-arresting capacity upon irradiation, elimination of cracks is desirable.

The brittle phase may be reduced or eliminated if less alloy is present since there is less silicon to diffuse and it has only to diffuse a relatively short distance to the stainless steel. It is also possible to reduce the amount of this phase by holding the assembly at brazing temperature for a longer period of time to aid the diffusion of silicon. Tests showed that both methods helped reduce this brittle phase with control of the quantity of alloy having the greater effect. However, holding the assembly at brazing temperature for 1 1/2 to 2 hr was found to provide additional insurance against cracking since the brittle phase was reduced to the point that no cracks appeared in the fillets when the quantity of alloy was slightly greater than optimum. Figure 8 shows the excellent results obtained with careful control of alloy and with a brazing time of 1 1/2 hr at temperature.

Early in the program, several methods of alloy placement were attempted including oxyacetylene spraying, the use of a slurry of powdered alloy and liquid binder, and dry powders. The preplacement methods finally adopted are described below for each of the various types of joints.

Spacer-to-Plate Joints

A Lucite bar (see Fig. 9) of the same length as the fuel plate with a machined longitudinal groove (0.030 × 0.040 in.) was used to accurately measure and dispense the powdered brazing alloy along the spacer-to-plate joints. Drawings of the bar are presented in Appendix B-3. The procedure used was to fill the groove with powdered alloy (-150 mesh), scrape the excess off, and tilt the bar so as to place the alloy along the joint. A

Fig. 7. Joint Between a Center Spacer and Dummy Fuel Plate. Note the existence of cracks in the brittle intermetallic phase at the center of each fillet. Etched in aqua regia.

Fig. 8. Edge and Center Spacer-to-Plate Joints with Controlled Quantity of Alloy. Excellent brazes are evident. Etched in glyceria regia.

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Fig. 9. Lucite Brazing Alloy Placement Bar.

small brush was then used to position the powder in a fillet reaching in height almost to the top of the spacer. A liquid, air-drying, acrylic plastic or nitrocellulose binder was used to fix the alloy in this position. After brazing alloy was placed at each joint, the assembly was set aside while the binder dried.

Seal Strip-to-Fuel Plate Joints

A bar of a similar type (see Appendix B-3) was used for the seal strip-to-fuel plate joints with the groove dimensions being $0.030 \times 0.020 \times 3$ -in. long. The alloy, in this case, is placed along the transverse seal strip edge which contacts with the fuel plate and not under the raised portion of the seal strip. Large fillets are undesirable since they may cause hot spots on the fuel plate under the fillets. Excess alloy also tends to promote buildup on the seal strip and thereby impair its flexing capability.

Bushing-to-Fuel Plate Joints

The quantity of brazing alloy is also critical at the joints between the end bushing and fuel plates and between the top and bottom center bushings and their respective fuel plates. In these cases, a sufficient amount of alloy must be used to completely seal any UO_2 exposed during machining of the recesses for the bushings. If, however, too much alloy is used on the end bushing joints, the resulting buildup may cause a constriction in one or more coolant channels, usually the bottom one. It is possible that use of rings of braze metal might alleviate the problems of alloy preplacement around the end bushing; however, this approach was not examined in this program.

Occasionally, poor fit-up around the square side bushings precluded complete sealing. Additional alloy only increased the hazard of large fillet formation in the adjacent coolant channel. Therefore, in these cases, a "wide-gap" brazing technique was employed. A filler consisting of -100 mesh nickel (or stainless steel) powder and plastic binder was placed in the wide joints prior to brazing alloy placement. This method was used successfully several times during this development program.

Removal of excess brazing alloy from the 54-mil-thick channels after brazing is extremely difficult if not impossible. Since this nickel-chromium-silicon alloy is very hard, conventional tools are almost useless. A spark-discharge type of machining has been used with some success on small amounts of alloy buildup located within about 1 in. of the end of the fuel element. However, this method was extremely slow and did not leave a good surface finish. This condition is shown in Fig. 10 where the excess alloy has, for the most part, been removed. The approximate amounts of brazing alloy and the placement methods which were found to adequately braze each joint are listed in Table 4. Fabrication of the proof test assembly, however, indicated a need for slightly more alloy in the edge spacer-to-fuel plate joints. (See section of Fabrication of Proof Test Assembly for explanation.)

Subassembly Fabrication

Fuel Plate-Spacer Joining

The prebrazed attachment of the center and edge spacers to the fuel plates was done by spot welding in a special Micarta fixture as shown in Figs. 11 and 12. Detailed drawings of this fixture are presented in Appendix B-2. To maintain the required tolerance (2.246 ± 0.002 in.) between the edge spacers (see Inspection section), the fixture is spring loaded to force the spacers against accurately machined fixture edges. Two locating pins on the Micarta spot welding fixture and corresponding holes in the fuel plates are used to locate the spacers with reference to the center line of the fuel core (the plate holes having been previously machined with reference to the core).¹² The energy input for these spots was 70 w-sec $\pm$ 10% with a 10-lb clamping force.

After removal of the spacer-plate subassembly from the fixture, additional spot welds were made to insure good attachment. It was found necessary also to spot weld a short section of center spacer (referred

¹²J. H. Cherubini et al., Fabrication Development of UO₂-Stainless Steel Composite Fuel Plates for Core B of the Enrico Fermi Fast Breeder Reactor, ORNL-3077, p 46-52 (April 4, 1961).

Fig. 10. Results of Spark-Discharge Machining of Excess Brazing Alloy in Lower Coolant Channel at End Bushing. Apparent inconsistencies in fuel contour result from end effects produced during hot rolling. Etched in glyceric regia.

Table 4. Braze Alloy Preplacement Data

Joint	Alloy Form	Approximate Quantity per Joint (g)	Preplacement Technique
Edge spacer-to-fuel plate	Powder ^a	1.15	Alloy placement bar (0.030 × 0.040-in. groove)
Center spacer-to-fuel plate	Powder ^a	1.15	Alloy placement bar (0.030 × 0.040-in. groove)
Seal strip-to-fuel plate	Powder ^a	0.05	Alloy placement bar (0.030 × 0.020-in. groove)
Round center bushing-to-fuel plate	Powder ^a	0.15	Uniformly around joint
Square center bushing-to-fuel element side	Powder ^a	0.17	Uniformly around joint
Wear bearing-to-spring finger	Powder ^a	0.02	Spot placement
End bushing-to-fuel plate	None		Joint fed from center spacers
Inside of side spring finger-to-fuel plate	Paste ^b		1/16-in.-diam spot
Side spring finger-to-fuel element side	Paste ^b		1/16-in.-diam bead, 2/3 length of joint
Interlock lug-to-fuel element	Paste ^b		1/16-in.-diam bead, 1/8-in. long on both sides of each lug-to-plate, 4 places

^aAfter powder placement, wet with plastic or nitrocellulose binder.

^bMicrobraz 30-S (powder premixed with binder) in plastic syringe.

Fig. 11. Spot Welding Fixture with Plate and Spacers.

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Fig. 12. Spot Welding Spacers to a Fuel Plate.

to as a center-spacer stub) between the end bushing hole and the plate end. Without this section of spacer, the unsupported ends of the plates tended to collapse slightly during assembly thus violating the plate-to-plate tolerance. However, this may not be necessary if the bundle is not subjected to high pressures when bolted into the brazing fixture. This problem is discussed in the Fabrication of the Proof Test Assembly section of this report.

Seal Strip Attachment

Spot welding with a 500-w electronic power supply was used to locate the seal strips on the top and bottom fuel plates. As the stainless steel fuel plate cladding was 5-mils thick, only a very light spot weld could be used without risking damage to the fueled portion of the plate. About 30 welds of 30 w-sec $\pm$ 10% energy input were made per strip along both contacting edges to insure that the seal strips did not break away from the plate during the brazing cycle. Brazing alloy preplacement along the strips has been discussed previously.

Type 347 stainless steel strips, 0.006 and 0.009-in. thick, were used, but both of these were found to sag when brazed at 2150°F. Thus it was necessary to re-form them by hand. This was done by an "ironing" process in which a die was inserted under the seal strips. Later, substitution of 0.009-in.-thick, type 19-9-DL stainless steel seal strips eliminated this problem but, as will be noted subsequently in the Brazing Conditions section of this report, added a brazing problem. The seal strips placed on the sides of the element are attached by spot welding only. Since they are not mounted on primary heat transfer surfaces, metallurgical bonding over the full contact area was not required.

Bushing Attachment

The simplest method for attaching the top and bottom center bushings to their respective plates prior to brazing was found to be spot welding. As an added safety measure, the bottom bushing was also held in place by a molybdenum leaf spring coated with stop-off material. The square-center bushings were located for brazing merely by fitting them into the recess created by the prenotched fuel plates.

Wear Bearing Attachment

The Stellite No. 93 wear bearings also were held in place for brazing by spot welding. A contoured copper electrode was found necessary to assure a good spot weld. In those cases where bearings were dislodged during brazing, it was found possible to reattach them by gas tungsten-arc torch brazing.

Spring Finger Attachment

Prior to the placement of spacers, each fuel plate was notched to accept the side spring fingers. After the element was assembled in the brazing fixture, the spring fingers were attached with two TIG tack welds. It is obvious that the alignment of one plate over another and the alignment of the edge spacers with the spring finger notches must be accurate if a well-brazed joint is to be realized. If the notches are gang-machined with the locating end pins in place, this alignment can be obtained readily.

Development of Brazing Procedure

Brazing Fixture

The first brazing fixture developed consisted of two 3/8-in.-thick type 304 stainless steel platens (see Appendix B-4) and fourteen 3/16-in.-diam Hastelloy B bolts with nuts. This fixture, with a fuel element enclosed, is shown in Fig. 13. This fixture, however, made no provision for attainment of the correct stack-up height, nor did it provide for lateral support of the element. Thus, the element was free to skew either from side to side or from front to back. Hastelloy B was chosen for the bolt material because its coefficient of expansion was slightly less than that of the stainless steel. As the element and fixture were heated to the brazing temperature, the differential expansion held the element tightly in the fixture.

Later, a new fixture was fabricated (Fig. 14a and b) and, as can be seen, provision was made for holding the assembled element rigid. The platens were made of 1-in.-thick type 347 stainless steel plate, and the vertical posts were accurately machined so that, when the top platen contacted the posts, the stack-up height of the element was established.

Fig. 13. Fuel Element in First Brazing Fixture.

Fig. 14. Prototype Brazing Fixture.

However, in order to make the top platen meet the vertical stops, it was found necessary to use heavier bolts than before. Thus, sixteen 5/8-in.-diam stainless steel bolts were used with carbon steel nuts. By using this combination of materials and by coating the threads before assembly with a water slurry of MgO, the nuts and bolts could be loosened easily after brazing and then reused.

Access holes were provided for all seal strip, bushing, and wear bearing recesses. This enabled the hydrogen to circulate freely to all joints during brazing.

To assure that the element was not inadvertently brazed to the fixture, a commercially available stop-off material¹³ was painted on all points of contact.

Lateral support of the element between the vertical posts is assured since the top platen is fixed rigidly by pins located on two diagonal, vertical supports. Therefore, the two halves of the fixture cannot shift in relation to each other. By using the end bushing and an auxiliary locating pin in the other end of the element (removed prior to brazing) the element is assembled in the fixture and held true to the vertical. A rapid check for plate shifting and element skewing can be made before the element is removed from the fixture since the locating pin can be reinserted through the bundle after brazing.

In addition, it was necessary to support the bundle by wedging shims between the vertical side and end posts and the bundle. Since the assembly procedures were still being developed, a large gap was provided between these supports and the fuel element bundle. This necessitated the use of compounded shims with a thin (about 0.005-in.) stainless steel shim in contact with the bundle. Before inserting the thin shim, it was painted with a stop-off material and allowed to dry. These shims usually brazed to the fuel element and are considered expendable. The stop-off, however, does keep the shim from robbing any appreciable amount of alloy from the spacer-to-plate joints.

¹³Microbraz Stop-Off, Wall-Colmonoy Corp., Detroit, Michigan.

Brazing Conditions

Both dry-hydrogen and vacuum atmospheres were used in brazing dummy and prototype fuel elements. The dry-hydrogen brazing studies were performed at ORNL. Since a vacuum brazing furnace was not available at ORNL, drawings and components for four elements were sent to a commercial brazing concern¹⁴ on a purchase order basis for assembly and vacuum brazing. The techniques used were left to the vendor's judgment. This permitted determination of some of the assembly and brazing difficulties that a commercial fabricator might encounter. These problems were studied subsequently during the ORNL developmental program.

It was demonstrated that both brazing methods gave good results. Hydrogen brazing was carried out in -60°F dew point gas or lower, flowing at 15 cfh. Vacuum brazing was performed with a vacuum of at least 1×10^{-3} torr at brazing temperature.

A typical vacuum brazing cycle was very similar to the hydrogen brazing cycle shown in Fig. 15 except that the rate of temperature rise to the holding temperature was much faster as was cooling down from the brazing temperature. The reason for this was that vacuum brazing was carried out in a retort that could be lifted in and out of the furnace.

In either case, for brazing, the fuel elements were inverted from the position in which they were assembled. In the inverted position, the brazing alloy (initially placed at the spacer-to-fuel plate joints) then would be concentrated at the top of the joint and advantage could be taken of gravity for supplying alloy to the lower spacer-to-plate joint as shown in Fig. 16.

In the dry-hydrogen brazing cycle, the temperature of the assembly was increased to 1975°F and held for 20 to 30 min. This prebrazing hold period allows the assembly to reach temperature equilibrium. The temperature variation over the element at the end of this hold was generally less than 8°F . The assembly was then brought up to the brazing temperature

¹⁴UCNC Purchase Order No. 93X-24566 with Vac-Hyd Processing, Inc., Detroit, Michigan, Nov. 14, 1960.

Fig. 15. Typical Furnace Cycle Used in Hydrogen Brazing Prototype Core B Fuel Elements.

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PLATE - SPACER SUBASSEMBLIES AS STACKED IN
BRAZING FIXTURE. ALLOY MUST FLOW UP HILL
TO BRAZE SPACERS TO PLATE ABOVE.

PLATE - SPACER SUBASSEMBLIES INVERTED FOR
BRAZING. GRAVITY AIDS ALLOY FLOW TO BRAZE
SPACERS TO PLATE BELOW.

Fig. 16. Method of Assembly of Spacer-Plate Subassemblies in
Brazing Fixture.

of 2150°F at a rate of rise of about 300°F/hr. This rapid rate of rise was used to eliminate liquation of the alloy which might result in an incomplete braze.

As mentioned previously in the Brazing Alloy Placement section of this report, it was found that the use of an extended time at brazing temperature could reduce the amount of the brittle, silicon-rich compound in a braze fillet. Thus, to minimize the possibility of obtaining this phase, the brazing temperature was maintained for 1 1/2 to 2 hr. The nickel-chromium-silicon alloy did not appear to "undercut" or cause dissolution of the base material for more than 1 or 2 mils even after these extended times at brazing temperature.

With the two-zone furnace used for these studies, it was possible to hold the temperature differential over the length of the fuel element to a minimum. Thermocouple readings for all brazes at 2150°F varied from 0 to 8°F from nominal. Such close control minimizes distortion and uneven brazing alloy flow. After the prescribed time at brazing temperature, the element was allowed to furnace cool. The hydrogen-brazing atmosphere flow was changed to helium when the temperature fell below 575°F. The element was then removed from the furnace at a maximum temperature of 300°F.

The results obtained with these procedures on prototype fuel element P-6 are illustrated in Figs. 17-19. The validity of the developed procedures for producing sound joints is apparent.

Metallographic examination of the brazed joints between type 19-9-DL stainless steel seal strips and the fuel plates revealed incomplete bonding when brazing was done in hydrogen. It is felt that this is caused by the titanium in type 19-9-DL stainless steel since there was no problem in brazing the type 347 stainless steel seal strips. Therefore, since the surface titanium oxide is usually not reduced in commercial hydrogen brazing atmospheres at these temperatures, vacuum brazing should be used if seal strips of this alloy are necessary.

Fig. 17. (a) Edge Spacer-to-Fuel Plate Joints from Prototype Element P-6. (b) Photomicrograph of Edge Spacer-to-Fuel Plate Joint. Note grain growth across joint. Etched in glyceria regia. Reduced 31%.

Fig. 18. (a) Center Spacer-to-Fuel Plate Joints from Prototype Element P-6. Etched in glyceria regia. 20X. (b) Photomicrograph of Center Spacer-to-Fuel Plate Joint. Note grain growth across joint. Etched in glyceria regia. Reduced 33%.

Fig. 19. (a) Center Bushing-Fuel Plate Joint in Prototype Element P-6. Etched in glyceria regia. 13X. (b) End Bushing to Fuel Plate Joints in Prototype Element P-6. Etched in glyceria regia. 13X. Reduced 12%.

POSTBRAZE OPERATIONS

Machining

General Procedure

After brazing is completed, the fuel element must undergo several machining operations, all of which can be performed on a universal milling machine. Originally, machining was carried out with respect to reference edges as noted in Appendix A-3 drawings. However, adoption of the gage pin and hole permits the more desirable practice of machining with respect to the core center line. Therefore, using the end bushing and gage pin-hole center lines for reference, the element is accurately positioned for machining.

An upper fuel element containing an interlock lug is mounted for machining as in Fig. 20. Advantage is taken of the presence of the lug by center-drilling for mounting on the tail stock. The spring-finger end of the element is then held in an indexing head with a head stock end holding fixture (see Appendix C-3 for fixtures).

A lower fuel element with a recess instead of an interlock lug must be mounted in a reversed position from an upper element. In this case, the spring-finger end of the element is held in the tail stock with a tail stock holding fixture. The other end of the element is held in the indexing head with the head stock holding fixture.

With the element positioned in this manner, the sides are milled as in Fig. 20. Both end-bushing recesses are then machined as shown in Fig. 21. The top and bottom (round) center bushings are machined before the side (square) center bushings as in Fig. 22. The device clamped to the element in this figure contains two steps (see Appendix C-4); a dial indicator, in conjunction with this device, is used to measure the depth dimension during recessing, while two other indicators measure translation movements in the remaining two dimensions.

If the element is a lower type, the end recess (mate to the interlock lug) is machined with an end mill. The longitudinal edges of the fuel element are then rounded and wear bearing positions are set by bending the appropriate spring fingers to complete the machining operations.

Fig. 20. Upper Fuel Element Centered by Head Stock Holding Fixture with Indexing Head on Spring-Finger End and Center-Drilled Interlock Lug for Tail Stock Mount.

Fig. 21. Machining End Bushing Recess.

Fig. 22. Machining Center Bushing Recesses. Note dial gages to indicate movements in all three dimensions.

Special Considerations

Since the brazing alloy used on this fuel element is very hard, it is obvious that tool wear will be a major consideration when machining the element sides. The bushing material, Stellite 6B, is also very difficult to machine. It is of particular importance to use the proper tool material, cutting speeds, tool pressures, and tool design for machining the very close-tolerance recesses in the bushing. When machining these recesses, as in Figs. 21 and 22, the slight side pressure on the tool necessary to cut the Stellite material may cause the slender tool to flex, thus resulting in (1) a tapered recess which does not meet the width tolerance of $+0.0004$ in. and (2) a convex-bottomed recess. In addition, it was found that the side pressure and tool flexing caused a "dog-bone" effect at the rounded ends of the recesses where the tool is started and stopped.

During this program, it was found advisable not to demount the fuel element once machining was started. Also, the temperature variation of the element from the beginning of the shift to the end as machining progressed was found to significantly affect the close-tolerance work.

Handling Precaution

The delicate nature of the seal strips requires that protective measures be taken to keep them from being bent. Plexiglas protector plates shown in Fig. 23 were found to be very helpful.

Inspection

Dimensional

After the machining operations, the fuel elements underwent an extensive dimensional check. Records of these inspections are presented in Appendix D-3. As a result of these inspections improvements were incorporated into each successive experimental assembly, the problems noted in the Special Precautions section were realized, and the dimensioning scheme was altered in many respects.¹⁵ With the new dimensions on the

¹⁵APDA Preliminary Core B Drawings.

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Fig. 23. Completed Prototype Fuel Element with Plexiglas Protector Plates Attached.

bushing recesses, most of the later fuel elements would undoubtedly be within tolerance. Also, the inability to obtain correct stack-up height on several of the fuel elements made it impossible for the machinist to satisfy all of the bushing-to-bushing dimensional tolerances. In addition to the machined dimensions, assembly dimensions such as the stack-up height and plate spacing were also checked. The instrument used to measure the plate spacing is shown in Fig. 24. The eddy-current probe, developed by the Nondestructive Testing Development Group of the Metals and Ceramics Division at ORNL,¹⁶ was constructed as illustrated in Fig. 25. Variations in the plate spacings are reflected in the leaf spring-to-coil distance and produce a change in signal that may be read directly on the Dermitron instrument (Fig. 24). Sufficient sensitivity was obtained to make readings to the nearest 0.5 mil with a 10-mil range.

Frequency vs distribution plots of these data are presented in Appendix D-1. The requirements on this dimension were that point measurements made with the probe should be 0.054 ± 0.005 in. and that the average measurement per coolant channel should be 0.054 ± 0.002 in. In only a few cases were these tolerances not met (elements ORNL P-1, P-3, P-4, and Vac-Hyd-3). The pattern of occurrence seemed significant with all of the out-of-tolerance measurements, both individual and average except for ORNL P-3, located in an outer coolant channel (that is, between plates Nos. 1 and 2 or 13 and 14). It is believed that this effect is caused by excessive compressive forces obtained when bolting the plate-spacer assemblies in the brazing fixture. When the individual tolerances of 14 fuel plates and 13 layers of spacers are cumulatively positive, high compressive forces were found necessary to obtain the proper fuel element stack-up height. However, even this did not always accomplish the job. The final solution to this problem was to use spacers that were all 1 to 2 mils undersize (0.052 – 0.053 in.). This technique is discussed in detail in the Fabrication of Proof Test Assembly section of this report.

¹⁶C. V. Dodd and R. W. McClung, Fuel Element Coolant Channel and Other Spacing Measurements by Eddy-Current Techniques, ORNL-TM-129 (March 20, 1962).

Fig. 24. Dermitron Eddy-Current Instrument Being Used to Measure Fuel-Plate Spacing.

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Fig. 25. Schematic of Plate Spacing Measuring Probe.

The third critical assembly dimension, besides the plate spacing and stack-up height, was the coolant-channel width (2.246 ± 0.002 in.). This is the dimension between the inside edges of the edge spacers in a coolant channel. Not only does this dimension affect the coolant flow in the channel, but also it reveals two other critical points: (1) If this dimension is too large, the edge spacers after machining are narrow, thus adversely affecting the strength of the element. (2) If the dimension is too small, one or both of the edge spacers involved could be positioned over the core material of the fuel plates, thus not allowing effective cooling of these portions of the plate.

Measurements taken on plate-spacer subassemblies prior to placement of brazing alloy indicate that a ± 0.002 -in. variation in this dimension can be maintained with care up to this point. However, this did not guarantee that the measurements would be within tolerance after assembly and brazing.

Measurement of this dimension in a completed fuel element was attempted with an instrument shown in Figs. 26 and 27 which was developed for this particular purpose by the Nondestructive Testing Development Group. Basically, the instrument consists of two thin calipers lightly spring-loaded to contact the inside edges of the edge spacers in one coolant channel. The variation of distance between caliper ends is reflected at the opposite end of the calipers where an eddy-current coil and ferromagnetic plate are located. Variations in the coil-to-plate distance produce a change in signal in a manner similar to the system used for the fuel plate spacing measurements. Measurements can be read directly from the Dermitron dial or may be traced on a strip chart if the caliper drive is synchronized with the chart drive. A chart is presented in Appendix D-2 for element ORNL P-6. Approximately 50% of the scan length, total length of all channels measured, was within the 2.246 ± 0.002 -in. dimension. About 87% of the scan length was within ± 0.005 in. of the nominal. However, direct measurements from two random metallographic sections of this same fuel element revealed that this dimension was held to a much higher degree than indicated by the caliper device. These measurements are presented in Table 5. It should be pointed out, however, that these measurements were taken between the relatively flat

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Fig. 26. Eddy-Current Device for Measuring Internal Coolant-Channel Width.

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Fig. 27. Eddy-Current Device for Measuring Internal Coolant-Channel Width with Readout Instrument.

Table 5. Direct Measurements of Coolant-Channel Width
Dimension from Metallographic Sections of ORNL P-6 Fuel Element

Coolant Channel	Section A		Section B	
	Measurement (in.)	Amount out of Tolerance (in.)	Measurement (in.)	Amount out of Tolerance (in.)
1	2.248		2.242	-0.002
2	2.247		2.245	
3	2.247		2.247	
4	2.248		2.245	
5	2.246		2.250	+0.002
6	2.245		2.247	
7	2.247		2.247	
8	2.246		2.245	
9	2.249	+0.001	2.247	
10	2.248		2.245	
11	2.248		2.249	+0.001
12	2.251	+0.003	2.245	
13	2.244		2.252	-0.002

faces of the spacers and no attempt was made to measure all the variations due to filleting or lack of filleting. If the effects of fillets are considered, it is doubtful that a ± 0.010 -in. tolerance could be met.

In view of the discrepancy between the eddy-current instrument measurements and the direct measurements on metallographic samples, the latter were used as the basis of evaluation. However, it is realized that measurements to be made on actual fuel elements must be made with appropriate instruments. It appears probable that improvements to the existing instrument would provide an acceptable means for obtaining these measurements.

Braze Integrity

As a check on the quality of the braze, the fuel element sides which expose the plate-to-spacer joints were fluorescent-penetrant inspected after machining. Indications were obtained on nearly all fuel elements. These ranged from short isolated lines to elements with nearly a full side of indications. The appearance of the indications is attributed to the partial closing off of these joints by tightly bolting the fuel element stack in the brazing fixture. Marked reductions in bolting pressure, as used in the improved procedures for fabricating the proof test assembly, described in the following section, serve to eliminate the problem by permitting complete flow of the alloy through the joint.

These penetrant indications, although obviously undesirable, may be tolerable to some extent. For example, two three-plate instrumented test assemblies, which did exhibit penetrant indications, successfully passed thermal gradient tests performed by APDA with no apparent adverse effects.¹⁷

If necessary, it is possible to repair poorly brazed joints by rebrazing. In this case, the lower melting nickel-chromium-phosphorus alloy should be used to prevent the first alloy from remelting. In addition, only the minimum amount of alloy necessary to do the job should be used. Obviously, repair brazing should be done before machining.

FABRICATION OF PROOF TEST ASSEMBLY

As has been pointed out throughout this report, problems in machining, constriction of coolant channels, and braze joint soundness occurred which were directly attributable to the difficulty in obtaining the correct fuel element stack-up height. As stated in the section on Dimensional Inspection, this difficulty was due to the fact that the individual tolerances of 14 plates and 13 layers of spacers are cumulatively positive. Therefore, using undersize spacers (0.052 to 0.053 in.), most of this accumulation of tolerance should be accommodated without the use of very high bolting forces in the brazing fixture. To test this hypothesis, a short, full height assembly of solid stainless steel plates and undersize spacers was fabricated.

¹⁷Private Communication with A. A. Shoudy (APDA).

The proof test assembly was built in the exact manner as the later prototype elements with the exception of the undersize spacers. As a result of this exception, the assembly was easily brought to stack-up height with only nominal torque on the brazing fixture bolts. After brazing, the plate spacing was measured and found to be within tolerance in all cases. In fact, as can be seen from the frequency vs distribution chart of plate spacing in Appendix D-1, this assembly probably has the best distribution of any element made with a peak on the nominal spacing of 0.054 in.

Dye penetrant examination of the sides of the assembly revealed that all brazed joints were sound as opposed to the many indications of lack of alloy penetration observed on other fuel elements. Metallographic examination of the sectioned element revealed no filleting; in some cases, a slight recess in the joint was observed. Although it is recognized that gross filleting on the fuel plate is undesirable from heat transfer considerations, a small fillet (or at least the elimination of recessing) is desirable from a stress standpoint. An estimated increase of about 10% in the amount of brazing alloy preplaced at these plate-to-spacer joints (Table 4) would appear desirable.

CONCLUSIONS AND RECOMMENDATIONS

Using procedures developed in this study, fabrication of fuel elements for Core B of the Enrico Fermi Fast Breeder Reactor appears to be definitely feasible. During the course of this investigation, numerous test and demonstration prototype elements have been built. The latest assemblies have met the many requirements originally imposed by this design except for the tolerance on the coolant-channel width dimension which has not consistently been met.

The use of welding as the primary technique was investigated and discarded because of distortion and the failure to consistently obtain full penetration at the spacer-to-fuel plate joints. Brazing was required, in any case, to permit attachment of such components as center spacers, bushings, and seal strips.

High-temperature furnace brazing procedures have been developed to permit attachment of the approximately 100 individual parts in one operation. The nickel-chromium-silicon brazing alloy which meets all flowability, corrosion, strength, and nuclear requirements has been successfully used and techniques for accurate placement of this alloy have been demonstrated. Both vacuum and dry-hydrogen atmospheres can be used in brazing these elements, but vacuum is preferred if type 19-9-DL stainless steel seal strips are to be brazed.

With spacers of a nominal 0.054-in. thickness, the high bolting pressures necessary to approach the fuel element height dimension of 2.270 ± 0.005 in. will make the joints between the spacers and plates exceedingly tight and will not permit the brazing alloy to flow freely into the joints. The high bolting pressure will also tend to constrict the top and bottom coolant channel below the acceptable 0.054 ± 0.002 -in. range and may tend to deform the plates and constrict all coolant channels at the end-bushing end of the element. Even with the use of high pressures, it may not be possible to obtain the correct fuel element height which will make proper machining of the bushing recesses impossible. These problems can be completely eliminated by using spacers that are between 0.052 and 0.053 in. in thickness (for a nominal plate spacing of 0.054 in.).

Difficulty has been experienced in maintaining the coolant-channel width dimension of 2.246 ± 0.002 in. Variations in this dimension arise from several sources. These are (1) sides of spacers not perfectly square, (2) variations in locating spacers on plates for spot welding, (3) brazing alloy buildup on spacers, and (4) brazing alloy fillets or lack thereof. With these four sources for error operating on both edge spacers in a channel, the dimension of 2.246 ± 0.002 in. cannot be maintained consistently. With the techniques set forth in this report, it is felt that a tolerance range of 0.010 in. (such as ± 0.005 in.) could be maintained if the effect of brazing alloy fillets on this dimension is ignored.

Machining fixtures and techniques have been developed and are consistent with the complex and close-tolerance dimensioning. Care is necessary in machining the hard Stellite bushings to the very close tolerances imposed, and tool wear is significant when machining the brazed

fuel element sides because the brazing alloy is also very hard. Correct location of the bushing recesses with respect to the fuel element center line is nearly impossible unless the element is square and constant in stack-up height.

An eddy-current device has been developed which will accurately measure the plate spacing. A second eddy-current device for measuring the coolant-channel width dimension has also been developed but problems in accuracy and repeatability of measurements still exist.

An outline of the fabrication procedure which was used to assemble the latest prototype fuel elements is presented in Appendix E.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions of the following: L. G. Bryson, Metals and Ceramics Division of ORNL, for the assembly and brazing of fuel elements; Atomic Power Development Associates and, in particular, A. A. Shoudy and R. C. Williams for design and coordination efforts; and the ORNL shops for the machining and fixturing. The following groups of the Metals and Ceramics Division are also acknowledged for their invaluable services: the Metal Forming and Casting Group for the fabrication of fuel plates and spacers; the Nondestructive Testing Development Group for the development of coolant-channel measuring instruments; the Metallography Group for the preparation of specimens and photomicrographs; and the Reports Office for preparation of this document.

APPENDIX A

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APPENDIX A

Fuel Element Drawings

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DETAIL PART LIST FOR DRAWING					6XN-3786
ITEM NO.	SHOWN ON DWG. NO.	QTY.	DESCRIPTION	U.T.L.	USED ON DWG. NO.
1			LOWER OUTER FUEL PLATE		6XN-3781
2			INNER FUEL PL. TEL.		6XN-3782
3			NOTCHED FUEL PLATE		6XN-3783
4			UPPER OUTER FUEL PLATE		6XN-3784

SECTION-B B C-C
2 X SIZE

SECTION A-A
2 X SIZE

SECTION E-E
2 X SIZE

.065 R.

SECTION D-D
2" X 5" SIZE

- NOTES:
1. ALL DECIMAL DIMENSIONS $\pm .005$
 2. ALL FRACTIONAL DIMENSIONS $\pm 1/16$
 3. FINISH 125-1 INFS RMS
UNLESS OTHERWISE NOTED
 4. REMOVE ALL BURRS & BREAK SHARP EDGES $.005/.015$
 5. SURFACE U14 MUST BE STRAIGHT WITHIN $.002$
 6. SURFACE V MUST BE PARALLEL TO SURFACE U WITHIN $.002$
 7. SURFACE W MUST BE PERPENDICULAR TO SURFACE U WITHIN $.001$ INCHES DEP INCH T.I.R.
 8. STACK 6 MACHINE NOTCH IN FUEL PLATE. FOR EACH BUNDLE SIMULTANEOUSLY

[illegible]

DETAIL PART LIST FOR DRAWG 5XN-3785

ITEM	SHOWN ON DEG. A/E	QTY	DESCRIPTION	MATERIAL	USED ON DEG. NO.
1			LONG EDGE SPACER	347 S.S.	5XN-3781
2			SHORT REAR EDGE SPACER	347 S.S.	5XN-3781
3			SHORT FRONT EDGE SPACER	347 S.S.	5XN-3781
4			CENTER SPACER	347 S.S.	5XN-3781
5			CENTER SPACER STUB	347 S.S.	5XN-3781

NOTES:

- THESE DETAILS MUST BE STRAIGHT WITHIN .020 IN A FREE HORIZONTAL POSITION & MAY NOT EXHIBIT MORE THAN TWO WAVES IN THEIR FULL LENGTH
- REMOVE ALL BURRS
- SURFACE FINISH 63 μ INCHES RMS UNLESS OTHERWISE NOTED

NAME	DATE	TITLE
MADE BY: BANAC 3-22-61		SPACERS
CHECKED BY: M. VALBERG 3-22-61		FLOW ENDURANCE TEST MODEL
CHECKED BY: J. J. J. 3-22-61		CORE "B" FUEL SUBASSEMBLY
APPROVED BY: J. J. J. 3-22-61		ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.
DATE NOTED	DATE PRINTED	DRAWING NUMBER
		5XN-3785

①

END BUSHING

NOTE:
FINISH 125 INS RMS
REMOVE ALL BURRS

DETAIL PART LIST FOR DRAWING 3XN-3783

ITEM NO	SHOW ON DRG NR	Q'TY	DESCRIPTION	MATERIAL	USED ON DRG NR
1			END BUSHING	WROUGHT STELLITE-6B	6XN-3780 6XN-3787

LTR	CHANGE		MADE BY	CHK'D	DATE	APP'D	DATE
	NAME	DATE	TITLE END BUSHING ~				
MADE BY	Barcl	2-21-61	FLOW ENDURANCE TEST MODEL				
CHK'D BY	H. WABERG	3-6-61	CORE B* FUEL SUBASSEMBLY				
CHK'D BY	W. J. J. J.	3-10-61	ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.				
APP'D BY	W. J. J. J.	3-17-61	SCALE 2 X DATE PRINTED				
APP'D BY			DRAWING NUMBER 3XN-3783				
USE DIMENSIONS ONLY							

SHREVE-WALKER ASSOC. 7-102-201 SK: B104

DETAIL PART LIST FOR DRAWING 3XN-3782

ITEM NO	SHOWN ON DRG NO	QTY	DESCRIPTION	MATERIAL	USED ON DRG NO
1			ROUND CENTER BUSHING	WROUGHT STELLITE-6B	6XN-3780 6XN-3787
2			SQUARE CENTER BUSHING	WROUGHT STELLITE-6B	6XN-3780 6XN-3787

NOTE:
FINISH 125 μ IN. RMS.
REMOVE ALL BURRS & BLEAK
ALL SHARP EDGES .010/.020

A		DESCRIPTION IF MATERIAL CHANGED.		J.E.G. RAM 4-13-61		4/13/61	
CENTERS & NOTE ADDED							
LTR	CHANGE		MADE BY	CHK'D	DATE	APP'D	DATE
NAME		DATE	TITLE CENTER BUSHING ~				
MADE BY		M.B.	2-22-61	FLOW ENDURANCE TEST MODEL			
CHK'D BY		H. WARBERG	3-6-61	CORE 'B' FUEL SUBASSEMBLY			
CHK'D BY		MacFarland	3-10-61				
APP'D BY		Isaacs	3-13-61				
APP'D BY							
SCALE 4X		DATE PRINTED	DRAWING NUMBER		3XN-3782		
USE DIMENSIONS ONLY							

DETAIL PART LIST FOR DRAWING 3XN-3779

ITEM	SHOWN ON DRWG NO	QTY	DESCRIPTION	MATERIAL	USED ON DRWG NO
1			1/8 PLATE	307 SS.	3XN-3776

① SPRING FINGER

NOTE :

ALL DECIMAL DIMENSIONS $\pm .005$
 ALL FRACTIONAL DIMENSIONS $\pm 1/64$
 FINISH 125 μ IN5 RMS
 UNLESS OTHERWISE NOTED
 REMOVE ALL BURRS
 BREAK CORNERS & SHARP EDGES .015/.030

LIT.		CHANGE		MADE BY	CHWD	DATE	APP'D	DATED
NAME		DATE		TITLE <u>SPRING FINGER</u>				
MADE BY <u>EWAL</u>		2-22-61		FLOW ENDURANCE TEST MODEL				
CH'KD BY <u>X. WARBERG</u>		3-6-61		CORE "B" FUEL SUBASSEMBLY				
CH'KD BY <u>Mac Tool</u>		3-13-61		ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.				
APP'D BY <u>JSD</u>		3-13-61		FILL IN BOXED				
APP'D BY				SCALE		DATE PRINTED		DRAWING NUMBER
								<u>3XN-3779</u>
USE DIMENSIONS ONLY								

SHRIVE WALKER & ASSOC. 7-102-201 SC-1B10B

- ① LONG SEAL STRIP "L" = 2.220 ±.005
 ② SHORT SEAL STRIP "L" = 2.100 ±.005

SECTION A-A
 5X SIZE

DETAIL PART LIST FOR DRAWING 3XN-3777

ITEM	SHOWN ON DWG NR	QTY	DESCRIPTION	MTL	USED ON DWG NR
1			LONG STRIP	19-9DL	6XN-3780 6XN-3787
2			SHORT STRIP	00	6XN-3787 6XN-3788

DETAIL "X"
 20X SIZE

LTR	CHANGE	MADE BY	CHK'D	DATE	APP'D	DATE
MADE BY	L. FRON	DATE	2-22-61			
CHK'D BY	H. WARBERG	DATE	3-6-61			
CHK'D BY	MacFar	DATE	3-10-61			
APP'D BY	J. B. H.	DATE	3-13-61			
APP'D BY		DATE				
TITLE				SEAL STRIPS LONG & SHORT		
FLOW ENDURANCE TEST MODEL						
CORE "B" FUEL SUBASSEMBLY						
ATOMIC POWER DEVELOPMENT ASSOCIATES, INC						
SCALE FULL & NOTED				DATE PRINTED		DRAWING NUMBER
USE DIMENSIONS ONLY						3XN-3777

DETAIL PART LIST FOR DRAWING 3XN-3778

ITEM	SHOWN ON DWG. NO.	QTY.	DESCRIPTION	MATERIAL	USED ON DWG. NO.
1			$\pm .001$.031" SQ. STOCK	347 S.S.	6XN-3767 6XN-3768

1 BEARING BAR

L'T'L.		CHANGE		MADE BY	CH'KD.	DATE	APP'D.	DATE
MADE BY	NAME	DATE	TITLE <u>BEARING BAR</u>					
CH'KD BY			FLOW ENDURANCE TEST MODEL					
CH'KD BY			CORE "B" FUEL SUBASSEMBLY					
APP'D BY			ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.					
APP'D BY			SCALE	DATE PRINTED	DRAWING NUMBER			
			FULL		3XN-3778			
			USE DIMENSIONS ONLY

① CENTER INTERLOCK LUG

GENERAL NOTE
FINISH 125 AL IN R.M.S.

DETAIL PART LIST FOR DWG. 3XN-3786

ITEM NO	SHOWN ON DWG	QTY	DESCRIPTION	MTL	USED ON DWG
1			CENTER INTERLOCK LUG	INROUCHY STELLITE 68	6XN-3780

LTR	CHANGE		MADE BY	CHK'D	DATE	APP'D	DATE
	NAME	DATE	TITLE CENTER INTERLOCK LUG				
MADE BY	A.R. Junkulis	3-7-61	FLOW ENDURANCE TEST MODEL				
CHK'D BY	H. Warkling	3-15-61	CORE "B" FUEL SUBASSEMBLY				
CHK'D BY	MacTee	3-13-61	ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.				
APP'D BY	John H. Walker	3-13-61	SCALE 4x SIZE DATE PRINTED				
APP'D BY			DRAWING NUMBER				
			3XN-3786				
			USE DIMENSIONS ONLY				

SHREVE, WALKER & ASSOCIATES 7-102-201 SK-1B117

A-2. Assembly Drawings		Page
Spring Finger Subassembly	3XN-3776	71
Fuel Plate and and Spacer Sub- assembly	5XN-3781	72
Fuel Bundle Lower - First Assembly	6XN-3787	73
Fuel Bundle Lower - Final Assembly	6XN-3768	74
Fuel Bundle Upper - First Assembly	6XN-3780	75
Fuel Bundle Upper - Final Assembly	6XN-3767	76

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(1) SPRING FINGER SUBASSEMBLY

ASSEMBLY TAKEOFF LIST FOR DRAWING 3XN-3776

ITEM No.	SHOW ON DWG No.	QTY	DESCRIPTION	MTL	USED ON DWG NO
1			SPRING FINGER SUBASSY		6XN-3767 6XN-3768
2	3XN-3776	1	SPRING FINGER		
3	PURCHASED	2	G.E. GRADE 44 A TUNGSTEN CARBIDE $\frac{1}{8}$ DIA. BALL		

LTR			CHANGE			MADE BY	CHKD	DATE	APPL	DATE	
NAME	DATE	TITLE SPRING FINGER SUBASSEMBLY									
MADE BY	M.B.	2-22-61	FLOW ENDURANCE TEST MODEL								
CHG'D BY	H. WARBERG	3-6-61	CORE "B" FUEL SUBASSEMBLY								
CHG'D BY	<i>MacFaul</i>	3-10-61	ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.								
APPR'D BY	<i>Leah</i>	7-17-61	SCALE FULL DATE PRINTED								
APPR'D BY			DRAWING NUMBER 3XN-3776								
USE DIMENSIONS ONLY

NOTES
PLANE 'X' TO BE FLAT WITHIN .005 AFTER ASSEMBLY
BRACE ALL JOINTS PER A.P.C.A. SPEC. 11
NOTE ORIENTATION OF EDGES '11'

[illegible]

ASSEMBLY TAKEOFF LIST FOR DE'G 6W-3768					
ITEM	QUANTITY	DESCRIPTION	MATERIAL	UNIT	REMARKS
1	1	FUEL BUNDLE FINAL ASSEMBLY			
2	1	FUEL BUNDLE FINAL ASSEMBLY			
3	1	SEAL STRIP-SHOET			
4	1	SPRING RINGS-TUBULAR			
5	1	SPRING RING

① LOWER FUEL BUNDLE - FINAL ASSEMBLY

REV.	CHANGE	BY	DATE	APPROVED
1	1	WALKER	12-11	
2	2	WALKER	12-11	
3	3	WALKER	12-11	
4	4	WALKER	12-11	
5	5	WALKER	12-11	
6	6	WALKER	12-11	
7	7	WALKER	12-11	
8	8	WALKER	12-11	
9	9	WALKER	12-11	
10	10	WALKER	12-11

ASSEMBLY TAKEOFF LIST FOR DWG. 6XN-3780				
ITEM NO.	SHOWN ON DWG.	QTY	DESCRIPTION	USED ON DWG.
			FUEL BUNDLE UPPER ASSY	6XN-3774
1	3XN-3777	16	LONG SEAL STRIP	
2	6XN-3784	1	UPPER OUTER FUEL PLATE ASSY	
3	5XN-3781	1	LOWER OUTER FUEL PLATE ASSY	
4	5XN-3781	9	INNER FUEL PLATE ASSEMBLY	
5	5XN-3781	1	NOTCHED FUEL SUPPORT SPACERS ON BOTH SIDES	
6	5XN-3781	1	INNER FUEL R. W/NO SPACERS	
8	3XN-3782	2	CENTER BUSHING	
9	3XN-3782	2	CENTER BUSHING	
10	3XN-3783	1	END BUSHING	
11	3XN-3786	1	CENTER INTERLOCK LUG	
12	PURCHASE	8	SEE GRADE 44A TUNGSTEN CARBIDE FOR DIA. DIM.	
13	5XN-3781	1	NOTCHED FUEL R. W/NO SPACERS	
14	3XN-3779	2	SPRING FINGER	

FOR ORIENTATION OF SERIAL NUMBERS
SEE DWG. 6XN-3784

NOTES:
PLANE "X" TO BE FLAT WITHIN ±.005 AFTER ASSEMBLY
BRAZE ALL JOINTS PER APDA SPEC. NO.
NOTE ORIENTATION OF EDGES "U"

CHANGE		DATE	BY	DATE	APPROVED
1	NAME	DATE			
2	NAME	DATE			
3	NAME	DATE			
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6	NAME	DATE			
7	NAME	DATE			
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SHREVE WALKER & ASSOCIATES 7-102-201 SK-1B107

ASSEMBLY TAKEOFF LIST FOR DFG 61W-3767					
ITEM	WGMWQ Q3 DEG	QTY	DESCRIPTION	MATERIAL	USED QTY DEG W
1			FUEL BUNDLE FUEL ASSY		61W-376
2	61W-377B	1	FUEL BUNDLE FUEL MACH		
3	61W-3777	4	SEAL STRIP 3/80ET		
4	61W-5776	2	SPRNG RUBBER ASSY		
5	37U-5770B	2	BASE BAR

① UPPER FUEL BUNDLE - FINAL ASSEMBLY

[illegible]

A-3. Machining Drawings	Page
Fuel Bundle Lower - Machining	6XN-3775 79
Fuel Bundle Upper - Machining	6XN-3774 80

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ASSEMBLY TAKEOFF LIST FOR Dwg 6XN-3775				
ITEM	SHOWING ON Dwg OF	QTY	DESCRIPTION	USED ON Dwg OF
1			FUEL BUNDLE-LWR. MACHIN'G	
2	6XN-3787		FUEL BUNDLE-LWR. FIRST ASSY.	6XN-3788

DATE	BY	CHKD	APP'D	TITLE
10/1/77	BAWAC	10/1/77	10/1/77	FUEL BUNDLE LOWER-MACHINING
10/1/77	10/1/77	10/1/77	10/1/77	FLOW ENHANCEMENT TEST MODEL
10/1/77	10/1/77	10/1/77	10/1/77	CORE B FUEL SIM. ASSEMBLY
ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.				REVISIONS
6XN-3775				USE DIMENSIONS ONLY

ASSEMBLY TAKEOFF LIST FOR DRG 6XN-3774				
ITEM	SHOWING ON DRAWING IN	QTY	DESCRIPTION	MTL USED ON DRG OR
1			FUEL BUNDLE UPPER/FUHL MRLNG	6XN-3767
2	6XN-3760		FUEL BUNDLE UPPER-1ST ASS'Y

NOTES:

1. FINISH SURFACES MACHINED PER THIS DR'S TO BE
63.4 INS RM.S. MAX.
2. REMOVE ALL BURS
3. NOTE LOCATION OF PLANE 'X'

2. REMOVE ALL BUEPS

SIXTE LOCATION OF PLANE 'X'

TO		CHANGE		VADL BY		MWD		DATE		APPRO		DATE	
NAME		DATE		TITLE <u>FUEL BUINDE UPPER- WICHINGHAM</u> <u>FLW ENDURANCE TEST MODEL</u> <u>COLG 'B' FUEL SUBASSEMBLY</u>									
ISSUED BY	<u>SAWING</u>		<u>3-3-61</u>		ATOMIC POWER DEVELOPMENT ASSOCIATES, INC. POLYMERIZED ☐ IN ☐ ☐ ☐ DRAWING NUMBER <u>61W-3774</u> CASE (SEE DRAWING OR CASE) <u>Y</u>								
ISSUED BY	<u>WILSON</u>		<u>3-7-61</u>										
ISSUED BY	<u>WILSON</u>		<u>3-7-61</u>										
ISSUED BY	<u>WILSON</u>		<u>3-7-61</u>										

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A-4.	Wrapper Can Assembly Drawing and Pin Drawings	Page
	End Pin	3XN-3770 83
	Center Pin	3XN-3769 84
	Wrapper Tube	6XN-3766 85
	Wrapper Assembly	6XN-3765 86

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DETAIL PART LIST FOR DRAWING 3XN-3770

ITEM	SHOWN ON DRWG NO.	QTY	DESCRIPTION	MATERIAL	USED ON DRWG NO.
1				UNROUGHT STELLITE-6B	6XN-3765

NOTE
ALL FRACTIONAL DIMENSIONS $\pm 1/64$
ALL DECIMAL DIMENSIONS $\pm .005$
SURFACE FINISH 125 MICROINCH RMS
UNLESS NOTED OTHERWISE
REMOVE ALL BURRS
PENETRANT INSPECT PER
MIL STD-410

(A) $3/16$ CENTERS PERMISSIBLE

A CENTERS & NOTE ADDED		J. J. RAM	4-13-61	4/13/61
LTR	CHANGE	MADE BY	CHK'D	DATE
NAME	DATE	TITLE END PIN ~		
MADE BY	M.B.	2-23-61	FLOW ENDURANCE TEST MODEL	
CHK'D BY	H. W. BERG	3-6-61	CORE 'B' FUEL SUBASSEMBLY	
CHK'D BY	MacLeod	3-13-61	ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.	
APP'D BY	J. J. RAM	3-13-61	SCALE 2 X	
APP'D BY	J. J. RAM	4-13-61	DATE PRINTED	DRAWING NUMBER
USE DIMENSIONS ONLY			3XN-3770	

SHREVE WALKER & ASSOC. 7-102-201 SK-1B111

① CENTER PIN

NOTES:

REMOVE ALL BURRS
SURFACE FINISH 125 μ INCH RMS
UNLESS OTHERWISE NOTED
PENETRANT INSPECT PER MIL STD 410
① 3/16 CENTERS PERMISSIBLE

DETAIL PART LIST FOR DRAWING 3XN-3769

ITEM NO	SHOWN ON DRG NO	QTY	DESCRIPTION	MATERIAL	USED ON DRG NO
1				WROUGHT STELLITE-6B	6XN-3765

A		CENTERS & NOTE ADDED		J.E.Y.	RPM	4-13-61	4/13/61
ITEM	CHANGE			MADE BY	CHK'D	DATE	APP'D DATE
	NAME	DATE	TITLE CENTER PIN ~				
MADE BY	M.B.	2-23-61	FLOW ENDURANCE TEST MODEL				
CHK'D BY	H. WARDEN	3-6-61	COKE "B" FUEL SUBASSEMBLY				
CHK'D BY	W. J. JOHNSON	3-13-61	ATOMIC POWER DEVELOPMENT ASSOCIATES, INC.				
APP'D BY	J. E. JOHNSON	3-13-61	SCALE 4X				
APP'D BY	J. E. JOHNSON	4-13-61	DATE PRINTED				
			DRAWING NUMBER				
			3XN-3769				
			USE DIMENSIONS ONLY				

SHREVE-WALKER & ASSOC. 7-102-201 SK-1B110

DETAIL PART LIST FOR DRAWING 6XN-3766

ITEM NO.	DR'S. NO.	QTY.	DESCRIPTION	MATERIAL	USED ON DR'S. NO.
1	5AN-3497		MACHINED WRAPPER TUBE		61N-3765

WRAPPER TUBE

NOTE:
CENTERLINES OF HOLES TO BE
CENTRAL TO 2.390 & 2.506
DIMENSIONS WITHIN ±.001

[illegible]

ASSEMBLY TAKEOFF LIST FOR DRG 6XN-5765					
ITEM	SHOWN ON DRG. NO.	QTY	DESCRIPTION	MTL	USED ON DRG. NO.
1			WRAPPER TUBE ASSY		6XN-5764
2	6XN-5765	1	FUEL BUNDLE - LOWER		
3	6XN-5767	1	FUEL BUNDLE - UPPER		
4	6XN-5770	2	END PIN		
5	6XN-5769	2	CENTER PIN		
6	6XN-5766	1	WRAPPER TUBE - MACH'D

1 WRAPPER ASSEMBLY

DATE	CHANGE	MADE BY	DATE	APPROVED
10/1/61	1	W. J. HARRIS	10/1/61	W. J. HARRIS
10/1/61	2	W. J. HARRIS	10/1/61	W. J. HARRIS
10/1/61	3	W. J. HARRIS	10/1/61	W. J. HARRIS
10/1/61	4	W. J. HARRIS	10/1/61	W. J. HARRIS
10/1/61	5	W. J. HARRIS	10/1/61	W. J. HARRIS
10/1/61	6	W. J. HARRIS	10/1/61	W. J. HARRIS
10/1/61	7	W. J. HARRIS	10/1/61	W. J. HARRIS
10/1/61	8	W. J. HARRIS	10/1/61	W. J. HARRIS
10/1/61	9	W. J. HARRIS	10/1/61	W. J. HARRIS
10/1/61	10	W. J. HARRIS	10/1/61	W. J. HARRIS

SHAW-WALKER ASSOC. 7-102-201 1X-10121

APPENDIX B

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APPENDIX B

Assembly Fixtures

B-1. Spot Welding Fixture No. 1 Page 91

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SPOT WELDING FIXTURE #1
MAT'L. MICARTA

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B-2. Spot Welding Fixture No. 2	
Base	95
Side Support	96
Bottom Support	97
End Plate	98
Spreading Handle	99
Assembly	100

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NOTE:
NOTCHES & HOLES TO MATCH THOSE ON BASE.

$\frac{9}{16}$ WIDE SLOT 1" LONG (4 REQ'D)

SECTION "B-B"

SIDE SUPPORT
MATL. MICARTA
NO. REQ'D. 2

VIEW "A-A"

BOTTOM SUPPORT
 MAT'L. MICARTA
 NO. REQ'D. 4

END PLATE
MAT'L. MICARTA
NO. REQ'D. 2

NOTE: MAKE (2)
WITH DIM "A" = $\frac{1}{4}$ "
MAKE (2) WITH
DIM. "A" = $\frac{9}{32}$.

SPREADING HANDLE
MATL. MICARTA

PART A IS TO BE PERMANENTLY JOINED TO THE FOUR
B PARTS.
PART C AND C' ARE SLIDING FITS IN THE A-B ASSEMBLY,
AND ARE HELD TO THE ASSEMBLY BY THE FOUR SPRINGS D.

ASSEMBLY

	Page
B-3. Alloy Placement Bars	
Alloy Placement Bar	103
Alloy Placement Bar (Seal Strip)	104

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ALLOY PLACEMENT BAR
 MAT'L. LUCITE

PLACEMENT BAR
 (SEAL STRIP)
 MAT'L. LUCITE

B-4. Brazing Fixture No. 1	Page
Brazing Platen	107
Hex Head Bolt	108

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BRAZING PLATEN
 MAT'L. 304 SST
 NO. REQ'D. 2

HEX HEAD BOLT
MAT'L. HASTELLOY "B" OR "C"
NO. REQ'D 14

HEX NUT
MAT'L. HASTELLOY "B" OR "C"
NO. REQ'D. 14

	Page
B-5. Brazing Fixture No. 2	
Lower Platen	111
"U" Brace	112
End Brace	113
Bottom Platen Assembly	114
Top Platen	115
Hex Bolt	116

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111

LOWER PLATEN
MAT'L 347 SST
NO. REQ'D 1

NOTE: SEE MATING PART FOR REF. DIM.

"U" BRACE
 MAT'L. SST 347
 NO. REQ'D. 4

END BRACE
MAT'L. SST 347

BOTTOM PLATEN ASSEMBLY

NO. REQ'D. 1

HEX BOLT
MAT'L. SST
NO. REQ'D 16

HEX NUT
MAT'L. CARBON STEEL
NO. REQ'D 16

	Page
B-6. Seal Strip Protectors	
Seal Strip Protectors (Top and Bottom)	119
Seal Strip Protectors (Side)	120
Bracket A	121
Bracket B	122
Screw	123

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BRACKET A
 MAT'L. AL.
 NO. REQ'D. 4

BRACKET B
 MAT'L. AL
 NO. REQ'D. 4

SCREW
 MAT'L. AL.
 NO. REQ'D. 1

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APPENDIX C

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APPENDIX C

Machining Fixtures

	Page
C-1. Fuel Plate Machining Fixtures	
Fuel Plate Machining Fixture Top	129
Fuel Plate Machining Fixture Bottom	130
Centering Guide	131
Fuel Plate Machining Fixture Assembly	132

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FUEL PLATE MACHINING FIXTURE TOP

MAT'L. MILD STEEL
NO. REQD. 1

FUEL PLATE MACHINING FIXTURE BOTTOM

MAT'L. MILD STEEL
NO. REQ'D 1

CENTERING GUIDE

MAT'L. MILD STEEL
NO. REQ'D. 2

"T" BAR

MAT'L. MILD STEEL
NO. REQ'D. 4.

FUEL PLATE MACHINING FIXTURE
ASSEMBLY

C-2. Fuel Plate Drill Jig

Page 135

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	Page
C-3. Fuel Element Holding Fixtures	
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Fuel Element Holding Fixture (Tail Stock End)	140

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FUEL ELEMENT INSERT
MAT'L. MILD STEEL
NO. REQ'D 1

FUEL ELEMENT HOLDING FIXTURE (HEAD-STOCK END)

MAT'L. MILD STEEL
NO. REQ'D 1

FUEL ELEMENT HOLDING FIXTURE (TAIL-STOCK END)
MAT'L. MILD STEEL
NO. REQ'D. 1

C-4. Bushing Locating Gage	Page
Gage Frame, Slide, Plate, and Screw	143
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MAT'L. TOOL STEEL HARDEN TO
55 - 60 ROCKWELL
NO. REQ'D. 1

MAT'L. TOOL STEEL (HARDEN TO 55-60 ROCKWELL)
NO. REQ'D. 1

MAT'L. MILD STEEL
NO. REQ'D 1

MAT'L. MILD STEEL
NO. REQ'D. 1

CENTER BUSHING LOCATING GAGE

MAT'L. MILD STEEL
NO. REQ'D. 1

APPENDIX D

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APPENDIX D

Inspection Data

D-1. Frequency vs Distribution Plots of Plate Spacing Data

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Dummy Element No. 1; Braze by ORNL	54811R2	149
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Dummy Element No. 2; Braze by Vac-Hyd Processing Corp.	62615R	153
Dummy Element No. 3; Braze by Vac-Hyd Processing Corp.	58700R2	154
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UNCLASSIFIED
ORNL-LR-DWG 54811R2

UNCLASSIFIED
ORNL-LR-DWG 54812 R2

UNCLASSIFIED
ORNL-LR-DWG 55063R2

UNCLASSIFIED
ORNL-LR-DWG 63135R

UNCLASSIFIED
ORNL-LR-DWG 58710R2

UNCLASSIFIED
ORNL-LR-DWG 70408R

UNCLASSIFIED
ORNL-LR-DWG 70411R

UNCLASSIFIED
ORNL-DWG 64-410

D-2. Coolant-Channel Width Data (P-6 Element)

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END BUSHING END

SPRING FINGER END

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D-3. Results of Dimensional Inspection

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Dimension Letter	Dimension (in.)	Fuel Element Side	ORNL No. 1		ORNL No. 2		Vac-Hyd No. 2		ORNL No. 3		Vac-Hyd No. 3		Vac-Hyd No. P-1	
			Actual	Amount Out	Actual	Amount Out	Actual	Amount Out	Actual	Amount Out	Actual	Amount Out	Actual	Amount Out
A	9.270 ±0.005	1	9.2804	+0.0054	9.279	+0.004	9.2685	-----	9.2728	-----	9.2714	-----	9.269	-----
		2	9.274	-----	9.282	+0.007	9.2679	-----	9.273	-----	9.2677	-----	9.2659	-----
		3	9.2811	+0.0061	9.2836	+0.0086	9.2706	-----	9.273	-----	9.2715	-----	9.261	-0.004
		4	9.2770	+0.0020	9.2805	+0.0055	9.2669	-----	9.273	-----	9.2619	-0.0031	9.2659	-----
B	0.2510±0.0004 -0.0000	1	0.2549	+0.0035	0.2516	+0.0002	0.2515	+0.0001	0.2514	-----	0.2514	-----	0.2512	-----
		2	0.2514	-----	0.2531	+0.0017	0.2516	+0.0001	0.2525	+0.0011	0.2516	+0.0002	0.2511	-----
		3	0.2519	+0.0005	0.2526	+0.0012	0.2515	+0.0001	0.2512	-----	0.2519	+0.0005	0.2511	-----
		4	0.2520	+0.0006	0.2523	+0.0009	0.2515	+0.0002	0.2518	+0.0004	0.2545	+0.0031	0.2512	-----
C	0.310 ±0.005	1	0.3112	-----	0.310	-----	0.3119	-----	0.3111	-----	0.308	-----	0.3138	-----
		2	0.3098	-----	0.310	-----	0.3104	-----	0.3093	-----	0.3096	-----	0.3080	-----
		3	0.3104	-----	0.308	-----	0.3154	+0.0004	0.3094	-----	0.308	-----	0.3130	-----
		4	0.3094	-----	0.310	-----	0.3083	-----	0.309	-----	0.3075	-----	0.3080	-----
D	0.060 ±0.005	1							0.0601	-----	0.057	-----	0.0626	-----
		2							0.0583	-----	0.0586	-----	0.0569	-----
		3						o.k.	0.0584	-----	0.057	-----	0.0626	-----
		4							0.058	-----	0.0565	-----	0.0569	-----
E	0.030 ±0.005	1							0.030	-----	0.0285	-----	0.0313	-----
		2							0.0291	-----	0.0293	-----	0.0285	-----
		3						o.k.	0.0292	-----	0.0285	-----	0.0313	-----
		4							0.029	-----	0.0282	-----	0.0285	-----
F	0.214 ±0.005	1	0.2081	-0.0009	0.218	-----			0.2073	-0.0017	0.2127	-----	0.226	+0.007
		3	0.2148	-----	0.221	+0.002			0.2112	-----	0.2202	+0.0012	0.225	+0.006
G	0.3125±0.0005 -0.0000	1	0.3133	+0.0008	0.3140	+0.0010	0.3140	+0.0010	0.3139	+0.0009	0.3157	+0.0027	0.3135	+0.0005
		3	0.3163	+0.0038	0.3155	+0.0025	0.3140	+0.0010	0.3148	+0.0018	0.3129	-----	0.3135	+0.0005
H	0.030 ±0.005	1							0.0302	-----	0.0207	-0.0043	0.0297	-----
		3						o.k.	0.0307	-----	0.0172	-0.0078	0.0297	-----
I	0.060 ±0.005	1					0.060	-----	0.0604	-----	0.0599	-----	0.0585	-----
		3					0.0614	-----	0.0615	-----	0.0583	-----	0.0585	-----
J	0.372 ±0.005	1	0.3731	-----	0.3704	-----	0.372	-----	0.3729	-----	0.3724	-----	0.3720	-----
		3	0.3724	-----	0.3667	-0.0003	0.3734	-----	0.374	-----	0.3708	-----	0.3680	-----
K	0.156 ±0.005	1	0.1569	-----	0.155	-----	0.1572	-----	0.1555	-----	0.1577	-----	0.1567	-----
		3	0.1584	-----	0.154	-----	0.1570	-----	0.1547	-----	0.1575	-----	0.1567	-----
L	1.217 ±0.001	1	1.2174	-----	1.2153	-0.0007	1.2171	-----					1.2433	-----
		3	1.2166	-----	1.2155	-0.0005	1.2182	+0.0002					1.2439	-----
	1.243 ±0.001	1							1.2446	+0.0006	1.2459	+0.0019		
		3							1.2449	+0.0009	1.243	-----		
M	1.217 ±0.001	1	1.217	-----	1.2183	+0.0003	1.218	-----					1.2433	-----
		3	1.2153	-0.0007	1.2173	-----	1.218	-----					1.2439	-----
	1.243 ±0.001	1							1.243	-----	1.2424	-----		
		3							1.2431	-----	1.2425	-----		
N	1.131 ±0.002	1	1.1296	-----	1.1266	-0.0024	1.1305	-----					1.1579	-----
		3	1.130	-----	1.1264	-0.0026	1.1316	-----					1.1585	-----
	1.157 ±0.002	1							1.1597	+0.0007	1.1616	+0.0026		
		3							1.160	+0.001	1.1581	-----		
O	1.131 ±0.002	1	1.1275	-0.0015	1.1297	-----	1.1313	-----					1.1579	-----
		3	1.1289	-0.0001	1.1285	-0.0005	1.1313	-----					1.1585	-----
	1.157 ±0.002	1							1.1580	-----	1.1571	-----		
		3							1.1581	-----	1.1572	-----		
P	1.217 ±0.001	2	1.2199	+0.0019	1.2153	-0.0007	1.2169	-----						
		4	1.2114	-0.0046	1.2155	-0.0005	1.2142	-0.0018						
	1.185 ±0.001	2							1.187	+0.001	1.1847	-----	1.1806	-0.0034
		4							1.1855	-----	1.1844	-----	1.1923	+0.0063
Q	1.217 ±0.001	2	1.2141	-0.0019	1.220	+0.002	1.2186	+0.0006					1.1914	+0.0054
		4	1.2179	-----	1.2147	-0.0013	1.2168	-----					1.1797	-0.0043
	1.185 ±0.001	2							1.1874	+0.0014	1.1898	+0.0038		
		4							1.1817	-0.0023	1.1847	-----		
R	1.131 ±0.002	2	1.1253	-0.0037	1.1306	-----	1.1293	-----					1.0946	-0.0024
		4	1.1333	+0.0008	1.1314	-----	1.1266	-0.0024					1.1063	+0.0053
	1.099 ±0.002	2							1.1024	+0.0014	1.1001	-----		
		4							1.1009	-----	1.1013	+0.0003		
S	1.131 ±0.002	2	1.131	-----	1.1306	-----	1.1314	-----					1.0937	-0.0033
		4	1.1316	-----	1.1308	-----	1.1296	-----					1.1054	+0.0044
	1.099 ±0.002	2							1.1017	+0.0007	1.1036	+0.0026		
		4							1.096	-0.001	1.0979	-----		
T	90° ± 1°	1							90°	-----				
		2							91°	-----				
		3							89°	-----			o.k.	
		4							90°	-----				
U	2.386 ±0.002		2.386	-----	2.385	-----	2.384	-----	2.3835	-0.0005	2.3871	-----	2.3869	-----
			2.384	-----	2.387	-----	2.386	-----	2.3863	-----	2.3885	+0.0005	2.3865	-----
			2.387	-----	2.3869	-----	2.385	-----	2.3864	-----	2.3854	-----	2.3863	-----
V	2.380 Ref.		2.380		2.388								2.280	+0.005
			2.383		2.3805								2.281	+0.006
			2.3835		2.382								2.2748	
	2.270 ±0.005						2.272	-----	2.2725	-----	2.268	-----		
							2.2719	-----	2.271	-----	2.2618	-0.0032		
							2.2695	-----	2.271	-----	2.2655	-----		
W	0.030 +0.000 -0.010	1							0.025	-----	0.0315	+0.0015	0.039	+0.003
		3							0.034	+0.004	0.050	+0.020	0.039	+0.003
	0.035 ±0.001	1												
		3												

Dimension Letter	Dimension (in.)	Fuel Element Side	ORNL No. P-1		ORNL No. P-2		ORNL No. P-3		ORNL No. P-4		ORNL No. P-5		ORNL No. P-6	
			Actual	Amount Out	Actual	Amount Out	Actual	Amount Out	Actual	Amount Out	Actual	Amount Out	Actual	Amount Out
A	9.270 ±0.005	1	9.2754	+0.0004	9.2661	-----	9.272	-----	9.2705	-----	9.263	-0.002	9.2775	-----
		2	9.2613	-0.0037	9.2671	-----	9.273	-----						
		3	9.2741	-----	9.2666	-----	9.2725	-----	9.270	-----	9.268	-----	9.2775	-----
		4	9.2693	-----	9.2661	-----	9.2725	-----						
B	0.2510±0.0004 -0.0000	1	0.2490	-0.0010	0.2516	+0.0002	0.2515	+0.0001	0.2460	-0.0050	0.2525	+0.0009	0.2510	-----
		2	0.2510	-----	0.2516	+0.0002	0.2510	-----	0.2513	-----	0.2532	+0.0018	0.2510	-----
		3	0.2550	+0.0036	0.2516	+0.0002	0.2510	-----	0.2523	+0.0009	0.253	+0.0016	0.2505	-0.0005
		4	0.2480	-0.0030	0.2516	+0.0002	0.2507	-0.0003	0.2525	+0.0011	0.253	+0.0016	0.2510	-----
C	0.310 ±0.005	1	0.306	-----	0.3160	+0.0010	0.312	-----	0.325	+0.015	0.309	-----	0.309	-----
		2	0.311	-----	0.3110	-----	0.311	-----	0.308	-----	0.3118	-----	0.315	-----
		3	0.319	+0.004	0.3160	+0.0010	0.311	-----	0.310	-----	0.310	-----	0.313	-----
		4	0.302	-0.003	0.3130	-----	0.310	-----	0.317	+0.002	0.309	-----	0.314	-----
D	0.060 ±0.005	1	0.054	-0.001	0.0644	-----	0.0595	-----	0.067	+0.002				
		2	0.061	-----	0.0594	-----	0.059	-----	0.0585	-----				
		3	0.069	+0.004	0.0644	-----	0.059	-----	0.0595	-----				
		4	0.052	-0.003	0.0614	-----	0.0595	-----	0.063	-----				
E	0.030 ±0.005	1	0.0293	-----	0.0292	-----	0.030	-----	0.0335	-----				
		2	0.0262	-----	0.0267	-----	0.0295	-----	0.0293	-----				
		3	0.0365	+0.0015	0.0292	-----	0.029	-----	0.0297	-----				
		4	0.0259	-----	0.0277	-----	0.0295	-----	0.0315	-----				
F	0.214 ±0.005	1	0.2164	-----	0.2164	-----	0.2225	+0.0035	0.211	-----	0.212		0.216	-----
		3	0.2212	+0.0022	0.2178	-----	0.214	-----	0.183	-0.029	0.208	-0.001	0.2045	-0.0045
G	0.3125±0.0005 -0.0000	1	0.3135	+0.0005	0.3130	-----	0.314	+0.001	0.3165	+0.0035	0.315	+0.0020	0.315	+0.0020
		3	0.3135	+0.0005	0.3130	-----	0.314	+0.001	0.320	+0.007	0.315	+0.0020	0.3155	+0.0025
H	0.030 ±0.005	1	0.029	-----	0.0305	-----		0.0025	0.0305	-----				
		3	0.031	-----	0.0315	-----		0.0005	0.0307	-----				
I	0.060 ±0.005	1	0.060	-----	0.061	-----		0.005	0.061	-----				
		3	0.060	-----	0.063	-----		0.001	0.0615	-----				
J	0.372 ±0.005	1	0.373	-----	0.3740	-----	0.374	-----	0.3742	-----	0.370	-----	0.373	-----
		3	0.373	-----	0.3760	-----	0.375	-----	0.3753	-----	0.3695	-----	0.372	-----
K	0.156 ±0.005	1	0.1565	-----	0.1565	-----	o.k.	-----	o.k.	-----	o.k.	-----	o.k.	-----
		3	0.1565	-----	0.1565	-----		-----		-----		-----		-----
L	1.243 ±0.001	1	1.2427	-----	1.2435	-----	1.2405	-0.0015	1.244	-----	1.246	+0.002	1.2425	-----
		3	1.2427	-----	1.2435	-----	1.2355	-0.0065	1.244	-----	1.2395	-0.0025	1.240	-0.002
M	1.243 ±0.001	1	1.2438	-----	1.2435	-----	1.242	-----	1.243	-----	1.239	-0.003	1.2405	-0.0015
		3	1.2438	-----	1.2435	-----	1.239	-0.003	1.245	+0.001	1.2415	-0.0005	1.247	+0.003
N	1.157 ±0.002	1	1.1563	-----	1.1570	-----	1.164	+0.005	1.161	+0.002	1.158	-----	1.1575	-----
		3	1.1563	-----	1.1570	-----	1.1495	-0.0055	1.161	+0.002	1.1515	-0.0035	1.155	-----
O	1.157 ±0.002	1	1.1562	-----	1.1600	+0.001	1.160	+0.001	1.160	+0.001	1.1525	-0.0025	1.1525	-0.0025
		3	1.1562	-----	1.1600	+0.001	1.154	-0.001	1.162	+0.003	1.155	-----	1.160	+0.001
P	1.185 ±0.001	2	1.179	-0.005	1.1845	-----	1.1705	-0.0135	1.1815	-0.0025	1.183	-0.001	1.1985	+0.0125
		4	1.179	-0.005	1.1844	-----	1.1985	+0.0125	1.190	+0.004	1.1985	+0.0125	1.1925	+0.0065
Q	1.185 ±0.001	2	1.193	+0.007	1.1854	-----	1.1995	+0.0135	1.191	+0.005	1.1935	+0.0075	1.1815	-0.0025
		4	1.193	+0.007	1.1853	-----	1.1715	-0.0125	1.179	-0.005	1.1775	-0.0065	1.1845	-----
R	1.099 ±0.002	2	1.0926	-0.0044	1.0990	-----	1.093	-0.004	1.0945	-0.0025	1.100	-----	1.1125	+0.0115
		4	1.0926	-0.0044	1.0990	-----	1.088	-0.009	1.104	+0.003	1.1155	+0.0005	1.1065	+0.0055
S	1.099 ±0.002	2	1.1067	+0.0057	1.0985	-----	1.0845	-0.0125	1.1045	+0.0035	1.107	+0.006	1.0935	-0.0035
		4	1.1067	+0.0057	1.0985	-----	1.1155	+0.0145	1.0925	-0.0045	1.091	-0.006	1.0975	-----
T	90° ± 1°	1	within 1°			-----	1/2°	-----	0°	-----	0°	-----	0°	-----
		2				-----	1/2°	-----	+3/4°	-----	3/4°	-----	1/4°	-----
		3			o.k.	-----	1/2°	-----	+1/2°	-----	1/2°	-----	0°	-----
		4				-----	1/2°	-----	-1/4°	-----	1/2°	-----	0°	-----
U	2.386 ±0.002		2.386	-----	2.3870	-----	2.387	-----	2.385	-----	2.384	-----	2.384	-----
			2.386	-----	2.3880	-----	2.388	-----	2.383	-0.001	2.386	-----	2.3855	-----
			2.385	-----	2.3860	-----	2.387	-----	2.384	-----	2.3835	-0.0005	2.3875	-----
V	2.270 ±0.005		2.272	-----	2.2730	-----	2.277	+0.002						
			2.276	+0.001	2.2740	-----	2.279	+0.004						
			2.279	+0.004	2.2725	-----	2.279	+0.004						
	2.300 ±0.005								2.297	-----				
									2.300	-----				
									2.2995	-----				
	2.280 ±0.005										2.2825	-----		
											2.285	-----		
											2.282	-----		
	2.275 ±0.005												2.2785	-----
													2.2825	+0.0025
													2.278	-----
W	0.035 ±0.001	1	0.037	+0.001	0.038	+0.002	0.037	+0.001	0.043	+0.007	0.038	+0.002	0.031	-0.003
		3	0.035	-----	0.034	-----	0.036	-----	0.037	+0.001	0.0395	+0.0035	0.037	+0.001

APPENDIX E

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APPENDIX E

Suggested Fabrication Sequence

Assembly

1. Deburr all spacer edges. Degrease fuel plates and spacers in acetone. (It is assumed that fuel plates are fabricated as per Reference 1 and meet all tolerance requirements on fuel plate drawing in Appendix A-1).
2. Spot weld spacers to fuel plates (70-w-sec energy input), using spot welding fixture. Remove from fixture and add additional welds at spacer ends and between original welds. Remove any flash from spacer surface.
3. Spot weld round center bushings, wear bearings, and long seal strips to top and bottom fuel plates (about 80-w-sec for bushings and 30 w-sec for bearings and seal strips).
4. Using alloy placement bars, preplace brazing alloy powder at spacer-to-plate joints (about 1.15 g) and at seal strip-to-plate joints (about 0.05 g). Brush alloy into fillet, wet with acrylic binder, and alloy to dry. Be sure top surfaces of spacers are free of alloy powder. Apply alloy powder to round center bushing joints (about 0.15 g) and all eight wear-bearing joints (about 0.02 g) and wet with binder.
5. Coat brazing fixture bearing surface with thin layer of stop-off and let dry.
6. Stack plate-spacer subassemblies in brazing fixture (with spacers on top side of fuel plates) and insert end bushing and gage pin.
7. Position shims coated with stop-off between verticle supports of brazing fixture and fuel element. Position top plate of fixture.
8. Coat fixture bolts with MgO slurry and bolt fixture top plate down to meet verticle stops of fixture base.
9. Insert side center bushings, preplace brazing alloy (about 0.17-g powder per joint), and wet with binder.
10. Tack weld side spring-finger wear bearing subassemblies to fuel bundle with gas tungsten-arc torch in two places. Preplace brazing alloy on side joint (about 1/16-in.-diam bead of alloy paste, two-thirds the length of joint) and at spring finger-to-fuel plate joints (about 1/16-in.-diam spot of alloy paste at each joint).

11. If an upper fuel element is being assembled, insert interlock lug and preplace brazing alloy paste in 1/16-in.-diam bead, 1/8-in. long on both sides of each lug-to-plate joint, four places.

12. Remove gage pin.

13. Invert brazing fixture and attach thermocouples for brazing operation.

Brazing

1. Charge fuel element into brazing furnace, introduce brazing atmosphere (vacuum or dry hydrogen), and bring up to prebrazing holding temperature of 1975°F until thermocouples all read within about 8°F of each other or until assured of thermal equilibrium throughout the fuel element.

2. Increase to brazing temperature of 2150°F as quickly as possible (about 300°F/hr) to minimize the possibility of liquation of the brazing alloy. Hold for 1 1/2 to 2 hr. Slow cool at least to 575°F.

Postbrazing Operations

1. Measure height and check squareness of fuel element and visually inspect brazed joints. Repair unbrazed areas, if necessary, with nickel-chromium-phosphorus alloy at 1850°F. This alloy is preplaced as a powder slurry.

2. Measure coolant-channel width dimension and plate spacing using eddy-current measuring devices.

3. Completely machine element including sides, bushings, interlock lug recess (if lower element), and set wear bearing dimensions by bending spring fingers. Inspect machining.

4. Fluorescent-penetrant inspect fuel element sides to reveal cracked or unbrazed joints. Degrease when completed.

5. Spot weld side seal strips and bearing bars to fuel element using about 30 w-sec input. Spot weld seal strips along both contacting edges (30 welds total per strip).

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