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FABRICATION OF REBUILT BONUS REACTOR SUPERHEATER FUEL ASSEMBLY

G. M. Slaughter
E. A. Franco-Ferreira
E. C. Kirstowsky
K. K. Klindt
E. L. Long, Jr.
G. M. Tolson

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METALS AND CERAMICS DIVISION

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G. M. Slaughter E. A. Franco-Ferreira E. C. Kirstowsky
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JUNE 1967

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FABRICATION OF REBUILT BONUS REACTOR SUPERHEATER FUEL ASSEMBLY

G. M. Slaughter E. A. Franco-Ferreira E. C. Kirstowsky[1]
K. K. Klindt[2] E. L. Long, Jr. G. M. Tolson[1]

ABSTRACT

A superheater fuel assembly for the Boiling Nuclear Superheat (BONUS) Reactor that had been destructively dismantled for examination has been successfully rebuilt at Oak Ridge. This report describes the renovation of salvaged parts, the procurement of replacement parts, the fabrication of a new set of fuel rods, and final assembly into the rebuilt unit. Procedures developed and adopted for weld and braze qualification, process control, testing, and inspection to ensure product reliability are also covered.

The original design of the Inconel-clad UO_2 fuel rods was modified to ease fabrication and upgrade service performance. In addition steps were taken to ensure a fine grain size in the Inconel 600 cladding tubing after brazing of spacers.

The reconstruction of the unit was basically a rod-type fuel element fabrication operation. Thirty-two fuel rods were made and incorporated into the final assembly. Cracking in the weld regions resulted in leaks that rejected four rods. The findings of a metallographic examination of some of the cracked regions are discussed.

INTRODUCTION

To assist in the failure analysis of a superheater fuel assembly from the Boiling Nuclear Superheat Reactor, a spare unirradiated unit was

[1]Inspection, Welding, and Nuclear Engineering Department of the Engineering Division, Oak Ridge Gaseous Diffusion Plant.

[2]Inspection Engineering Department, ORNL.

obtained and examined.[3] The purpose of the examination was to obtain base-line information on the characteristics of a typical fuel assembly from the initial core loading in the as-fabricated state.

In order to examine the fuel rods and associated components, we had to partially dismantle the superheater assembly. Destructive examination of several fuel rods disclosed that a slight redesign of the fuel rods and deviation from the original manufacturing procedures were desirable. The unit was subsequently rebuilt at Oak Ridge using manufacturing procedures that provided significant improvements over those used for the original core loading. The rebuilding of this assembly satisfied two requirements:

1. repairing the spare element for reactor use, and
2. proving out the suitability of the proposed fabrication modifications on an actual fuel assembly.

This report documents the details of the manufacture of Assembly No. 29, including component procurement, inspection, fabrication procedure qualification and examination, and analysis of weld-cracking difficulties encountered on certain fuel rods during fabrication. The reasons for specific changes in manufacturing procedure, materials specification, and weld joint design from those used on the original core loadings are also discussed in the appropriate portions of this document.

DESCRIPTION OF SUPERHEATER FUEL ASSEMBLY

A general description of the reactor core components and their functions, as well as the operating characteristics of the BONUS system, has been given previously.[3,4] However, a brief description of the superheater fuel assembly and component parts is repeated here for reference. Figure 1 is a perspective drawing of the Core I superheater

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[3] J. E. Cunningham *et al.*, BONUS Reactor Fuel Assemblies – An Investigation of Failure and Method of Correction, ORNL-3910 (December 1965).

[4] Boiling Nuclear Superheater (BONUS) Power Station – Startup Summary Report, CEND/PR WRA-257 (February 1966).

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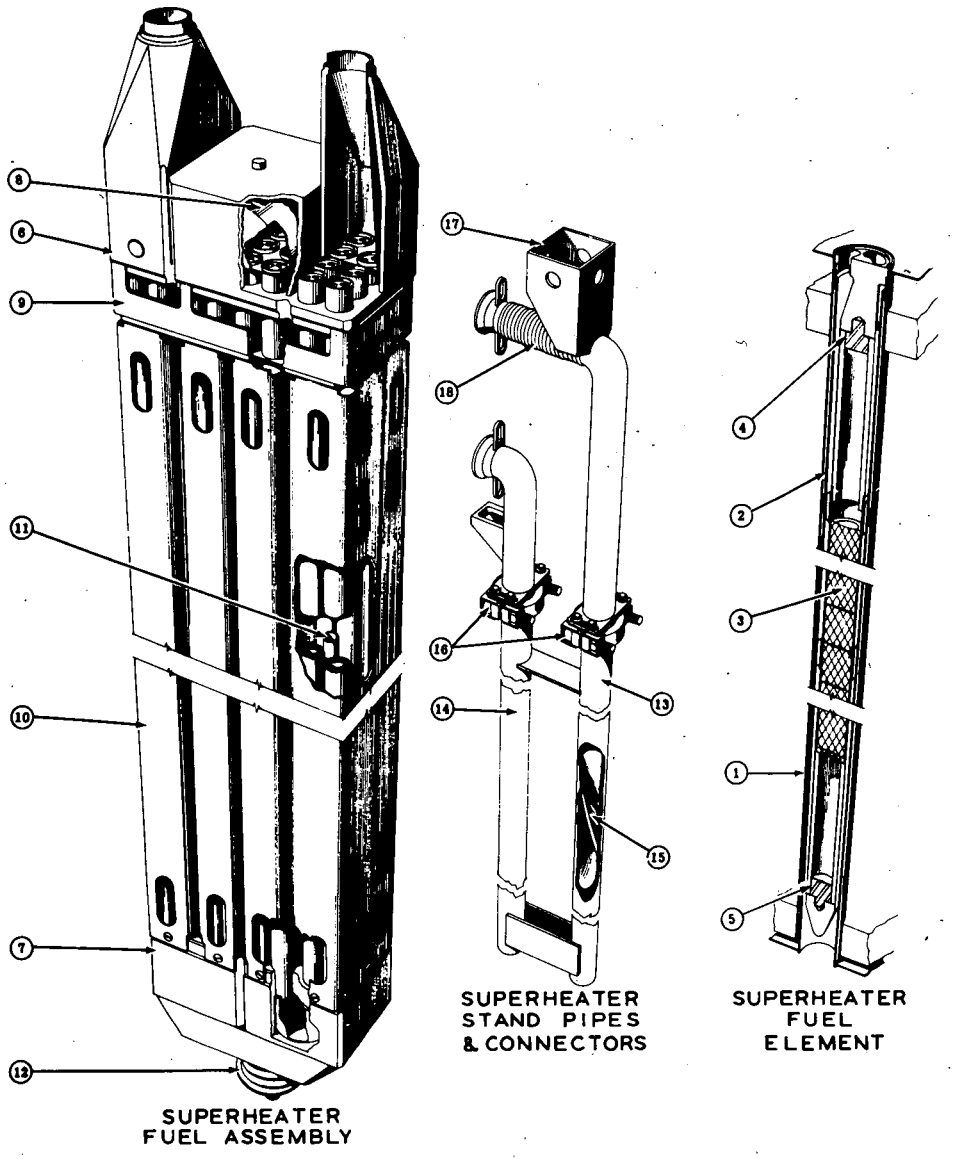

1. PRESSURE TUBE
2. COOLANT TUBE
3. FUEL PELLET
4. UPPER END CAP
5. LOWER END CAP
6. UPPER TUBE SHEET
7. LOWER TUBE SHEET
8. PASS CROSSOVER FLOW LINER
9. EMERGENCY SPRAY PAN
10. PROTECTIVE SHROUD
11. TUBE SUPPORT FERRULES
12. SUPPORT SPRING
13. SATURATED STEAM INLET STANDPIPE
14. SUPERHEATED STEAM OUTLET STANDPIPE
15. STEEL RADIATION SHIELD
16. CONNECTORS FOR ROTATING FUEL ASSEMBLY
17. FUEL HANDLING LIFTING LUG
18. EXPANSION BELLOWS

Fig. 1. Perspective of Superheater Fuel Assembly with Associated Pipe Connections.

assembly with associated standpipes and connectors. A sketch of the rebuilt fuel rod and coolant tube subassembly with details of the welded joint construction is shown in Fig. 2. Further details and assembly drawings are given in Appendix A. For comparison, a similar view of the Core I design is shown in Fig. 3.

Each superheater assembly is composed of 32 fuel-rod-and-coolant-tube subassemblies, a shell subassembly, the inlet and outlet transition pieces and liners, the upper and lower crossover box liners and covers, lower end fittings, and a protective shroud. The shell assembly forms the basic support structure for the assembly, positions the fuel, and provides a pressure barrier between the moderator and the superheated steam. When a fuel-rod subassembly is inserted into a pressure tube and edge welded, the resulting annular space between the pressure and coolant tubes forms an insulating gap where stagnant steam resides. The annular space between fuel rod and the coolant tube serves as the main coolant channel where heat is transferred from fuel to steam. A Zircaloy-2 shroud protects the thin-walled pressure tubes from damage during handling.

The liners serve the important function of directing steam flow so that it makes four parallel passes in traversing through each superheater assembly. The liners also provide an insulating steam gap. The housing at the top of the assembly contains an inlet and outlet flow liner and a crossover box liner, while the housing at the bottom contains two crossover box liners. Upon entrance to the superheater assembly from the inlet standpipe at the top, steam flows downward in the first pass along two parallel rows of fuel rods (eight individual rods) located adjacent to the boiler region of the reactor. The steam reverses direction at the bottom of the assembly, travels upward in the second pass along the second bank of eight parallel rods, reverses again at the top of the assembly, flows downward along the third bank of rods, reverses again at the bottom, and completes its final pass through the fuel region by traveling upward along the fourth bank of fuel rods.

The lower end fittings locate and seat the assembly within the core structure. The support spring minimizes the load imposed on the top support and compensates for differential thermal expansion between superheater fuel assembly and reactor vessel during operation.

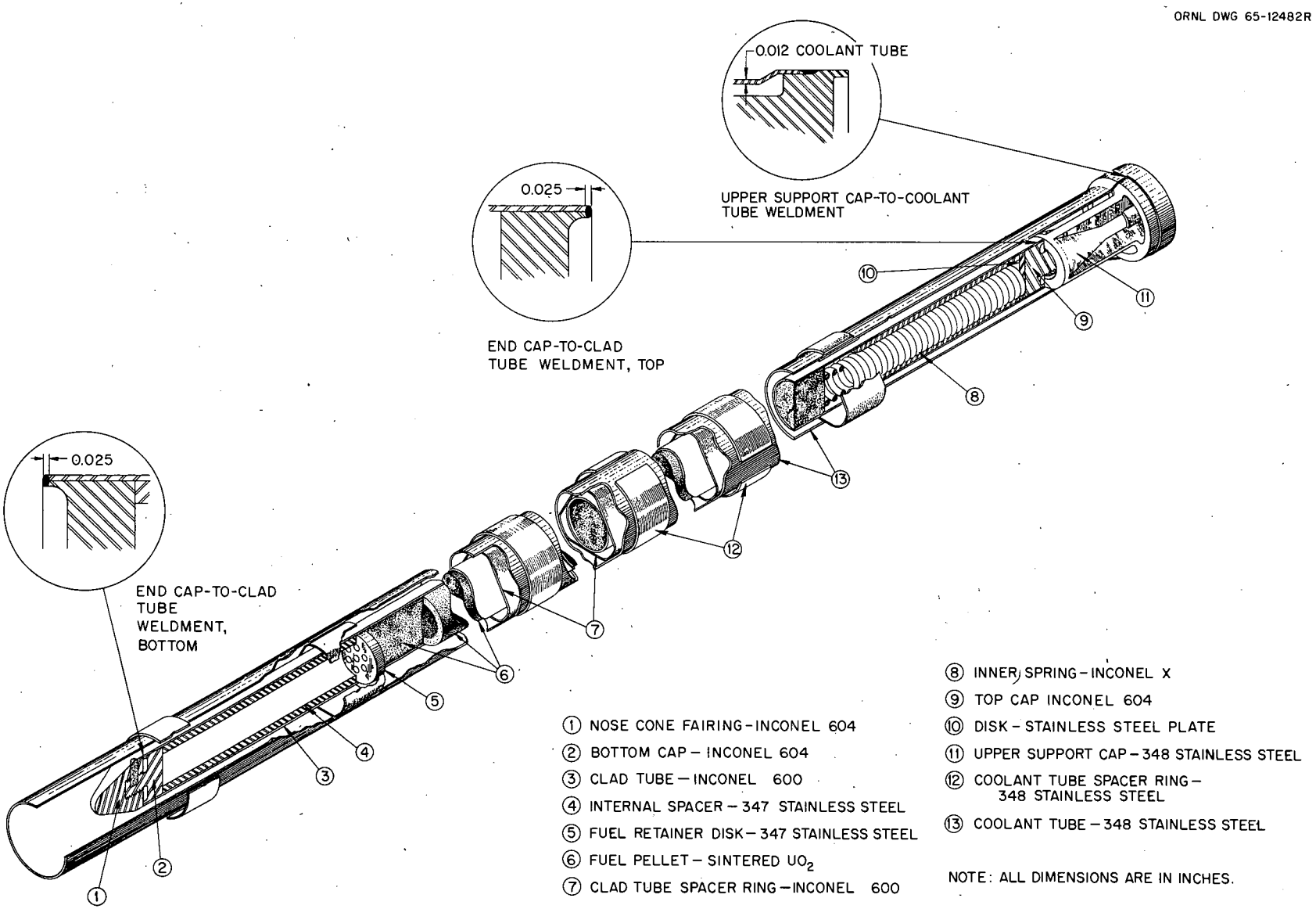

Fig. 2. Perspective of Fuel-Rod and Coolant-Tube Subassembly with Details of New Design.

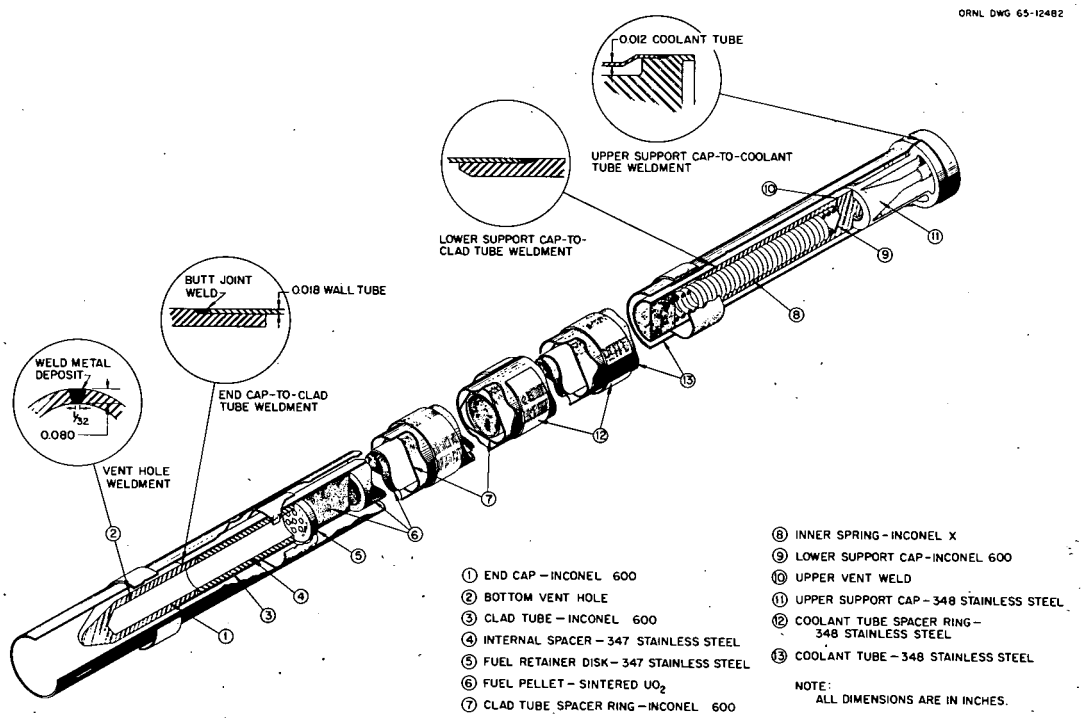

Fig. 3. Perspective of Fuel-Rod-and-Coolant-Tube Assembly with Details of Original Design.

The superheater assembly is designed to be uncoupled, rotated 180°, and recoupled. This reversing feature allows one to achieve a more uniform burnup of fuel with a corresponding gain in reactivity lifetime.

Shell Subassembly

The superheater shell subassembly consists of the upper and lower tube sheets, 32 pressure tubes, 16 ferrules, and the emergency cooling pan, all brazed together in the form of an integral support structure. A modified niobium-stabilized, type 348 stainless steel with increased nickel content and lower-than-normal limits on B, Co, and Ta, is the main material of construction. Dimensional specifications on the pressure tubing used in the fabrication process are: seamless tubing of 0.833 ± 0.001-in. OD × 0.018 ± 0.001-in. wall thickness; maximum ovality of 3 mils; maximum bow of 0.040 in. over the 62.5-in. length. The brazing alloy is Nicrobraz 50 (Ni–13% Cr–10% P).

Fuel-Rod-and-Coolant-Tube Subassembly

The fuel-rod-and-coolant-tube subassembly is composed of a fuel rod and a coolant tube welded together at the upper support cap. The coolant tube portion of the assembly consists merely of a seamless tube with five spring-type spacer rings brazed on the outer surface of the tube. These spacer rings (0.833-in. OD × 0.023-in. wall thickness × 0.375 in. wide) are spaced along the tube at intervals of 12 to 15 in. The main function of the spacers is to maintain the annular insulating gap (0.0315 in. nominal) between coolant and pressure tubes. Other factors that were considered in their design include: (1) provision for adequate bearing surface to minimize vibration and wear; (2) maintaining minimum metal-to-metal contact with pressure tube to minimize heat loss from the coolant tube; (3) provision for adequate drainage of condensate at the tube-to-spacer joint; and (4) use of minimum volume of material to reduce neutron absorption.

Both coolant tube and spacer rings are constructed from modified type 348 stainless steel. Each coolant tube is 0.710 ± 0.0015-in. ID by 0.0125 ± 0.0015-in. wall thickness with a maximum ovality of 3 mils. One end of the tube is expanded for fit-up in making the fusion weldment between the support cap and the coolant tube.

Fuel Rod

The fuel rod consists of a cladding tube, fuel pellets, end caps, nose-cone fairing, upper support cap, inner spring, internal spacer, fuel-retainer disks, and the cladding-tube spacer rings. Void space is provided within the rod at both ends for accumulation of fission gas. The fuel-retainer disk, which establishes the axial position of the fuel column, is perforated to allow free movement of fission gas; the holes are sized to prevent large fragments of fuel from falling into the void space. The internal compression spring prevents shifting of the fuel column during transportation and handling. The cladding-tube spacer rings of triangular cross section maintain the annular coolant channel of 0.085 in. (nominal) required for steam flow. The fuel-rod-and-coolant-tube subassembly is welded to the shell subassembly at the top end only;

hence, the fuel rod and coolant tube are free to move axially with respect to one another to avoid damage from differential thermal expansion encountered in service.

PROCUREMENT AND INSPECTION OF COMPONENT PARTS

A major task in the rebuilding of Assembly No. 29 was to fabricate a new set of fuel rods. Prior to actual fabrication, however, the task entailed modification of shop construction drawings to conform with the proposed and adopted design changes, revision of procurement specifications for fuel pellets, cladding tubing, end caps, and cladding-tube spacers as well as the purchase and inspection of these items.

We monitored this particular phase of the assembly rebuilding program rather closely to ensure that the quality standards required for upgrading reliability of the fuel assembly were met. The composition of starting material as well as the process history in converting material into desired parts, for instance, was carefully followed and noted. In addition, special attention was given to those facets of work that bore directly on previously encountered problem areas, like excessive grain growth in cladding, hot cracks in weld metal, etc.

Our experience in procuring and inspecting various component parts used in rebuilding Assembly No. 29 is recorded below.

Fuel Pellets

The pellets required for loading the new fuel rods are of the same general character as those specified in the Core I design; namely, conventional sintered solid right-circular cylinders of UO_2 with 3.25% enrichment in ^{235}U. Dimensional details of the pellet appear on a drawing in Appendix A, while the applicable specification (NRS-12) is presented in Appendix B. The only significant deviation from Core I specifications is the requirement on chips, derived from our mechanical-property studies for the EGCR Program.

Under a competitive bid contract award, Nuclear Fuel Services of Erwin, Tennessee, produced and delivered 75 kg of sintered UO_2 pellets in the summer of 1965. Virgin UF_6 was connected to UO_2 powder, and pellets prepared directly from this powder source are designated as Batch 1. Batch 2, on the other hand, refers to reprocessed UO_2 powder. The chemical conversion and powder consolidation steps employed to produce pellets by each of the routes are listed below.

Batch 1 Route

1. Hydrolysis of UF_6, ammonium diuranate precipitation and pyrohydrolysis to UO_2 having a surface area of 5.450 m^2/g.
2. Wet agglomeration with 1 wt % PVA and 0.2 wt % sterotex; vacuum dry and screen.
3. Compact granules at 35,000 psi.
4. Presinter green compacts at 800°F for 6 hr in CO_2; maximum heating and/or cooling rate 200°F/hr.
5. Sinter pellets for 3 hr at 2700 ± 45°F in dry hydrogen.
6. Centerless grind sintered pellets with "Five Star Cimcool" coolant.

Batch 2 Route

1. Oxidation of clean hard scrap to U_3O_8, acid dissolution to uranyl nitrate, precipitation to ADU and pyrohydrolysis to UO_2.
2. Same as step 2 above.
3. Compact granules at 40,000 psi.
4. Same as step 4 above.
5. Sinter pellets for 3 hr at 2710 ± 45°F in hydrogen.
6. Same as step 6 above.

The certified chemical analyses on pellets prepared in each batch are shown in Appendix C. The first batch met the specification without deviation; the isotopic analysis was 3.24%. The iron content was slightly out of specification on the second batch, and the isotopic content was high (3.31% as compared to a maximum of 3.30% specified). These factors were discussed with appropriate project personnel and it was determined that the fuel would be acceptable for this application.

Pellets were given a 1.5% dimensional and visual inspection by Nuclear Fuels Services and a 100% visual inspection by ORNL prior to

loading. These pellets were very easily chipped on the edges because of the edge design of the flat face. All pellets met the dimensional requirements of the specification; the length dimension of these pellets averaged 0.646 in. The general appearance of a typical group of UO_2 pellets from the production run is illustrated in Fig. 4.

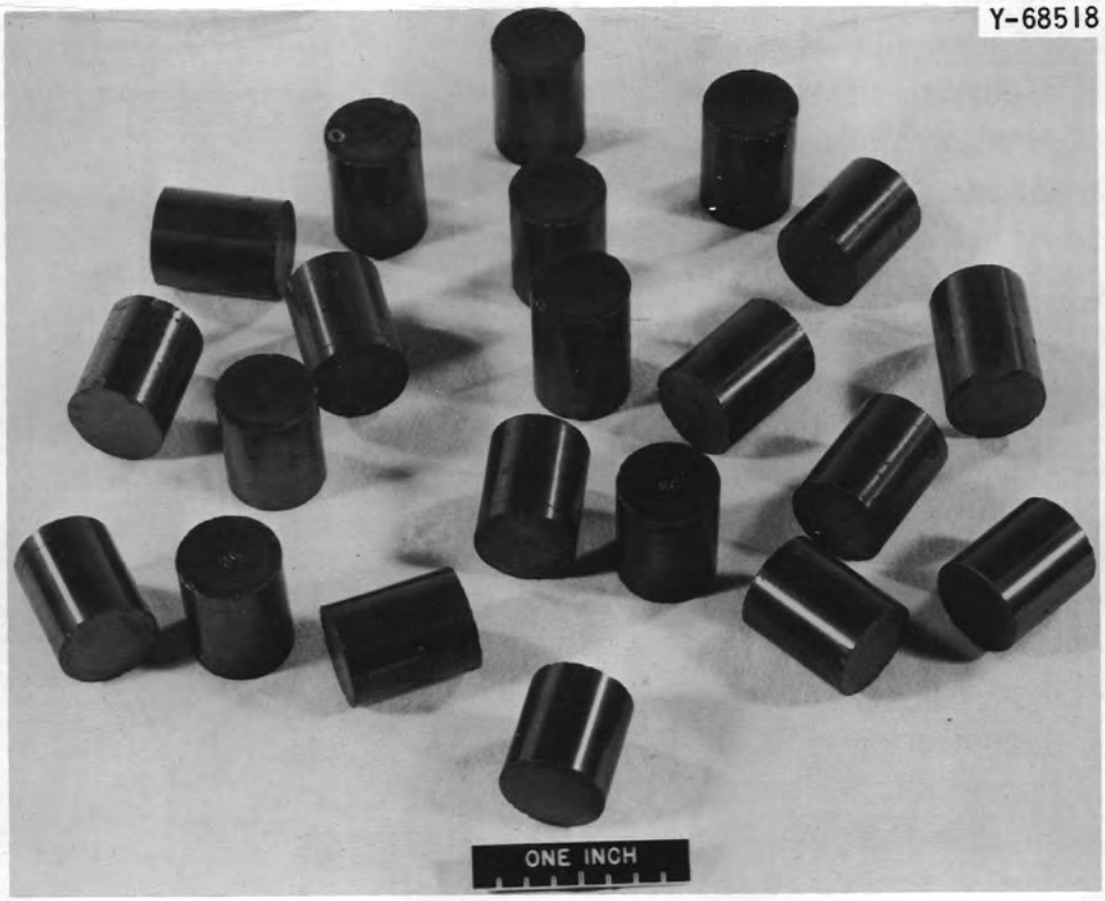

Fig. 4. Typical Group of UO_2 Fuel Pellets.

From each of the 31 boats in which the pellets were fired, one pellet was selected for immersion density measurement. Four samples, representing boats 8, 13, 20, and 26, failed to meet the minimum required density of 10.30 g/cm^3. The respective values obtained were 10.285, 10.262, 10.213, and 10.262 g/cm^3.

Nuclear Fuels Services elected to resinter these four boats of pellets to increase the density. After resintering, the densities were 10.52, 10.44, 10.32, and 10.33 g/cm^3. A random sampling was made on pellets from boats 6, 7, and 16 after grinding. The following results were reported: 6 = 10.370; 7 = 10.475; 16 = 10.285. The sampling after grinding was for information only and was not considered to affect the acceptability of the previous density test. Batch-2 densities ranged from 10.37 to 10.53 for the six sintered boat loads.

Although within the limits of acceptability, both the density and the diameter of the pellets were on the low side of the specification. These factors caused considerable difficulty in meeting the stack weight requirement.

Fuel Cladding

The Inconel 600 tubes for the fuel cladding were purchased to Specification NRS-13 (see Appendix B). A sketch showing the diameters of the tubes is included in Appendix A.

After competitive bidding, a fixed-price contract was awarded to Wall Tube and Metal Products Company, Newport, Tennessee, for purchase of the tubing. Although some difficulties were initially encountered in obtaining satisfactory inside surfaces on the tubes, the problem was resolved by the vendor and approximately 140 lengths of 1/4-hard tubing were procured.

Inspection of the tubing was witnessed at the vendor's plant. The liquid-penetrant inspection was performed using Magnaflux visible red dye, solvent cleaner, and liquid developer. Areas containing dye indications were cut out and scrapped; or, if the indications were numerous, the entire tube length was rejected. Spot inspection at Oak Ridge using Magnaflux postemulsification fluorescent penetrant (ZL-22) showed many dye indications. Examination of these indications showed that none exceeded the maximum permitted.

The ultrasonic inspection was performed using a water-immersion technique. The notches for the calibration standard were cut by ORNL in a length of tubing supplied by the vendor from the lot of tubing to be

inspected. A focused transducer was used for the inspection. The feed helix of the tubing through the inspection station was such that the defect alarm was consistently triggered on the 1/4-in. notch for three successive rotations. During the tubing inspection, a few rejectable areas were found and these were marked and scrapped.

The wall thickness was ultrasonically monitored during the ultrasonic flaw inspection. In addition to this, a 20% sampling for ultrasonic gaging was made after the tubing was cut to length; the wall thickness varied from 0.0175 to 0.020 in. An 0.019-in.-maximum wall thickness was permitted by the specification. After obtaining approval, the increased wall thickness was accepted rather than risking the danger of decreasing the wall thickness to under 0.017 in. in a centerless-grinding operation.

Air gage measurement of the inside diameter was performed on all cut lengths. This inspection produced some marks on the inside surface of the tubing, but close examination of several marks indicated they were superficial.

Vendor's certification analysis of the heat used in the tubing and ORNL chemical analyses are shown in Table 1, and the mechanical properties as presented by the supplier are in Table 2.

End Caps

The end caps were machined from Inconel 604 bar stock at ORNL. This alloy conforms to the composition of Inconel welding filler wire; it was felt that this would improve the weldability of the tube-to-end-cap closure joints.

The Inconel 604 bar was ultrasonically inspected using an immersion technique at Oak Ridge. No indications of internal flaws were found. After machining, all end caps were inspected dimensionally, visually, and with Magnaflux ZL-22 fluorescent penetrant. No dye indications were found except those due to machining burrs, tears, etc., which were readily removable. The chemical analysis of this material was made at ORNL and shown in Table 3.

Table 1. Chemical Analysis of Cladding Tubing (Heat NX-0109)

Element	Chemical Analysis, wt %		
	ORNL[a]	ORNL[b]	Manufacturer's Certification
Fe	6.50	7.5	6.59
Ni	77.1		77.49
Cr	15.5	14.0	15.45
Si	0.12	0.19	0.18
Co		0.060	
Nb		<0.005	
Ti		0.18	
Cu		0.06	0.07
Al		0.3	
B		0.002	
Mn			0.15
C			0.04
S		0.002	0.007
P		0.005	

[a]Wet chemical analysis.

[b]Spectrographic analysis.

Table 2. Mechanical Properties of Tubing

Yield Strength (psi)	Tensile Strength (psi)	Elongation (%)
35,700	83,200	40
35,700	84,000	36

Table 3. Chemical Analysis of Inconel 604 Bar for End Caps

Element	Chemical Analysis (wt %)	
	Wet Chemistry	Spectrography
Fe	7.50	8.3
Ni	74.1	
Cr	16.0	15.0
Si	0.09	0.13
Co		0.065
Nb		2.9
Ti		0.16
Cu		0.02
Al		0.1
B		0.003
Mn	0.05	
C	0.01	
S	0.001	
P	0.004	

Cladding Tube Spacers

The Inconel 600 cladding tube spacers were explosively formed from seamless tubing at the Y-12 Plant of Oak Ridge. Explosive forming was selected because it offered a suitable means of meeting the tight tolerances required.

Fabrication[5]

These spacers were made by two different procedures: the first or "initial" and the "final." A rubber liner was used to get a good vacuum and explosively form a finish-sized part. The "initial" procedure could not be used on the most of the spacers because (1) the die was not strong enough, and it opened up on successive shots and the spacers got larger; (2) it became increasingly more difficult to obtain a good vacuum. Since there was not time to rework the tools, an improvised "final" procedure

[5]Information supplied by W. T. Carey, Y-12 Plant.

was used. A more detailed description of these two procedures is shown in Appendix C. Photographs of the explosive forming tools used are shown in Figs. 5 and 6.

Figure 5 shows the assembled die without the explosive. The two halves are bolted together; the eye bolt on the end is used for carrying and supports the part during the firing. The two rubber hoses and the tee are used for evacuation (a similar tee on the opposite side is not shown), and the flanges to seal off the rubber tube (not shown) are bolted on each end.

Figure 6 shows the die halves separated. The contoured section in the center holds ten spacers; the enlargement at each end allows space for the machining of the center section; the conical opening on each end is the sealing surface for the inner tube. This picture was taken after the parts were finished and the die surfaces were improved.

Comments summarizing the die design and suggesting improved fabrication procedures are presented in Appendix C.

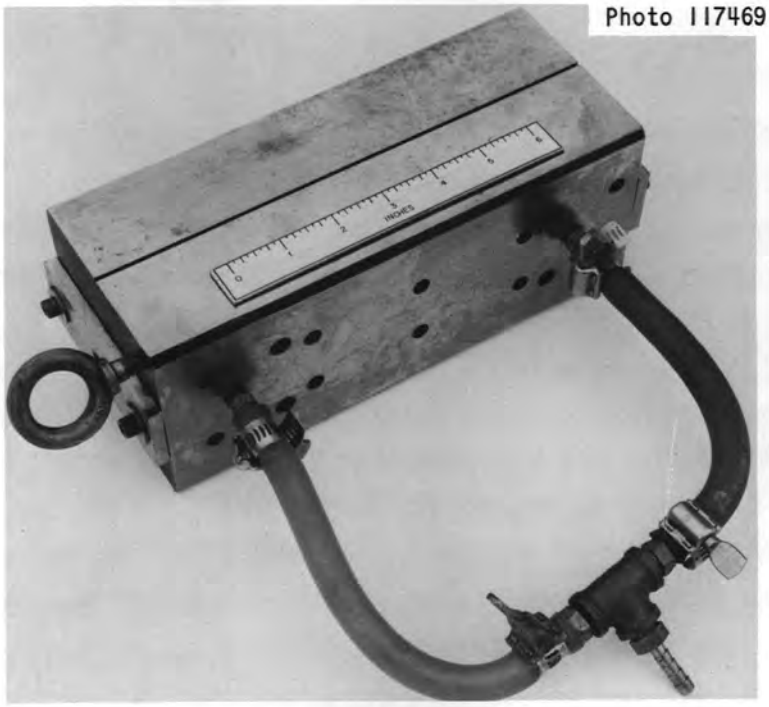

Fig. 5. Assembled Die Without the Explosive.

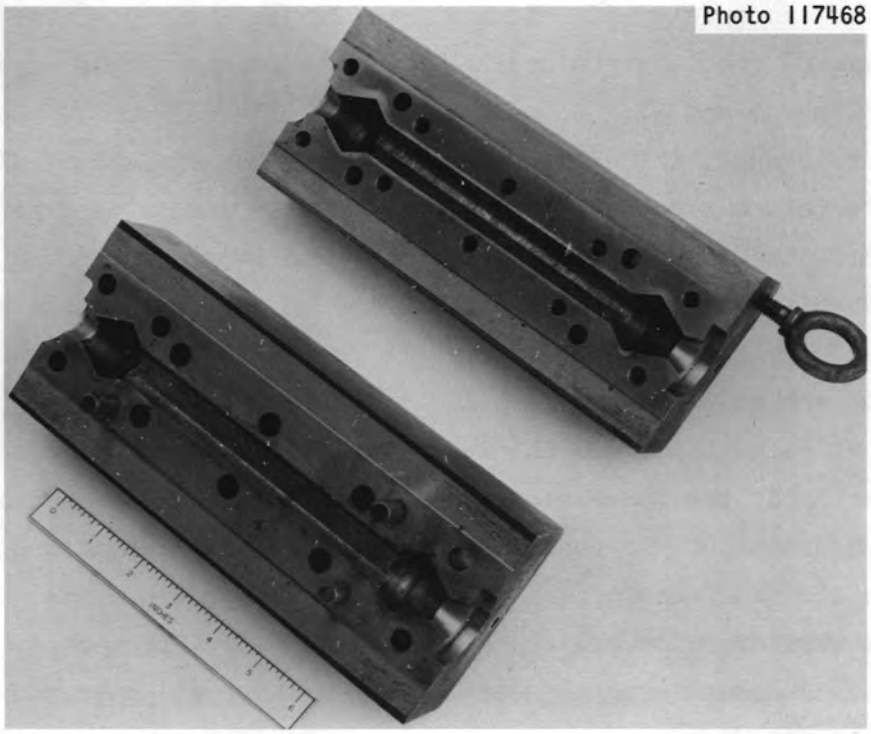

Fig. 6. Split Explosive Sizing Die.

Inspection

The spacers were given a visual and a fluorescent penetrant inspection by ORNL personnel. Those containing small dye indications were removed from the acceptable lot for later repair, if required.

The chemical analysis for the spacers is shown in Table 4.

Miscellaneous Components

The sleeves and end adaptors were machined from bar stock. The springs were wound from Inconel X-750 weld wire at Oak Ridge. The chemical analysis of this material was made at ORNL and is shown in Table 5. The coolant spacers were machined from tubing. All these items were visually and dimensionally inspected.

The coolant tubes were spares from the original manufacture and were used as received from Combustion Engineering Nuclear Division.

Table 4. Chemical Analyses of Inconel 600 for Cladding-Tube Spacers

Element	Chemical Analysis (wt %)	
	Wet Chemistry	Spectrography
Fe	6.68	7.5
Ni	77.0	
Cr	15.4	14.0
Si	0.09	0.15
Co		0.080
Nb		< 0.05
Ti		0.15
Cu		0.02
Al		0.2
B		0.003

Table 5. Chemical Analyses of Inconel X-750 Springs

Element	Chemical Analysis (wt %)	
	Wet Chemistry	Spectrography
Fe	6.39	7.4
Ni	71.7	
Cr	15.1	14.0
Si	0.35	0.57
Co		0.080
Nb		1.2
Ti		2.7
Cu		0.08
Al		0.6
B		0.0003
Mn		0.5

The perforated fuel-retainer disks, standpipe, and tube sheet assemblies were recovered from the disassembled element and reused. The nose-cone fairings were made at ORNL.

FABRICATION OF FUEL-ROD-AND-COOLANT-TUBE SUBASSEMBLIES

Design Modifications

As discussed previously,[6] it was decided to redesign the fuel rods in order to make them more easily fabricable and more reliable in operation. The primary areas affected by the redesign were the fuel-rod end closures. Two specific aims were involved: (1) to eliminate the vent-hole plug welds and (2) to change from the socket-type to edge-type joint design at both end-closure welds. The basic changes were carried out within the confines of the original fuel containment envelope specified by Combustion Engineering Nuclear Division.

Previous work[7] at ORNL on the Experimental Gas-Cooled Reactor Program demonstrated that an edge-weld joint design produces a reliable and easily fabricated end closure for thin-walled tubing. Thus, both the upper and lower end caps were redesigned to incorporate the edge-weld joint. Figure 7 shows the resulting configurations for the fuel-rod end caps. The threaded stud on the top end cap accommodates the existing investment-cast support hanger, while a similar threaded stud on the bottom end cap accommodates a newly fabricated nose-cone fairing; thus, the overall shape of the fuel rod remains unchanged.

The assembly sequence for the top end cap is shown in Fig. 8. At the left are shown the cladding tube and end cap ready for assembly. In the center, the end cap is pressed into place ready for welding and the cast support hanger is in position to be screwed on. The finished assembly is shown at the right.

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[6]J. E. Cunningham *et al.*, BONUS Reactor Fuel Assemblies — An Investigation of Failure and Method of Correction, ORNL-3910 (December 1965).

[7]W. D. Manly and J. H. Coobs, "Materials Development Program for Gas-Cooled Reactor Project at the Oak Ridge National Laboratory," pp. 150–67 in Gas-Cooled Reactors, A Symposium Sponsored Jointly by the Franklin Institute and the American Nuclear Society, Delaware Section, Monograph No. 7, Journal of the Franklin Institute, Lancaster, Pennsylvania, May 1960.

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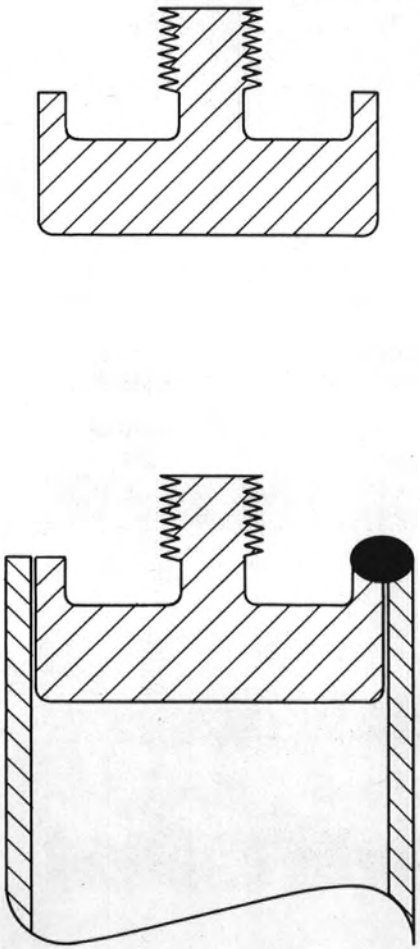

Fig. 7. Typical End Cap and Tube-to-End-Cap Edge Weld.

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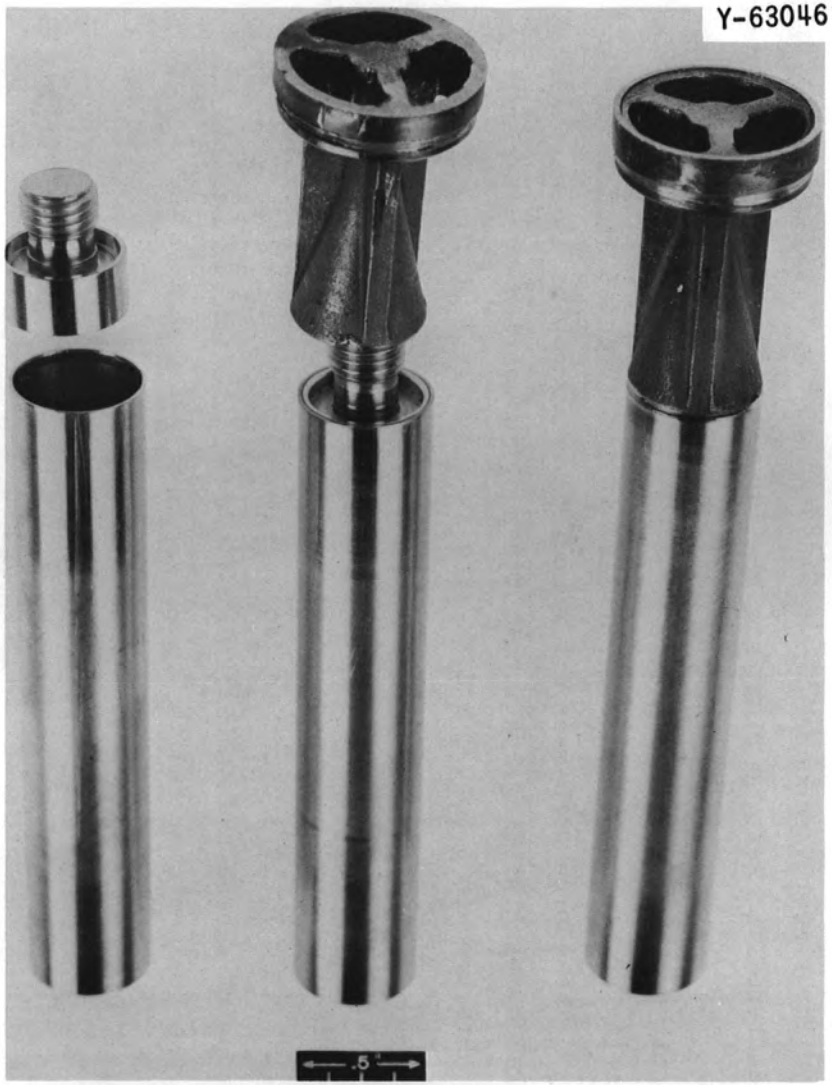

Fig. 8. Assembly Sequence for Top End Cap.

The assembly sequence for the bottom end cap is shown in Fig. 9. The steps from left to right are similar to those shown in Fig. 8.

The screwed-on fittings at each end of the fuel rods were permanently secured in position by a pin inserted through the side of each fitting and into a blind hole drilled in the threaded stud in the end cap. These pins were made of Inconel 62 welding wire and were securely fixed by plug welding. A longitudinal cross section of a typical joint of this type in a bottom end fairing is shown in Fig. 10.

In order to accommodate the shortened end cap and edge-weld joint design while keeping the fuel rod overall length the same as the original, the cladding tube had to be lengthened from 56.000 ± 0.010 in. to 60.187 ± 0.010 in. Since the fuel pellet stack length was left unchanged, a support sleeve had to be inserted between the top end cap and the top of the fuel column, and the lower support sleeve had to be lengthened.

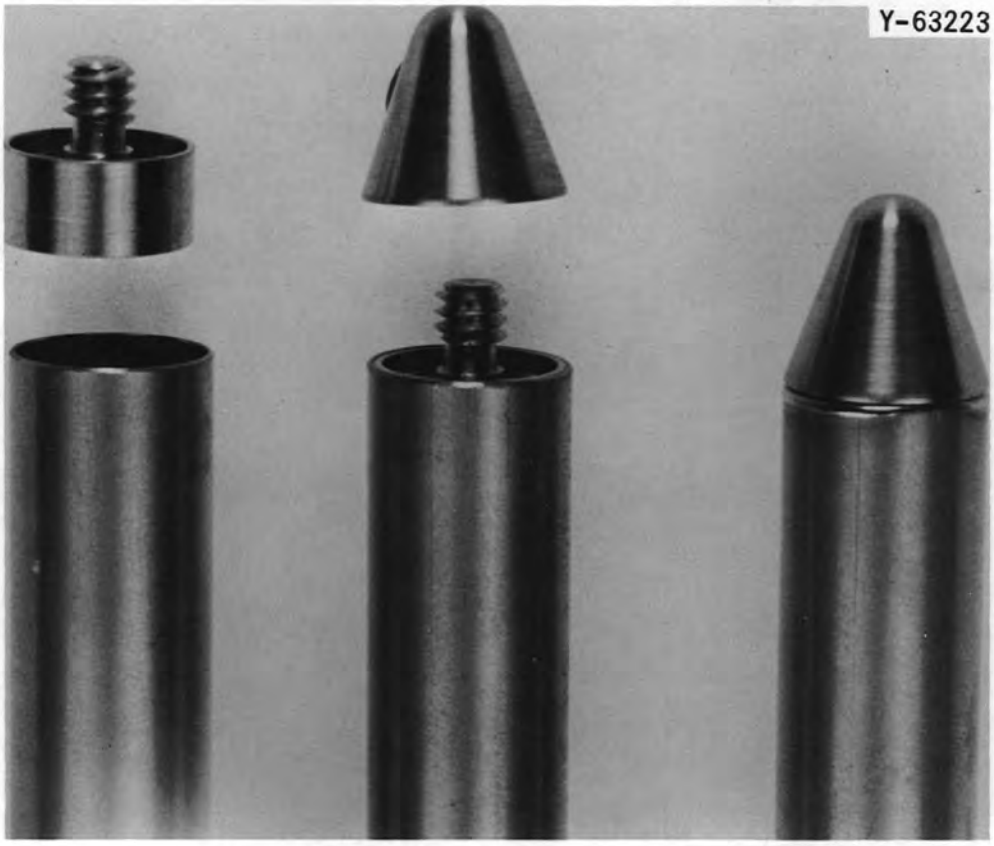

Fig. 9. Assembly Sequence for Bottom End Cap. 2×.

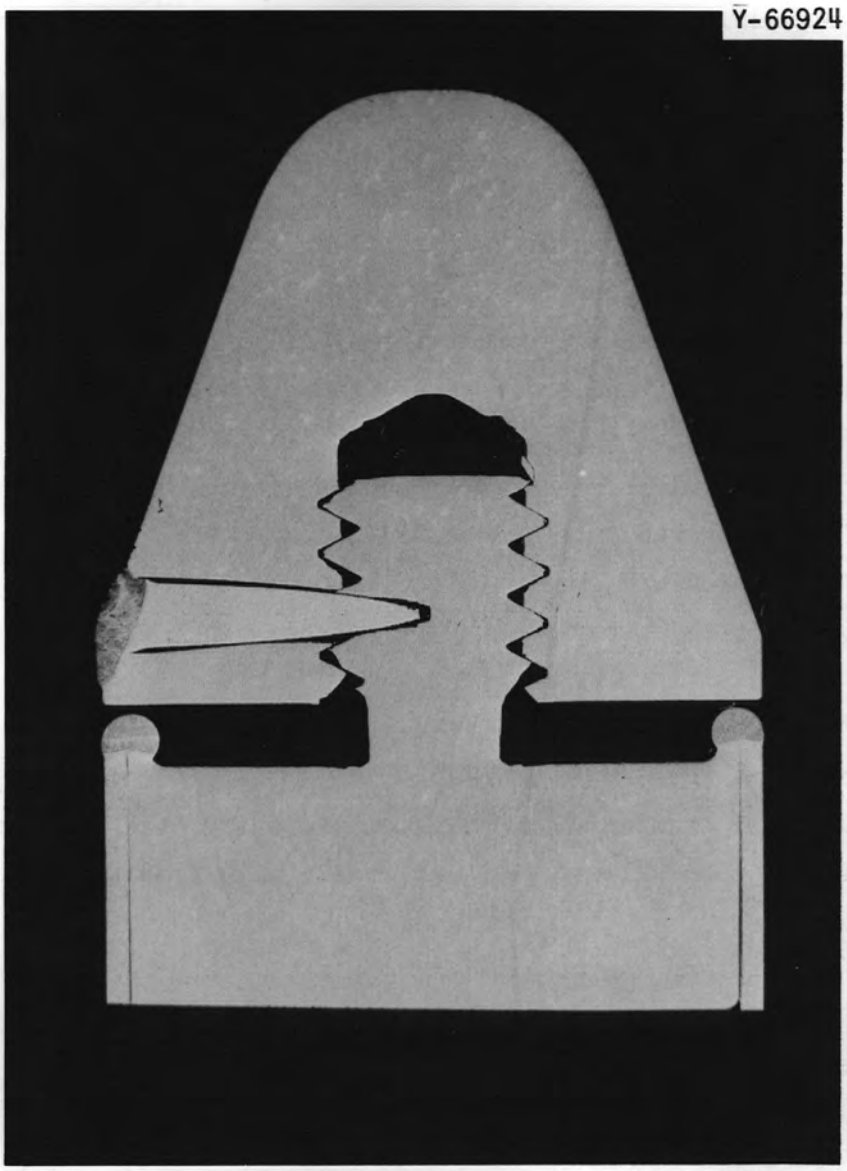

Fig. 10. Cross Section of Bottom End Cap and Fairing. The tube-to-end cap and the pin-to-fairing welds are evident. Etchant: Glyceria regia. 7X.

The purpose of these sleeves is to keep the unsupported cladding from collapsing during reactor operation.

The need for vent holes in the end caps (as called for in the original design) was easily circumvented. This was done by inserting and welding the final end cap into each fuel rod in a helium-filled, inert-atmosphere welding chamber.

No other design modifications were made, and all other aspects of the BONUS replacement fuel element were as originally designed by CEND.

Fuel Element Fabrication Sequence

The various operations used in rebuilding superheater fuel Assembly No. 29 are listed in sequential order below.

1. Inspect component parts, that is, cladding and coolant tubing, fuel pellets, spacers, and end caps.
2. Braze spacers onto cladding and coolant tubing. This operation was performed on commercial equipment under subcontract.
3. Inspect brazed tube-to-spacer joints.
4. Weld bottom end caps into fuel tubes.
5. Load bottom spacer sleeve, perforated disk, and UO_2 fuel into fuel tubes.
6. Place loaded fuel tubes into inert-atmosphere welding chamber and vacuum outgas for 4 hr at 570°F.
7. Backfill chamber with helium. Load an Inconel X-750 compression spring and top spacer sleeve into each fuel rod. Press top end cap into place.
8. Weld the top end cap in place.
9. Inspect both end closures.
10. Assemble the threaded end fittings onto the fuel rods and secure in place.
11. Insert the completed fuel rods into the coolant tubes.
12. Weld the top support hanger to coolant tube.
13. Dye-penetrant inspect the top-support-hanger-to-coolant-tube welds.
14. Load the fuel-rod-and-coolant-tube subassemblies into the pressure shell.
15. Transfer the pressure shell to ORGDP for final assembly operations.

The various operations will be discussed in detail in subsequent sections.

Spacer Brazing

A specification (NRS-14) was prepared to cover the brazing of spacers to both the cladding and coolant tubes.

Cladding Tubes

It was proposed[8] that the large grain size in the cladding tubes of the original BONUS fuel element was a result of the long-time high-temperature brazing cycle which was used. An additional complication was the possibility of germinative grain growth. Two specific measures were taken to overcome these difficulties. These were:

1. The fuel cladding tubing had a 1/4-hard mill temper before brazing.

2. Spacers were brazed on the cladding tubes before they were loaded with fuel.

The purpose of requiring a 1/4-hard mill temper in the tubing was to prevent excessive grain growth. This temper was selected as optimum after numerous grain size studies. The variables studied were brazing time, brazing temperature, and mill temper.

In order to limit the time at temperatures above 1600°F to 10 min, the cladding tubes were brazed without fuel inside. If the tubes had been loaded with fuel, their large masses would have precluded the possibility of using a rapid thermal cycle for brazing.

The adequacy of the grain size control achieved by the above means is shown in Figs. 11 and 12. Figure 11a shows the microstructure of the as-received 1/4-hard tubing. Figure 11b is the grain size after 10 min at the brazing temperature of 1850°F, and Fig. 11c is the grain size after 20 min at 1850°F. Figure 12 is the microstructure of an actual tube which went through the production brazing cycle.

The actual brazing of cladding-tube spacers proceeded as outlined below.

1. Five Inconel 600 cladding-tube-to-coolant-tube spacers were slipped on each cladding tube and spaced according to the applicable drawing

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[8] J. E. Cunningham *et al.*, BONUS Reactor Fuel Assemblies — An Investigation of Failure and Method of Correction, ORNL-3910 (December 1965).

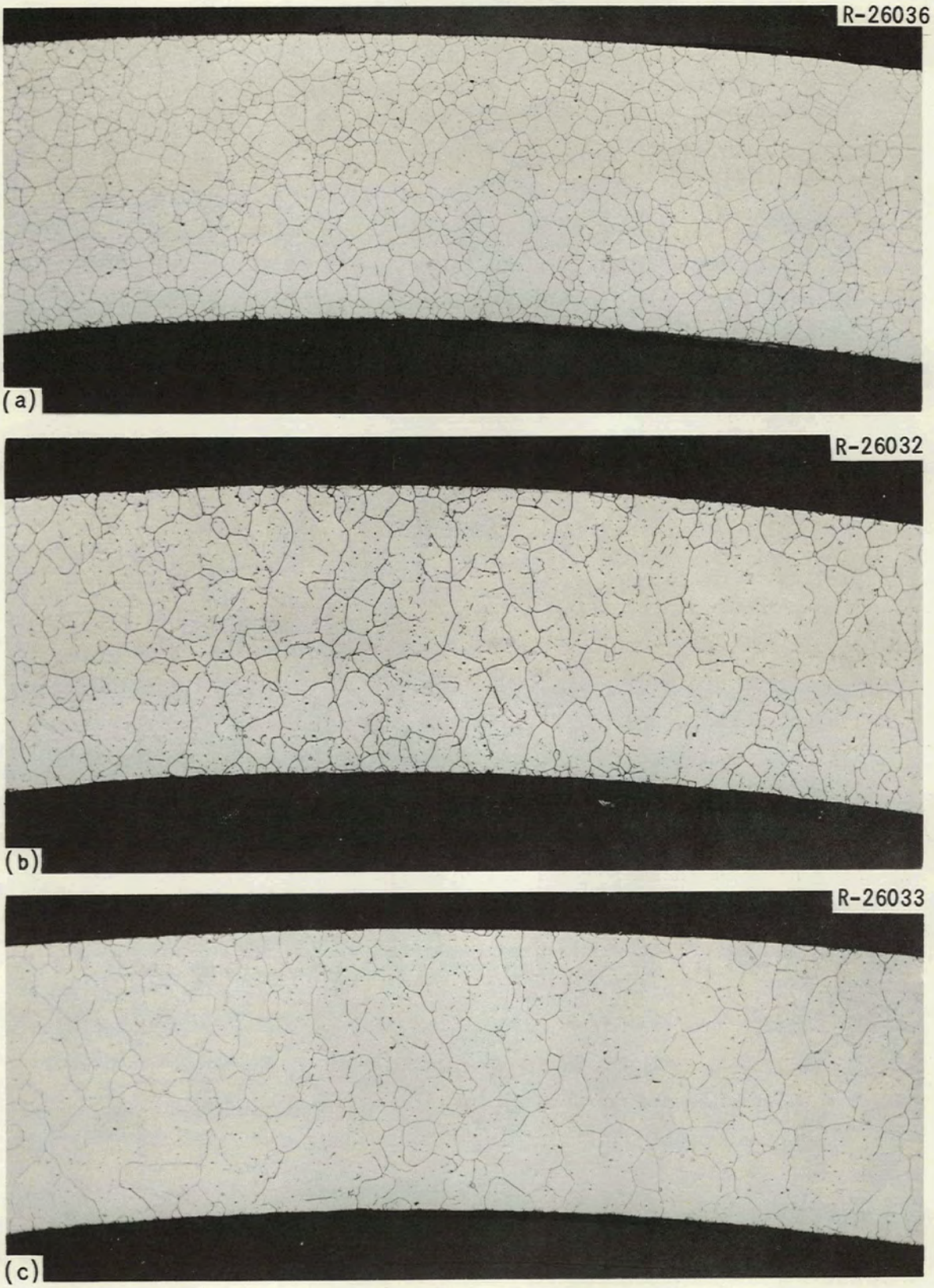


Fig. 11. Microstructure of Inconel 600 Cladding Showing Grain Size of (a) As-Received Tubing, (b) Tubing after Heating at 1850°F for 10 min, and (c) Tubing after Heating at 1850°F for 20 min. Etchant: oxalic-acid 10%. 100×.

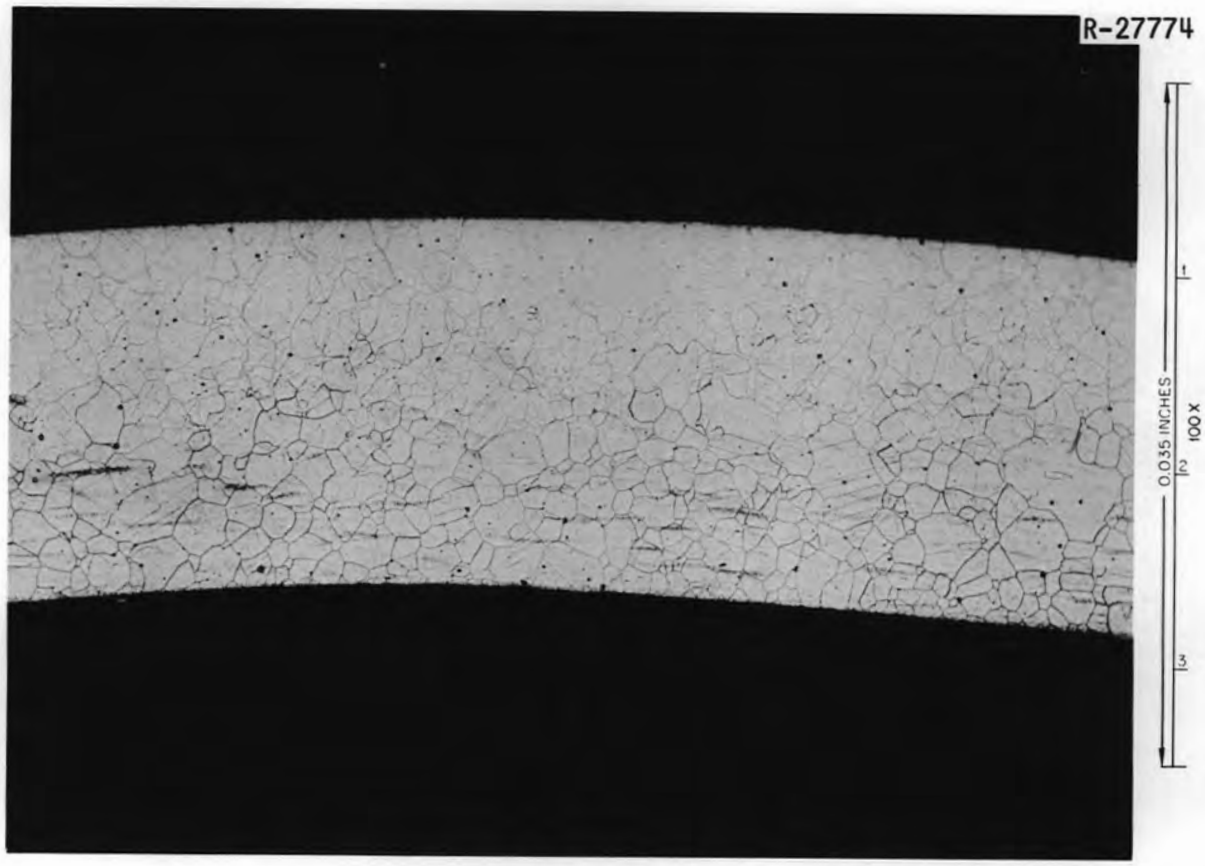


Fig. 12. Microstructure of Actual Cladding Tube That Has Gone Through Brazing Cycle. Etchant: Glyceria regia.

(Appendix A). Each spacer was secured to the tube by one spot weld made by a capacitor discharge welder set at 200 wsec output.

2. A slurry of powdered Nicrobraz-50 (Ni–13% Cr–10% P) brazing alloy in a volatile acrylic binder was preplaced at each braze joint, that is, the three tangency locations of each spacer-to-tube interface.

3. The tubes were crated and shipped to the brazing vendor, Ferrotherm Company, Cleveland, Ohio, for brazing. They were brazed under ORNL supervision.

4. The tubes were brazed in a single lot in a continuous, belt-hearth furnace in a dry hydrogen atmosphere of at least −70°F dew point. The brazing thermal cycle was specified as 10 min or less above 1600°F with a maximum temperature of 1850°F. A typical thermal cycle trace generated by a thermocouple contained inside a cladding tube as it passed through the furnace is shown in Fig. 13.

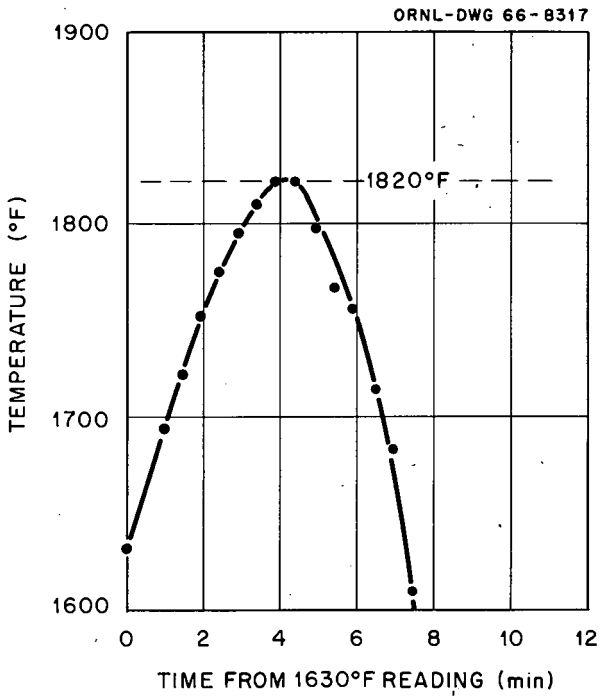


Fig. 13. Typical Thermal Cycle Used in Brazing Spacers to Cladding Tubes.

After brazing, the tubes were crated and returned to ORNL for inspection and subsequent assembly operations. A cross-sectional view of a typical satisfactory cladding-tube-to-spacer braze is shown in Fig. 14.

All tubing-spacer braze joints were inspected at ORNL after receipt from the Ferrotherm Company. The following tubes appeared to have inadequate braze material for the full circumference of the joint: 0-1, 0-2, 0-3, 0-6, 0-7, 0-10, 0-12, 0-15, 0-18, 0-20, 0-22, 0-23, 0-25, 0-26, 0-29, and 0-39.

A review of these tubes by project personnel resulted in an acceptance for use of 0-1, 0-2, 0-10, 0-15, 0-20, 0-22, and 0-25, and for "use if necessary" of 0-3 and 0-12.

Coolant Tubes

The coolant tubes were type 348 stainless steel and were available as surplus material from Combustion Engineering Nuclear Division. However, we had to fabricate new spacers from type 348 stainless steel tubing.

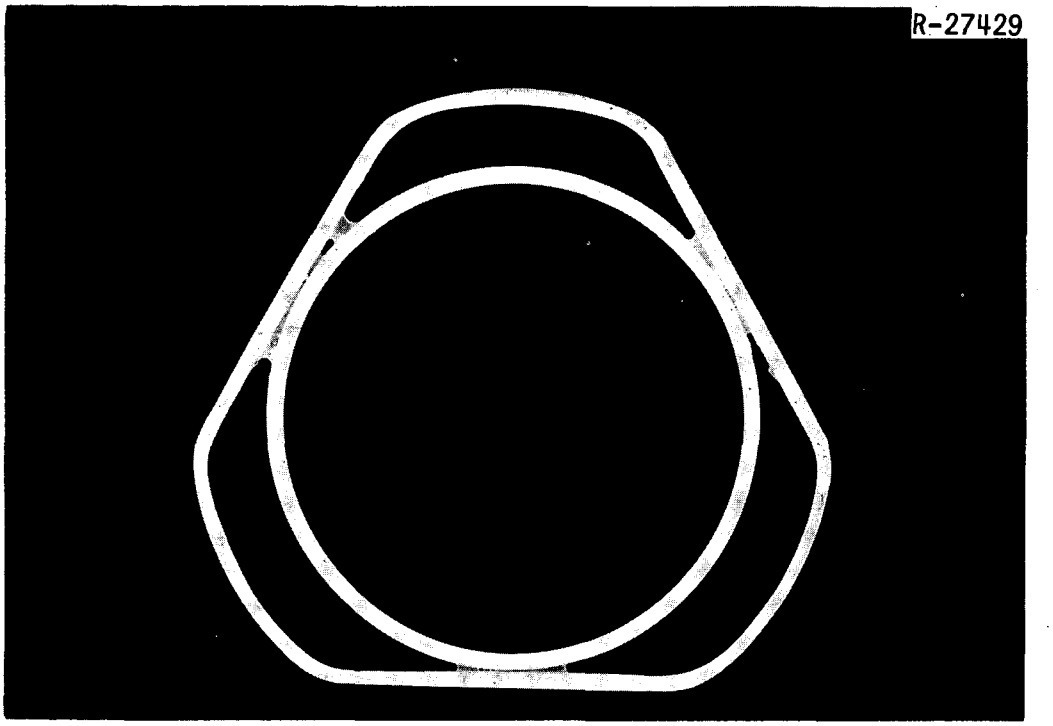


Fig. 14. Typical Cladding-Tube-to-Spacer Braze. Good general flow and filleting are evident, although a few scattered voids were obtained. As-polished. 5×.

The brazing of the coolant-tube spacers proceeded as outlined below:

1. Five type 348 stainless steel coolant tube-to-pressure tube spacers were slipped on each coolant tube and spaced according to the applicable drawing. Each spacer was secured to the tube by one spot weld made by a capacitor discharge welder set at 200 wsec output.

2. A slurry of powdered Nicrobraz-50 brazing alloy in a volatile acrylic binder was preplaced at each braze joint.

3. The tubes were crated and shipped to the brazing vendor, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, for brazing. Westinghouse was selected as the alternate vendor when the original brazing vendor was unable to maintain adequate hydrogen purity.

4. The tubes were brazed in a batch-type retort furnace in a dry hydrogen atmosphere of at least −94°F dew point. A typical brazing thermal cycle, as read from monitor thermocouples, is shown in Fig. 15.

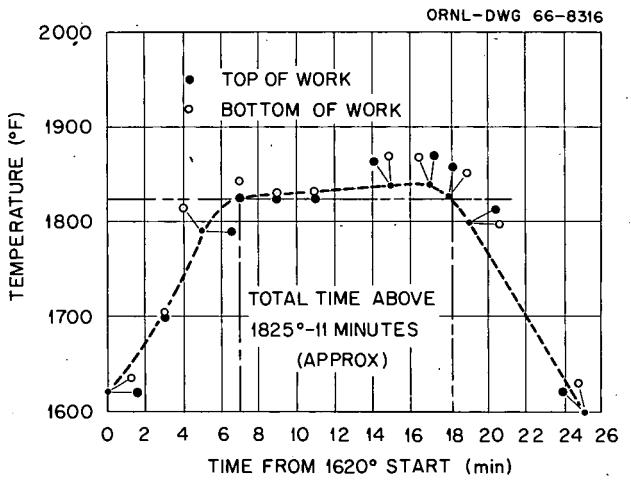


Fig. 15. Typical Thermal Cycle Used in Brazing Spacer to Coolant Tube.

5. The coolant tubes were brazed in the two lots itemized below. We used the original CEND numbers for tube identification.

Braze Lot Number 1			Braze Lot Number 2		
1389	1289	1419	1502	1497	1362
1490	1386	1379	1376	1381	1374
1495	1491	1499	1393	1500	
1501	1391	1297	1506	1380	
1293	1295	1504	1387	1390	
1288	1493	1498	1377	1513	
		1460			

6. After brazing, the tubes were crated and returned to ORNL for inspection and subsequent assembly operations.

Inspection revealed that the brazing, in general, met the requirement of the minimum 3/16-in. coverage.

Spacers on all 34 subassemblies had a slightly roughened surface where excess brazing alloy was removed. Tubes 1274, 1380, and 1381 had grinding marks on the tube wall. Tube 1274 also had a dent in the ground area. All 34 tubes had from 1/8- to 3/8-in. camber. On tube 1460, the braze material had a rough surface condition. A cross-sectional view of a typical coolant tube-to-spacer braze is shown in Fig. 16.

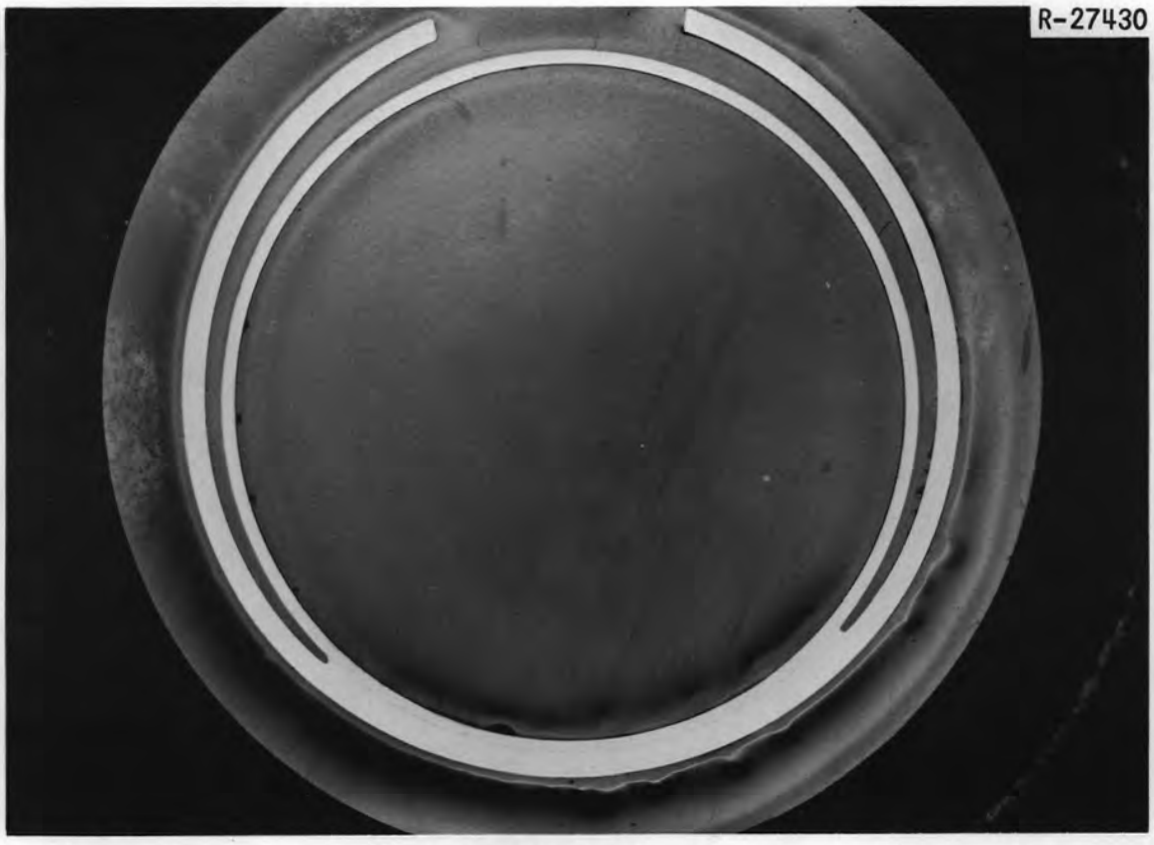


Fig. 16. Typical Coolant-Tube-to-Spacer Braze. Good bonding is evident. As-polished. 5×.

Welding of Bottom End Caps

During qualification of the end-cap welding procedures, several test samples were made. These were inspected in the same manner as the production welds (i.e. by leak test, radiography, and liquid penetrant, as described below under Inspection of Fuel Rods). In addition, extensive metallographic sectioning was used to verify weld integrity and adequacy of penetration.

Both the tubing and bottom end caps were ultrasonically cleaned in acetone prior to assembly. The end caps were then pressed into place in the cladding tubes. An edge weld was made without the addition of filler metal in the setup shown in Fig. 17. The tube was secured in a chuck and mechanically rotated under the welding torch at a constant speed by a direct-current motor. Current traces were recorded for all welds. A massive copper chill block was placed around the outside of the tubes and approximately 0.030 to 0.040 in. below the weld joint to

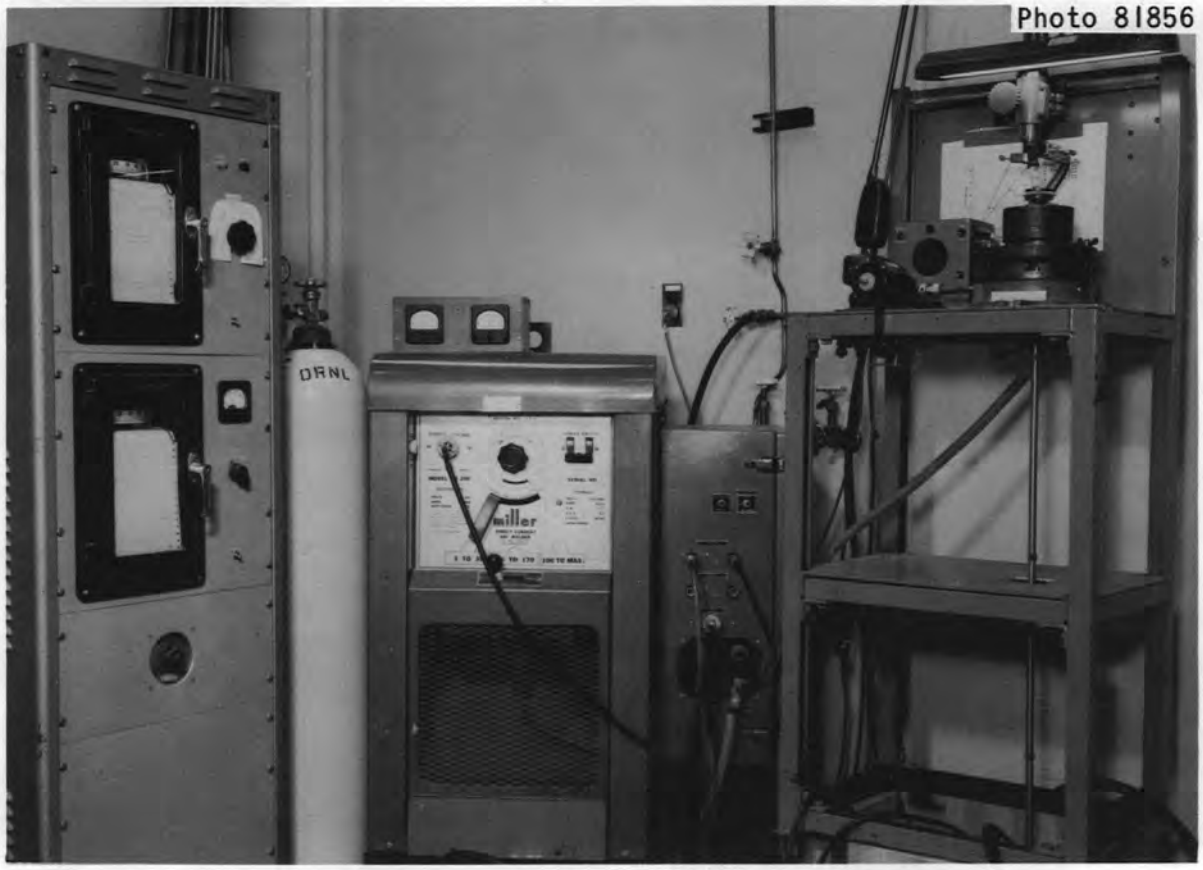


Fig. 17. Equipment Used for Welding End Caps to Cladding Tubes.

minimize rollover of weld metal. The chill block was carefully brushed clean after each use.

To make the weld, the tubing-and-end-cap assembly was rotated at a constant speed under the torch prior to arc initiation. The arc was started with the aid of a high-frequency arc starter. After the arc was established, the work was rotated 1 1/2 revolutions. The arc was tapered to extinction during an additional 1/2 revolution. The welding conditions used for all the bottom end-cap welds are (1) torch gas, argon at 15 cfh; (2) electrode, 1/16-in.-diam, 2% thoriated tungsten; (3) arc gap, 0.020 to 0.030 in.; (4) welding current, 16 to 19 amp, direct current, straight polarity; and (5) welding speed, 6.8 in./min.

A closeup view of a typical bottom end-cap weld is shown in Fig. 18a. A metallographic cross section of a bottom end-cap weld is shown in Fig. 18b. Except for visual examination, weld inspection was deferred until after the top closure.

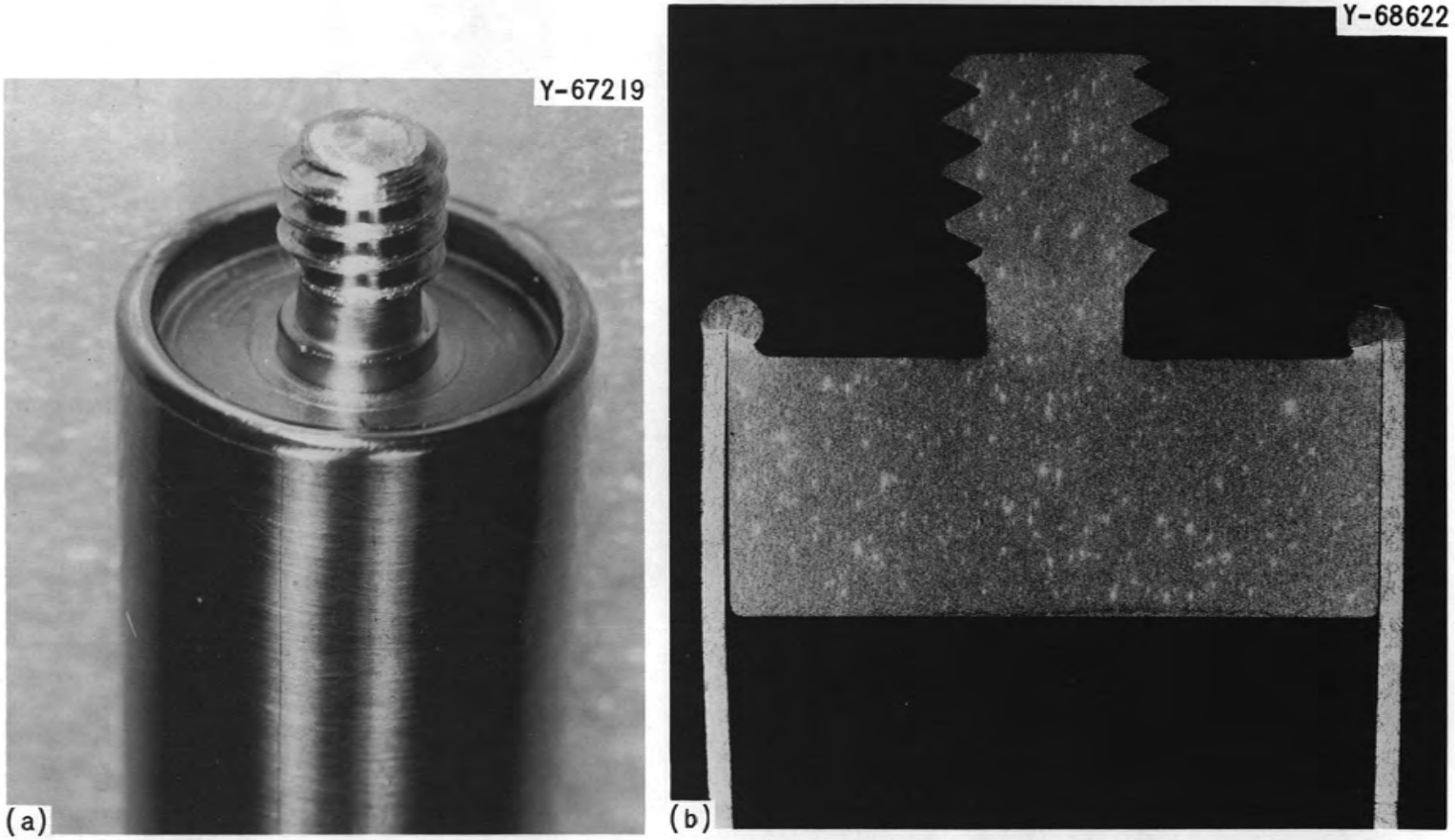


Fig. 18. Bottom End-Cap Weld. (a) General view. 5×. (b) Vertical metallographic section. 8×.

Loading of Fuel Rods

After the bottom-end cap welds were completed, a lower spacer sleeve and perforated disk were loaded into each fuel rod. Both of these items were made of type 348 stainless steel and are shown in Fig. 19.

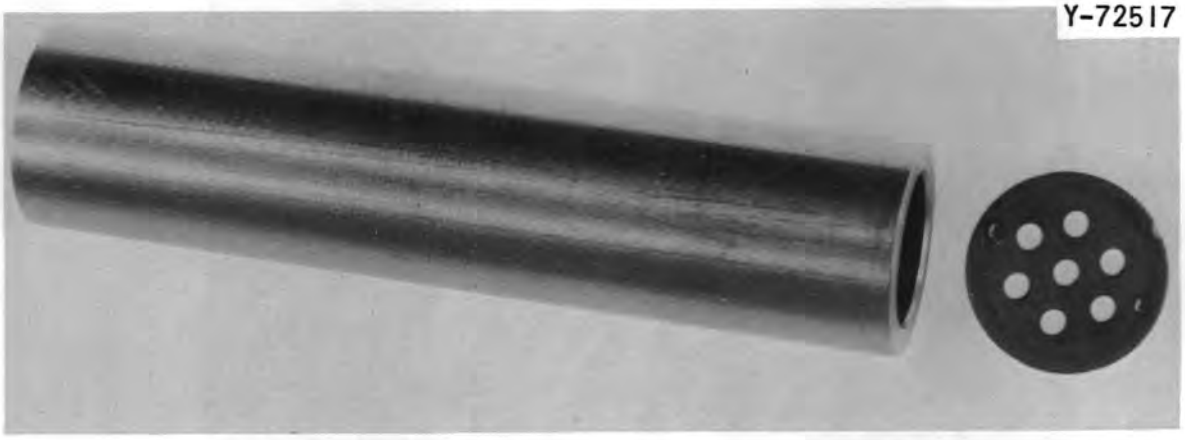


Fig. 19. Lower Spacer Sleeve and Perforated Disk. 2×.

The UO_2 fuel pellets were then loaded into the fuel rods. These pellets had been previously inspected and made up into stacked lengths of 54 5/8 ± 3/16 in. as specified by the applicable drawing. These stacked lengths had a specified weight of 1825 ± 25 g per fuel rod. The fuel weights for each rod are listed in Appendix D.

Outgassing of Fuel Pellets

The fuel rods, complete with fuel pellets but without compression springs, upper space sleeves, and top end caps, were loaded into an inert-atmosphere welding chamber for outgassing. The outgassing was performed under vacuum in a furnace extension to the welding chamber. A view of this setup can be seen in Fig. 20 which shows the 8-in.-ID × 58-in.-long clamshell furnace in place over the vacuum outgassing retort.

The outgassing cycle consisted of baking the fuel rods for 4 hr at 570°F under a dynamic vacuum of about 10^{-5} torr. The rods were then

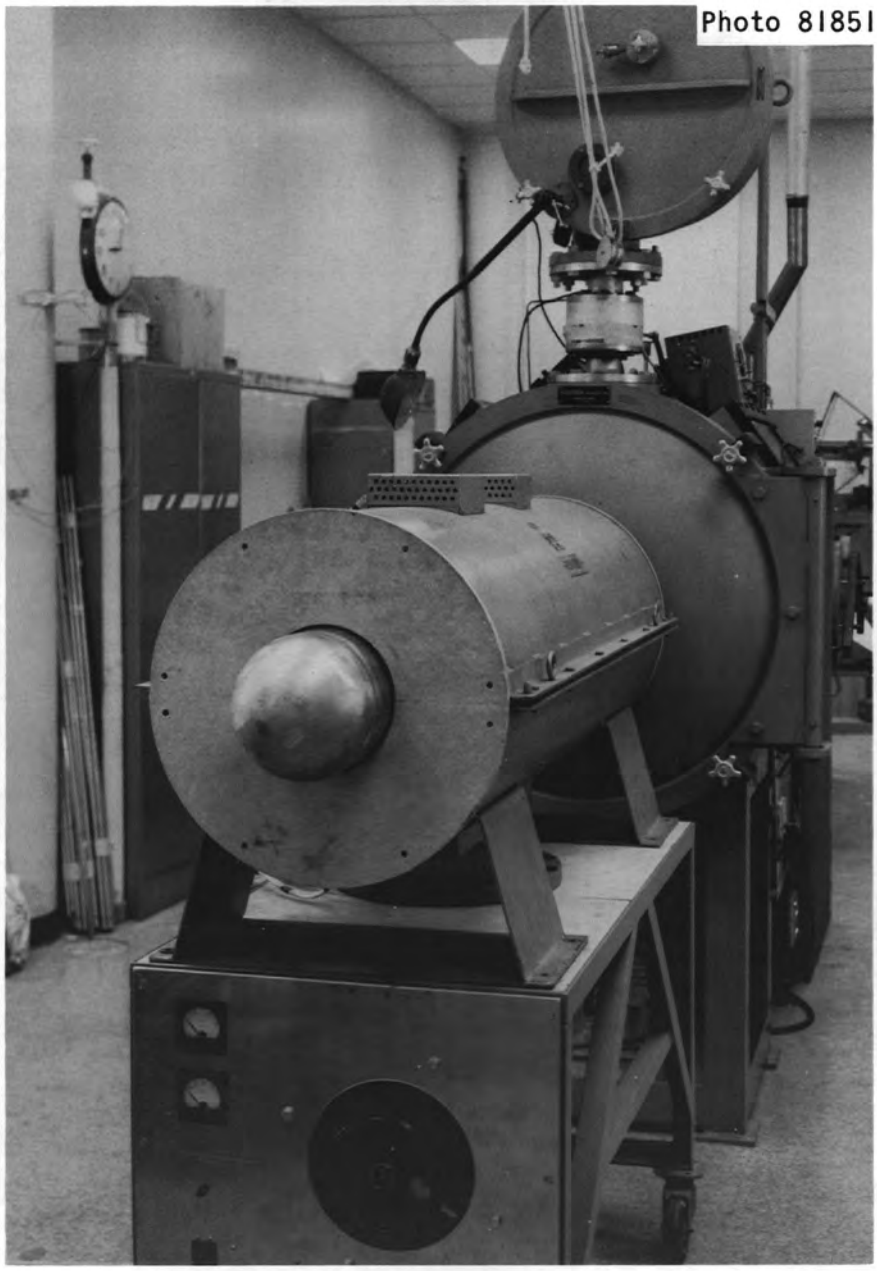


Fig. 20. Inert-Atmosphere Chamber and Furnace Extension.

cooled to room temperature under vacuum before the welding chamber was backfilled with high-purity helium (6 ppm H_2, 6 ppm H_2O, 9 ppm N_2 + CO, 1 ppm O_2, 21 ppm Ar, < 1 ppm CO_2).

In order to qualify this outgassing cycle, a special test was conducted prior to operations on any fuel rods. In this test, ten randomly selected fuel pellets were placed in a length of cladding tubing and outgassed as described above. Before they were removed from the welding

chamber, the pellets, under the protection of a helium atmosphere, were removed from the tube and placed in a glass transfer bottle. This was then sent for an assay of moisture content. The reported moisture content was 0.52 ppm, well within the 10 ppm specified in NRS-12, Appendix B.

Assembly of Top Closure Components

After the chamber was backfilled with high-purity helium, the top spacer sleeves, compression springs, and top end caps were inserted into the fuel rods. These components were placed in the welding chamber along with the fuel rods for outgassing. A view of these items is shown in Fig. 21.

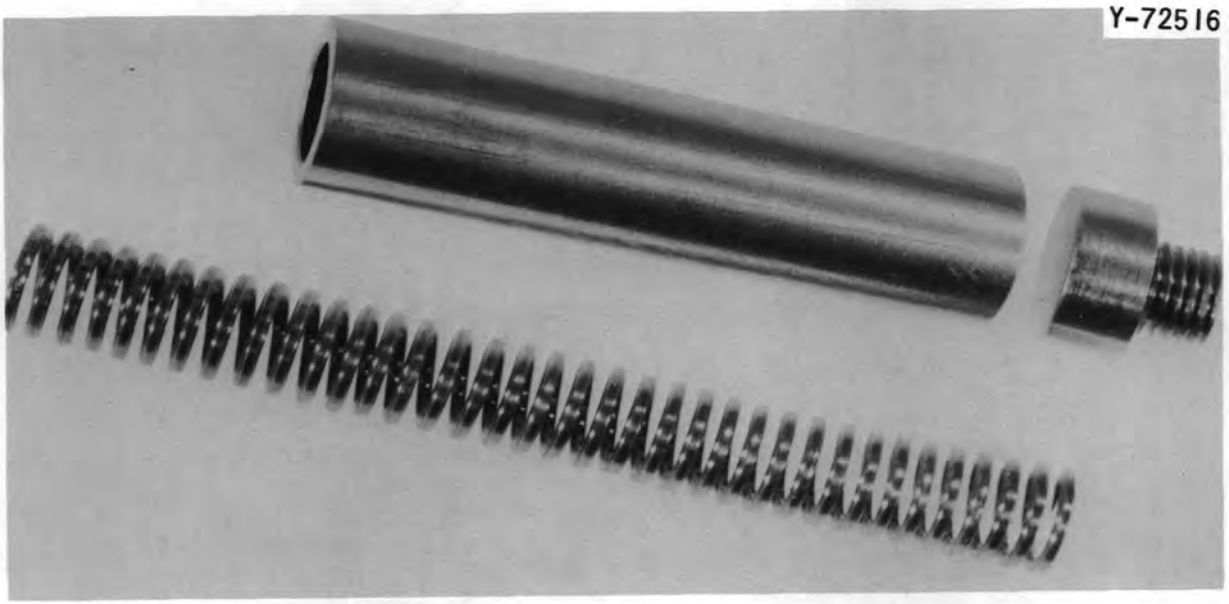


Fig. 21. Top Spacer Sleeve, Compression Spring, and Top End Cap. 2×.

Welding of Top End Caps

The top end-cap welding procedure was qualified in a manner similar to that described above for the bottom end-cap welds.

Prior to removal from the helium-filled welding chamber, the top end cap was welded in each fuel rod. Like for the closure at the bottom end cap, an edge-weld joint was used. It was made by mechanically rotating

the tube in a horizontal position in front of the stationary welding torch. The apparatus used for this operation is shown in Fig. 22. The frequently cleaned copper chill block used in making the bottom end-cap welds was also used in making these welds.

The fuel rod was rotated at a constant speed in front of the torch prior to arc initiation. Because of the difficulties in starting an arc in a helium-filled welding chamber, argon was introduced through the welding torch at the same time that the high-frequency arc starter was energized. Once the arc was established, the torch gas was immediately switched to pure helium. Like the bottom end caps, the workpiece was rotated 1 1/2 revolutions at full welding current. This was followed by a 1/2 revolution of arc taper to extinction. The welding conditions used for all top end cap welds are (1) torch gas, arc initiation with argon at 15 cfh and welding with helium at 15 cfh; (2) welding chamber gas, helium at 5 to 10 cfh; (3) electrode, 1/16-in.-diam, 2% thoriated tungsten; (4) arc gap, 0.020 to 0.030 in.; (5) welding current, 16 to 18 amp, direct current, straight polarity; and (6) welding speed, 6.8 in./min.

A closeup view of a typical top end-cap weld is shown in Fig. 23a, while a metallographic cross section is shown in Fig. 23b.

The top end-cap welds were made on a batch basis. For each welding batch, a sample qualification weld was made prior to actual fuel rod welding. This was done to verify the quality of the welding chamber atmosphere and the settings for all welding parameters. Metallographic examination revealed these welds to be satisfactory.

In addition to the qualification welds, a sample of the welding chamber atmosphere was taken for each welding batch. These samples were submitted for mass-spectrometer analysis. These analyses were compared with the original gas bottle analyses as further verification that no atmospheric contamination had occurred. The gas analyses for all the chamber welding batches are presented in Appendix D.

After completion of the top end-cap welding, the fuel rods were sent for a complete nondestructive evaluation prior to any further operations.

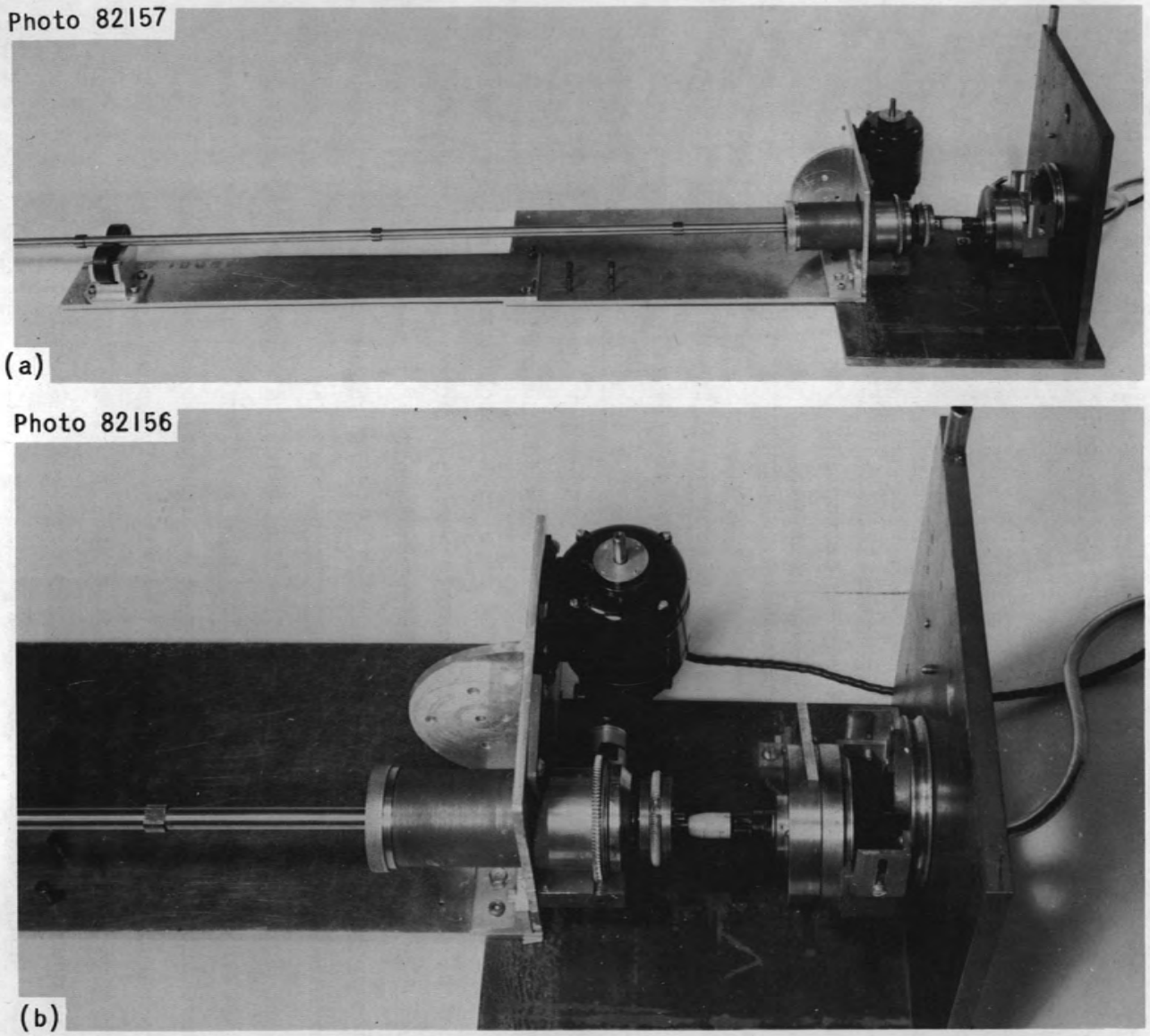
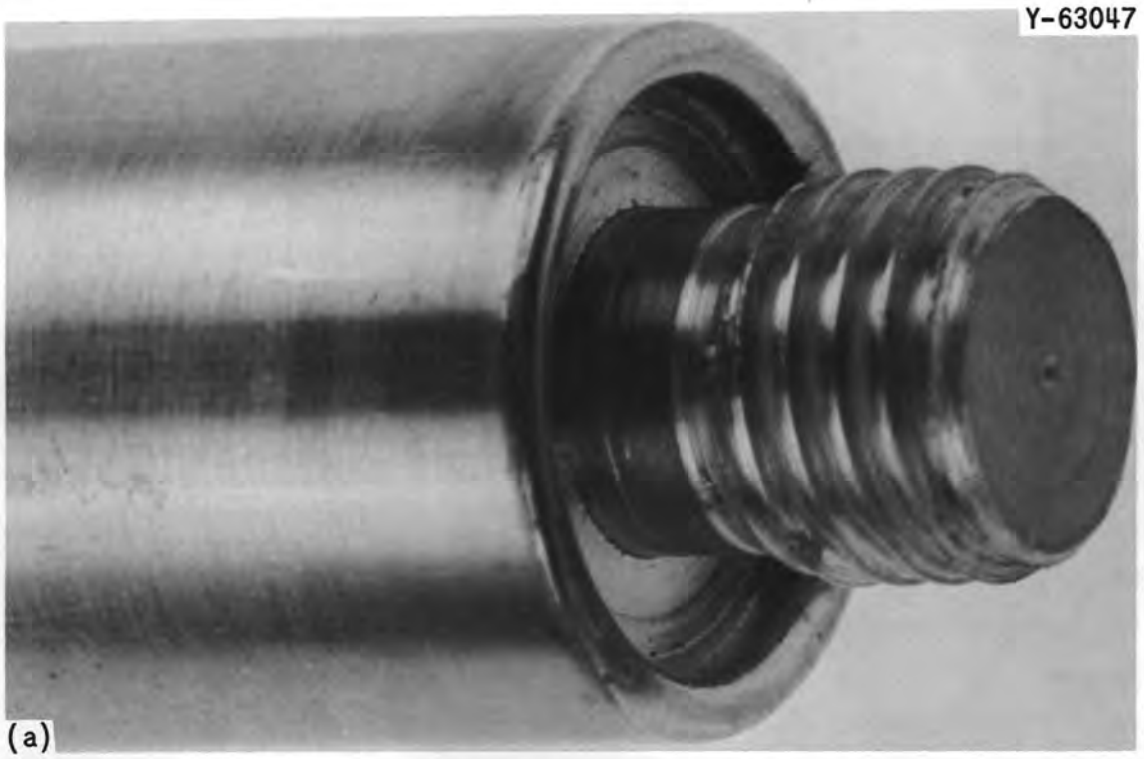


Fig. 22. Apparatus Used for Making Top End Cap Welds in Inert-Atmosphere Chamber. (a) Overall view. (b) Closeup view.



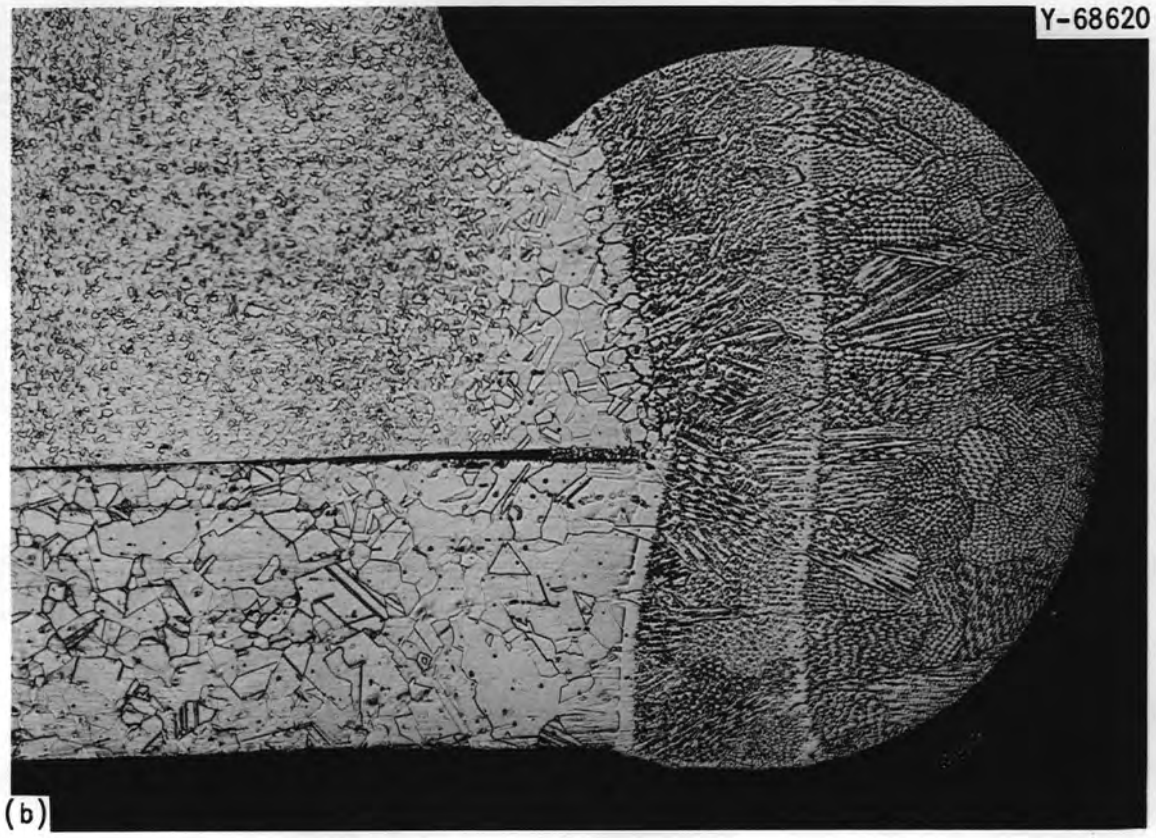


Fig. 23. Top-End Cap Weld. (a) General photograph. (b) Metallographic cross section. Etchant: Glyceria regia.

Inspection of Fuel Rods

A few fuel rods were helium leak tested by the Inspection Engineering Department; however, the instability of the leak detector instrument (Veeco MS-9A) at the high-sensitivity range prevented the reproducibility necessary for a valid test. The reproducibility was on the order of 5×10^{-10} std cm^3/sec. One of the fuel rods, No. 0-38, tested under these conditions was found to leak at a rate in excess of 1×10^{-5} std cm^3/sec. This leak rate left no question as to the unacceptability of the rod.

Because of the instrument difficulties, all rods were transferred to the leak test facilities in Bldg. 9201-3 at Y-12. The instruments used were CEC Model 24-120. Of the 35 rods, 32 were found to be acceptable and the test data are shown in Appendix C. One of these rods required repair; that is, the weld was ground away, the end cap was reinserted, and the weld was remade successfully. The fuel rods which were found to leak in excess of the permissible rate were 0-14, 0-28, 0-38, and 0-40. Each of these, when first detected, produced leak rate readings in excess of the maximum limit of the instrument of 1×10^{-5} std cm^3/sec. The meter readings on rods 0-24 and 0-32 were one division above the background (columns E and D in Appendix C-3); however, a check on the background level subsequent to the test on these rods showed that the background level had raised one division and that the rods were not leaking. In general, one division rise in meter reading above background was not considered as leakage.

The point of leakage on rods 0-28 and 0-40 was located by helium sniffing and with Zyglo penetrant. The welds were removed from each of these rods and rewelded with new end caps. The rods were retested for leakage; 0-40 showed no leak and 0-28 leaked at a rate greater than 1×10^{-5} std cm^3/sec. This leak was located by helium sniffing and with penetrant. Rod 0-40 was included in the 32 accepted rods.

After leak testing, penetrant inspection was performed on each closure weld using type ZL-22 fluorescent penetrant with a 30-min penetration time, type ZE-3 emulsifier with a 1-min emulsification time, and type ZP-4 dry developer. No indications were reproducible except on two of the rods previously rejected by the helium leak test.

Radiography of the welds was done with the central x-ray beam directed toward the weld and at an angle of approximately 30° to the rod. A special fixture was used to hold the rods and film in position. No rejectable indications were found on the radiographs.

The results of the dimensional inspection of the acceptable rods were satisfactory and the data are also shown in Appendix C. Metallographic examination of the leaking areas of the fuel rods revealed that a weld-cracking problem existed. This is discussed in detail in a subsequent section of this report.

Assembly of Threaded End Fittings

After passing the nondestructive testing evaluation, the fuel rods were equipped with the threaded end fittings. Once these fittings were screwed into place, they were secured by pinning as described earlier and shown in Fig. 10.

Insertion of Fuel Rods into Coolant Tubes

The fuel rods were manually inserted into the coolant tubes. Because of a close fit between the triangular spacers on the fuel rods and the inside surface of the coolant tubes, it was necessary to use a removable lubricant to prevent damage during assembly. The lubricant used was a solution of stearic acid in ethyl alcohol, which was hand painted on each fuel-rod-to-coolant-tube spacer and allowed to flow on the inside of each coolant tube. After assembly, the fuel-rod-coolant-tube subassemblies were rinsed out with 190-proof ethyl alcohol. After this operation, they were vacuum baked for 4 hr at 570°F to volatilize any residual stearic acid.

A correlation of the fuel rod identification numbers with the existing CEND numbers of the coolant tubes into which they were loaded is listed in Appendix D. The fuel tubes were numbered on the top cladding-tube spacer and on the outside of the top support cap.

Welding of Fuel Rods to Coolant Tubes

After vacuum baking, the fuel-rod-and-coolant-tube subassemblies were ready to have the coolant tubes welded to the fuel rods. This involved the making of a socket-type weld between the upper, flared edge of the coolant tube and the upper support hanger of the fuel rod. These welds were made manually with the addition of type 347 stainless steel filler metal at a current of 20 to 25 amp and a welding speed of approximately 4 in./min.

After welding, all welds were dye-penetrant inspected and accepted. The weld buildup was then dressed down as necessary so that the subassemblies would fit into the pressure shell. The appearance of a typical coolant-tube-to-fuel-rod weld is shown in Fig. 24a. A cross section of a coolant-tube-to-fuel-rod test weld is shown in Fig. 24b.

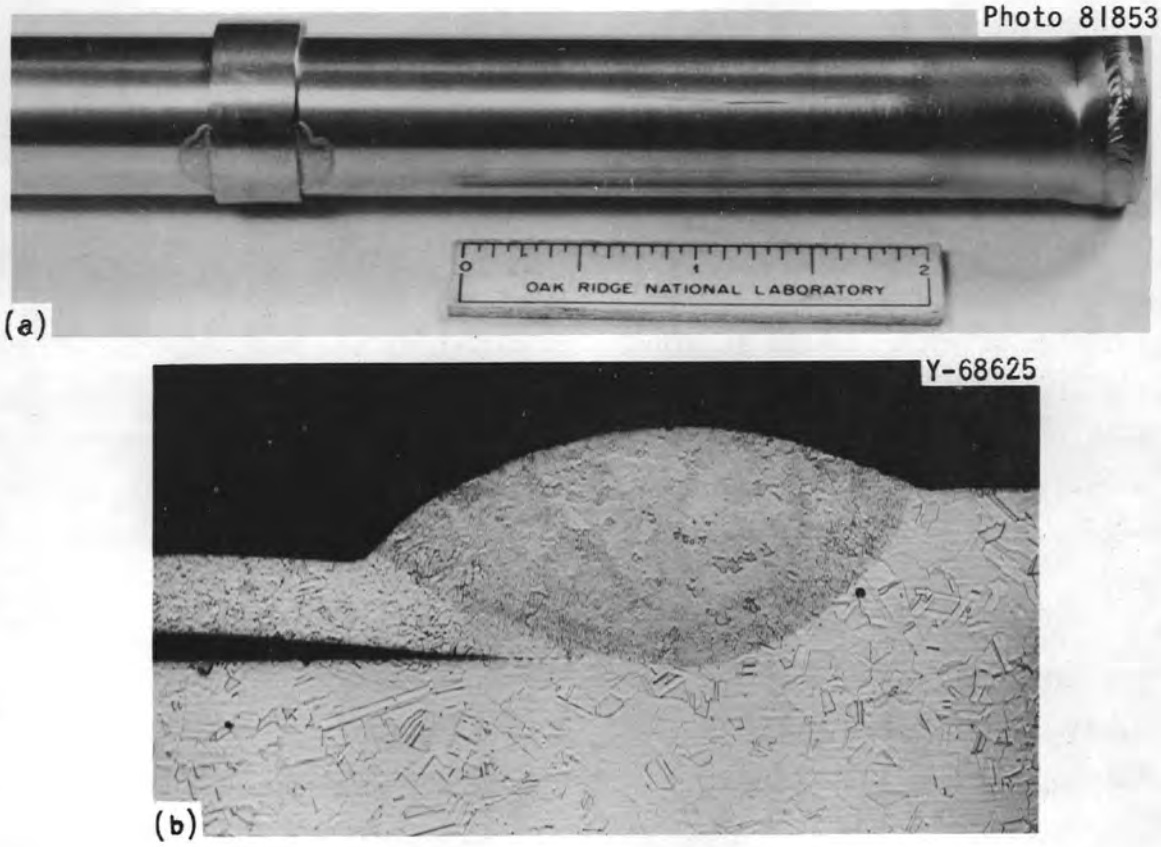


Fig. 24. Coolant-Tube-to-Fuel-Rod Weld. (a) General photograph. (b) Cross section. 40×. Etchant: glyceria regia.

Loading of Subassemblies into Pressure Shell

The fuel-rod coolant-tube subassemblies were manually inserted into the existing BONUS fuel element No. 29 pressure shell. A view of the top end of the pressure shell prior to loading of the subassemblies is shown in Fig. 25. The physical location of the fuel rods according to their assigned numbers is shown in the chart of Fig. 26. A view of the top end of the loaded fuel assembly is shown in Fig. 27.

Photo 81852

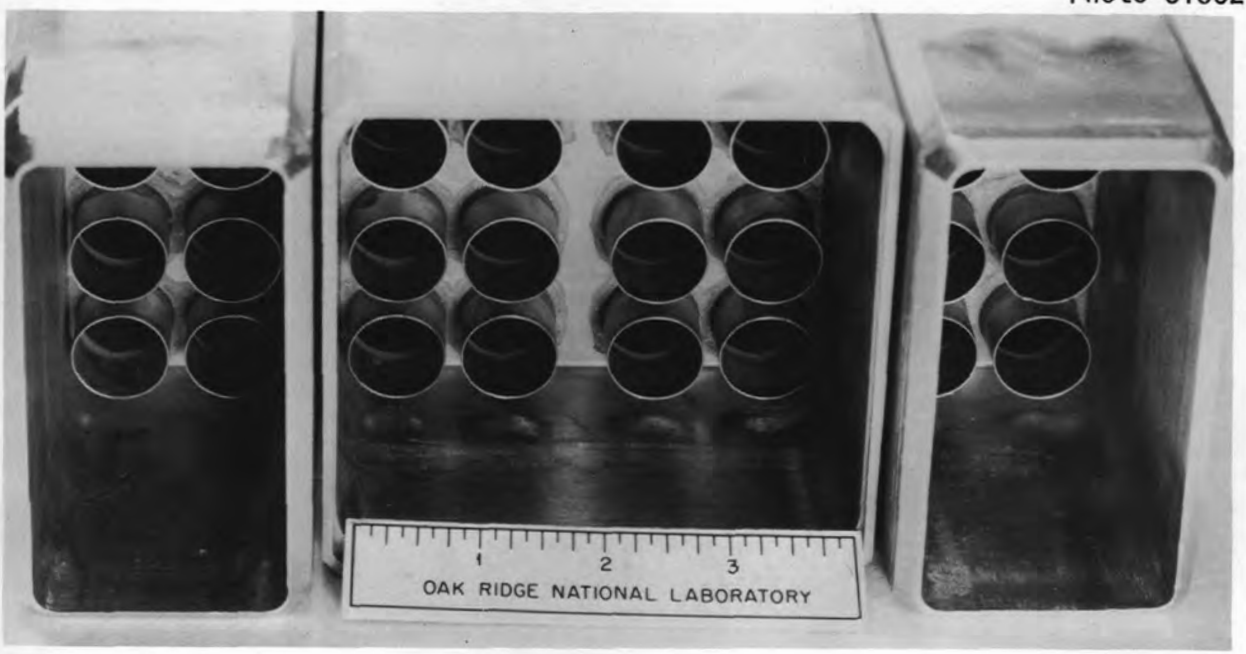


Fig. 25. Top End of Pressure Shell Prior to Loading of Fuel-Rod-and-Coolant-Tube Subassemblies.

ORNL-DWG 66-8465

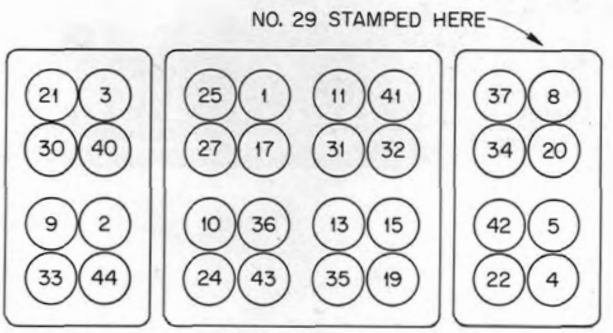


Fig. 26. Location of Fuel Rods into Pressure Shell.

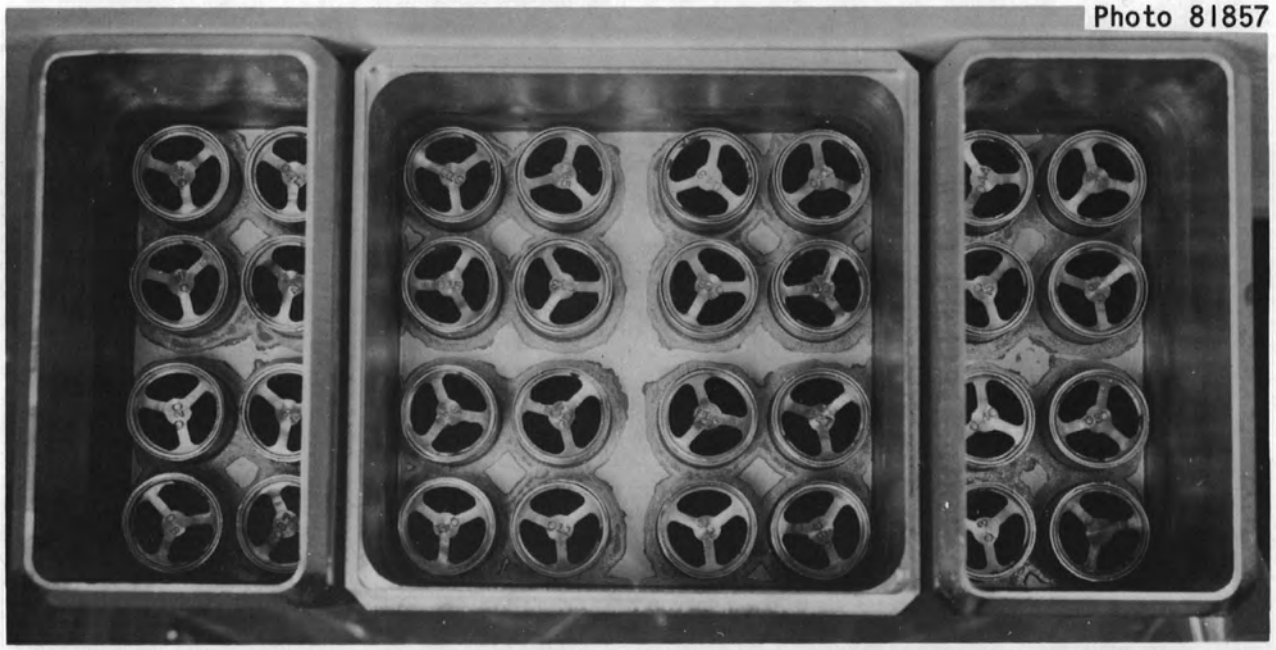


Fig. 27. Top End of Loaded Fuel Element Before Welding Pressure Tubes to Support Caps.

The fuel assembly was transferred to ORGDP for edge welding the subassemblies to the pressure tube upper ends and reinstallation of the steam-flow liners, crossover boxes, and standpipes.

FABRICATION OF REMAINDER OF FUEL ASSEMBLY

The standpipe subassembly and upper portion of the top end box had been machined off superheater Assembly No. 29 to permit us to remove the fuel rods and coolant tubes for examination. The reason for this examination was discussed in the introductory section of this report. The standpipe and shell portions of this assembly were transferred from ORNL to the ORGDP Fabrication Shops for remachining the weld joints in preparation for the final closure welds. Both the standpipe and tube sheet subassemblies were transferred into separate, hinged-top wooden boxes for cleanliness protection and to facilitate handling. Within the boxes, each was encased in a plastic covering and mounted on Styrofoam padding. A notice was posted on the exterior of each box, "HANDLE CONTENTS ONLY WITH WHITE, CLEAN GLOVES."

Cleanliness control specified for the original fuel building was strictly observed for the rebuilding of Assembly No. 29. All machining was done without cutting oils and by operators wearing clean, lint-free white gloves. Tube ends were sealed with plastic caps while machining the tube sheet joint edges. Turnings were blown off with dry air, and the pressure tubes were washed with laboratory-grade alcohol before inserting the fuel elements. Similar precautions for cleanliness and cleaning were followed while remachining the standpipe subassembly. Welds were checked for cracks using penetrant, cleaner, and developers certified by the vendor to meet the minimum NavShips 250-1500 requirements for sulfur and halogen contents. All residue was washed from each weld with the sulfur- and halide-free cleaner before continuing the next pass or at the completion of the weld.

During the process of rebuilding, components were shielded in plastic wrappings and all parts were handled with white gloves. Before sealing the unit for shipping, all exterior surfaces were washed with alcohol-saturated, lint-free cotton pads.

Tube Sheet Subassembly Reworking

As received at ORGDP, the pressure-shell subassembly had been mill cut through the upper cover plate near the edge weld and across the transition-to-tube-sheet weldments. All fuel rods had been freed by a square cut through the pressure-tube edge welds. No cuts had been made on the lower tube sheet.

To ready this component for reassembly required dressing the tube sheet joint edges for welding, cutting away tube sheet cover plates from the crossover liners, and other incidental buildup and repair work.

The first step for rebuilding consisted of buttering weld extensions onto the inlet-outlet compartment edges of the fuel box upper tube sheet. Buttering was intended to recover the length loss effected by the severance cut (the width of the mill cutting tool plus joint cleanup losses). Welding consisted of several overlay beads by the gas tungsten-arc process, using certified filler wire. The completed welds were accepted by a radiographic check.

The subassembly was transferred onto a flatbed-type milling machine for necessary machining. Shims were inserted between compartments and C-clamps were incorporated to lock the tube sheets onto the stationary bed. The buttered edges were squared to a common facing plane, internal shoulders were restored for the cover plate seats, and new bevels were machined. The subassembly was reversed, and with the lower tube sheet locked squarely onto the bed, attachment parts were machined off in the following order: the assembly guide, the sleeve end, and the guide sleeve. With all external parts removed, frame cuts were made alongside of the cover plate edge welds. Special attention was given to the depth of these cover plate cuts to preclude damage to the crossover liners.

Two items were noted during inspection of the upper tube sheet that required correction. First, several prominent casting and/or machining lines were found on the interior wall of the upper sheet. These potential stress-concentration lines were removed by buffing. Second, full penetration of the cover-plate-to-tube-sheet weldments had not been achieved. To assure a good repair joint, the lip height of the shoulder seat was

reduced to 3/32 in. to improve the welder's accessibility for making the critical root pass (Appendix B, "BONUS Superheater Repair Welding," UCN-1, Part B).

All original parts except the crossover plate covers were salvable. The guide sleeve cap, spring, seat washer, and fuel assembly guide were reusable as removed. The guide sleeve, shortened by the tool cut, was buttered and remachined to the design length. Upper- and lower-crossover flow liners were salvaged by cutting away the cover plates back to the positioning pins. This required the use of special clamping fixtures so that these thin-walled liners could be firmly chucked without indenting or tearing the metal surface.

Three new cover plates were fabricated. Plate edge bevels were modified to 45° by 1/16-in.-high land, again to facilitate better access into the weld root. The diameters of the plate holes were increased 1/16 in. to create an outlet passage for the inert backup gas used in the welding operation.

Standpipe Subassembly Reworking

Major rework on this component required the squaring and beveling of edges of the transition casting for final joint setup and the repairing of surface abrasions on the liners. During the original detachment cut, the thin-walled liner surface was damaged; besides two small mill nicks, a groove 4 × 1/16 × 0.010 in. deep had been inadvertently cut on a liner face. To make this groove accessible for repair, trimming of the transition casting an additional 1/8 in. was required. Both transition castings were squared to the cutback plane.

The surface defects on the liners were filled in with a tungsten-arc weld, using 0.035-in.-diam type 348 stainless steel filler wire with the welding machine adjusted for minimum heat output. No burn-through to the 0.030-in.-thick liner was experienced. The reinforcement crowns of these repair welds were blended into the base metal and polished with emery cloth, as was the sagged metal line that developed on the underside surface of each weld.

Welding

Fuel Element

The initial weldment involved tying the fuel rods into the assembly by joining the support caps to the pressure tubes. To attain proper fitup, it was necessary to pinch each tube tightly to the associated support cap with needle-nosed pliers, taking care to favor a 1/64-in.-high pressure tube lip so that any weld rollover would be directed inward.

Each rod was tacked twice while the subassembly was tabled (Figs. 28 and 29). The 32 joints were manually welded in the flat position with the shell subassembly strapped vertically against a positioner face as shown in Figs. 30 and 31. Welds were made in accordance with standard reference UCN-1, Part C (see Appendix B). All 32 joints were examined with a 10× magnifying lens. No cracks or undercuts were evidenced, but 12 tubes were marked and corrected with additional touch-up welding so that the diffusion crown bridged smoothly across both edges.

Upper Cover Plate

Moderate tapping was required to force the upper crossover liner into the compartment. The upper pin was centered in an upright position after inserting the cover plate. The edge joint and the pin-to-plate joints were welded in accordance with standard reference UCN-1, Part B, after flushing argon through the tube assembly for 2 hr. Weld reinforcements on the edge joint and the pin were not finish ground inasmuch as all blended smoothly into the base metal.

Lower Cover Plate

The tube sheet subassembly was rotated 180° on the fixture for sealing the two lower tube sheet cover plates. Preliminary to inserting the crossover liners, measurements were made of the extension of all coolant tubes off the tube sheet face; none exceeded specifications.

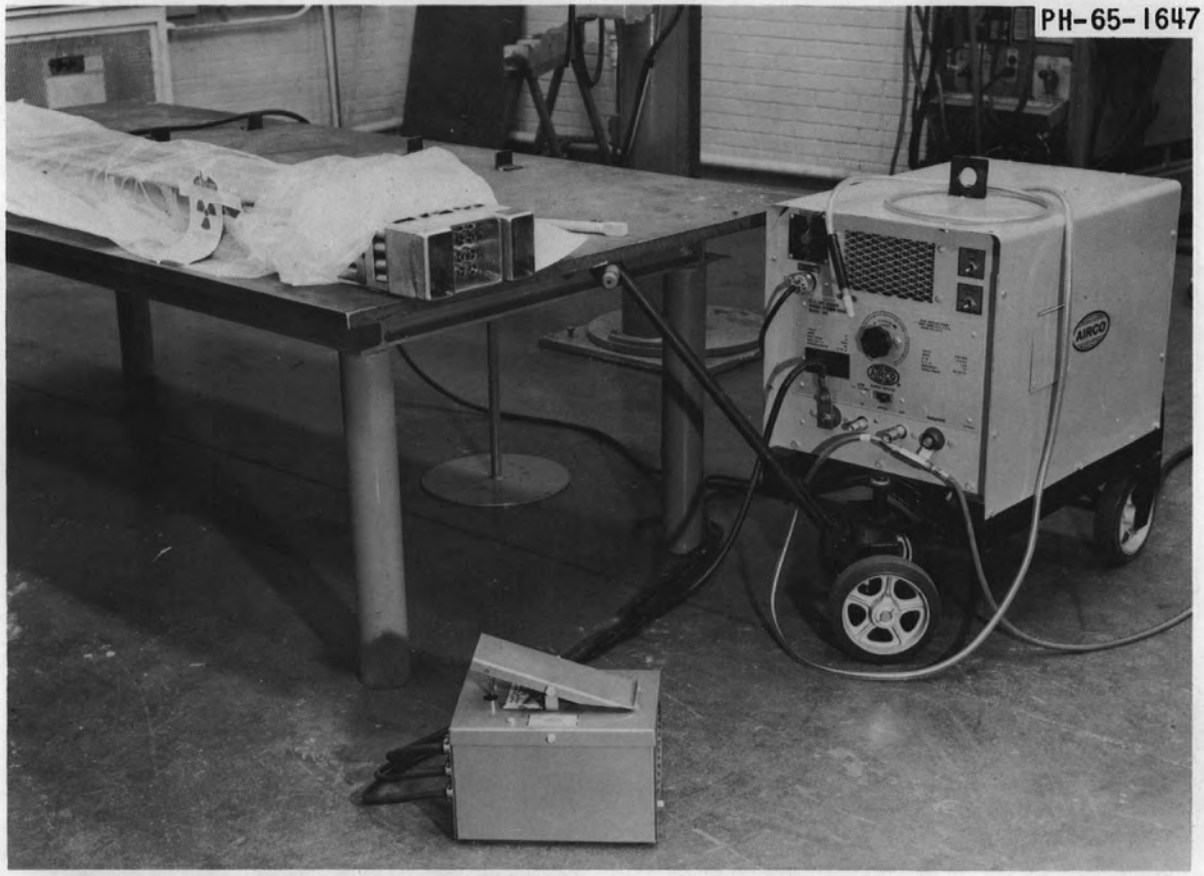


Fig. 28. Reloaded Fuel Subassembly Tabled in Clean Room Preparatory to Tack Welding the Pressure-Tube-to-Support-Cap Edge Weldments.

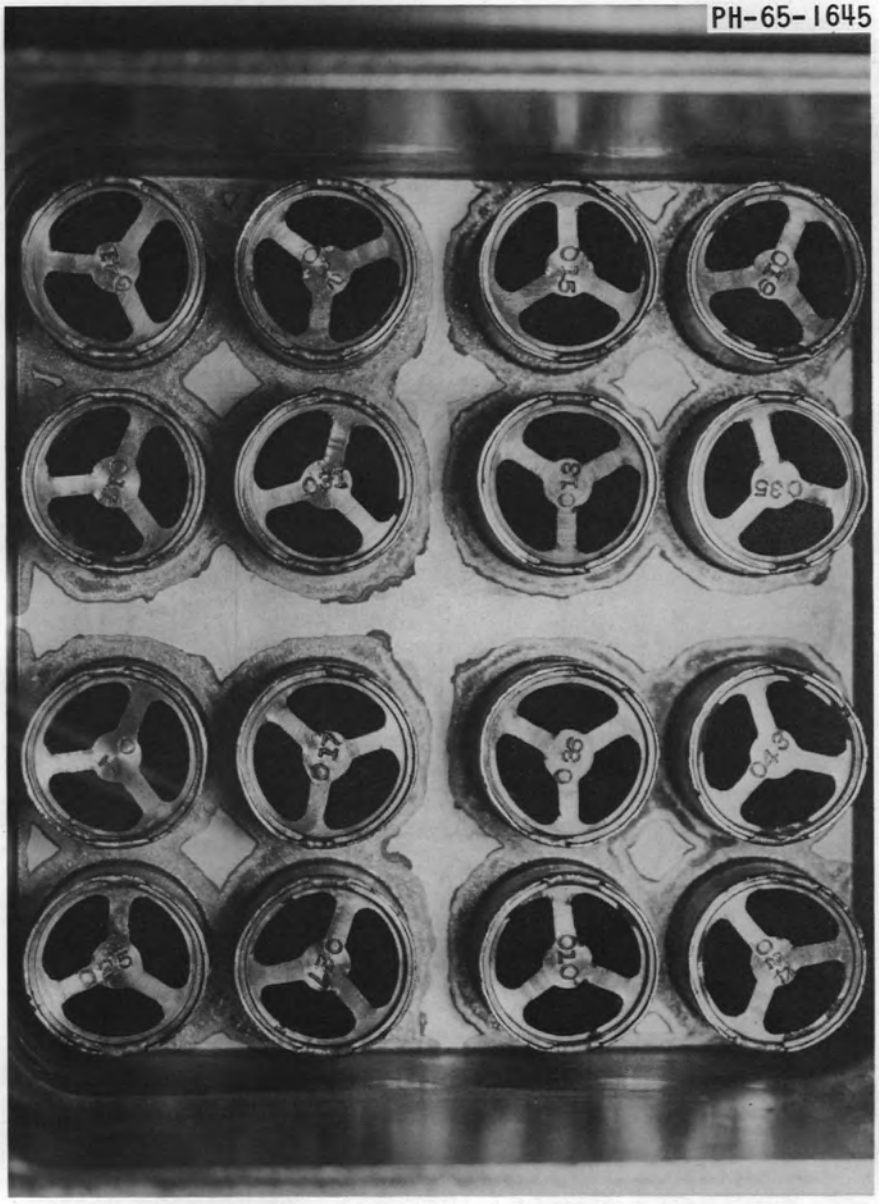


Fig. 29. Tacked Pressure-Tube-to-Support-Cap Joints in the Upper Crossover Box. Fused-out sections on the support-cap ring inside surface were as received.

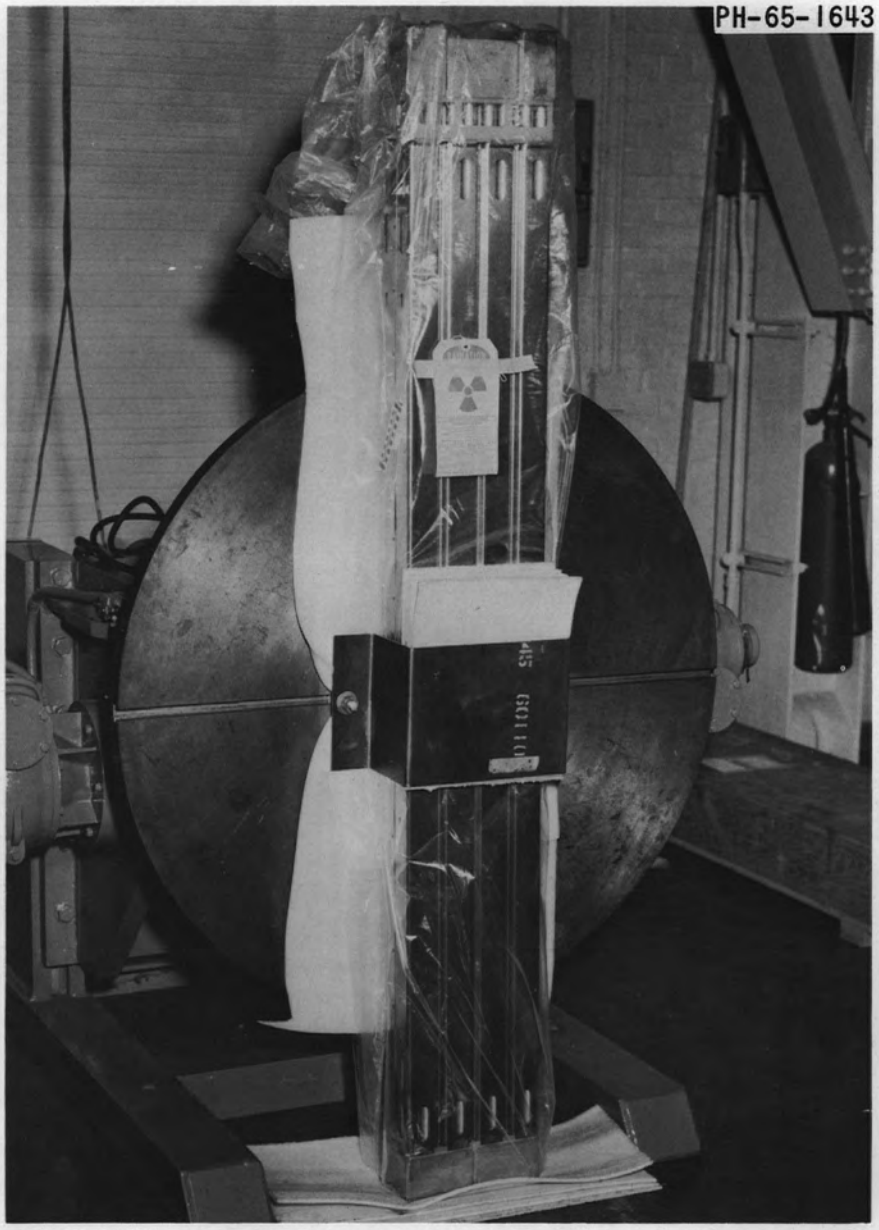


Fig. 30. Subassembly Loosely Clamped Against Positioner Face and Cushioned Against Scratching or Distortion. All fuel box welding was performed with the assembly vertical.

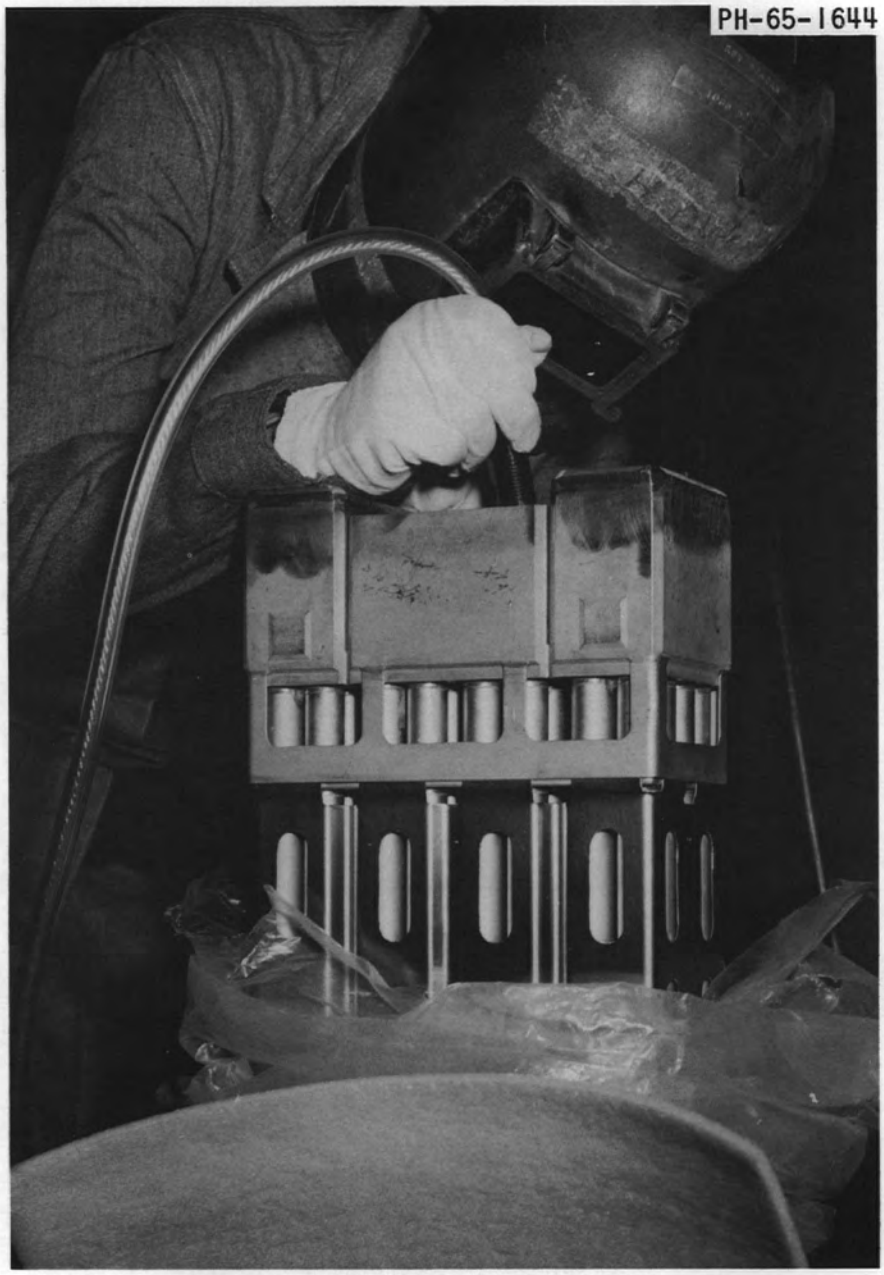


Fig. 31. Manual Edge Welding of Support Caps to Pressure Shell.

Figure 32 shows the final position of the coolant tubes prior to inserting the crossover liners. One crossover liner dropped into position easily, but the second would not slip. This interference was corrected by reaming all tube holes in the latter crossover liner an additional 10 mils. Preparatory to welding the cover plates, argon was flushed through the assembly for 2 hr. Two weld tacks were made on each of the four sides of both plates. When inspected, four tacks were found cracked. More important, burnthroughs were noted on the tube sheet wall lips where the weld heat had been concentrated. It should be noted that the original 1/4-in.-high lips had been remachined on the lower tube sheets. Burnthrough was cut off by milling the tube sheet lips down to a 3/32-in. height, making the joint geometry similar to that used on the upper tube sheet cover joint. All cracks were ground out. Final cover-plate edge welds and plate-to-pin welds were dye-penetrant tested and proved crack free. Figure 33 shows the completed edge welds. The reinforcement crowns of the pin weldments were ground flush with the cover plates to facilitate subsequent positioning of the guide sleeve fixtures.

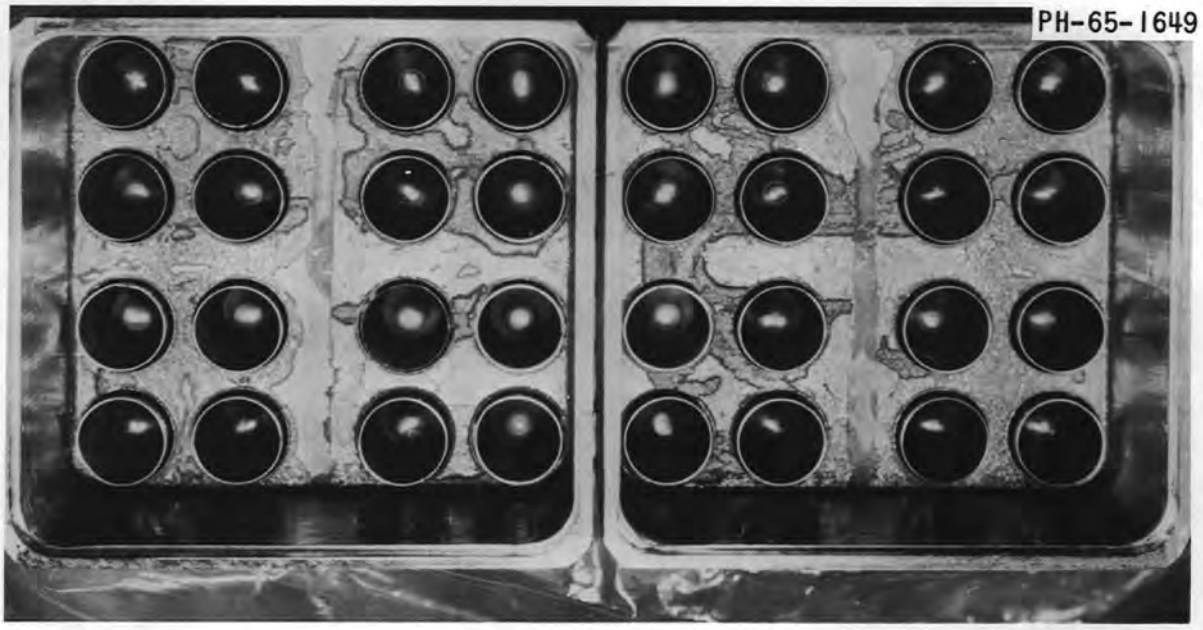


Fig. 32. Lower Tube Sheet Crossover Boxes Prior to Installation of Crossover Liners.

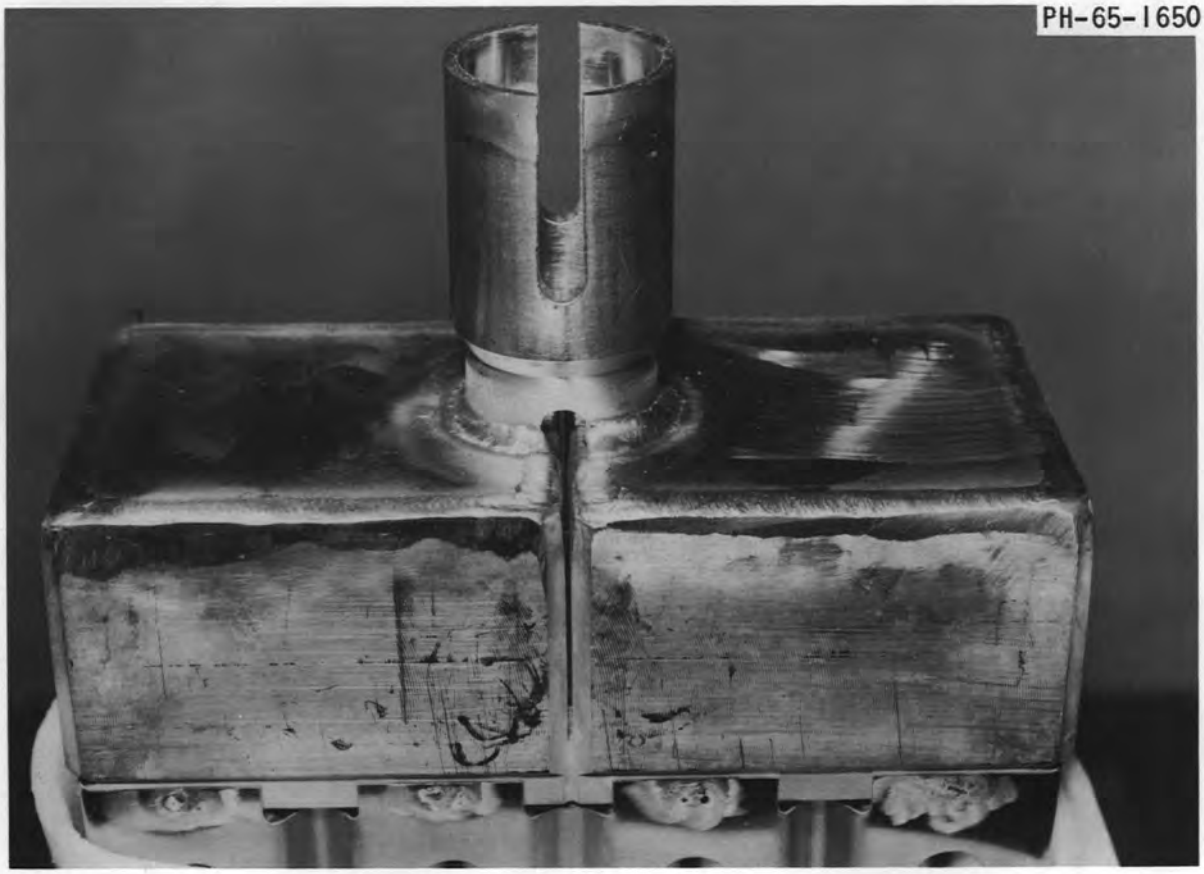


Fig. 33. Lower Tube Sheet with Cover Plates Welded and Assembly Guide Sleeve Attached.

Lower Tube Sheet Components

A specially fabricated holding fixture enabled the positioning of the lower guide sleeve onto the tube sheets. The guide sleeve fillet weld is shown in Fig. 33. A check showed that the sleeve was axially straight but that it was mispositioned 0.006 and 0.011 in. from the tube center point on the short and long centers of the rectangular tube sheet, respectively. These deviations were considered to be within a practical tolerance.

Figure 34 shows the lower tube sheet with the assembly guide, guide spring, guide washer, and guide sleeve top attached. All were joined and welded in accordance with design specifications except the assembly guide. Before making this attachment, it was necessary to build up the tube sheet corner edges to compensate for metal cut away during burnthrough zone correction.

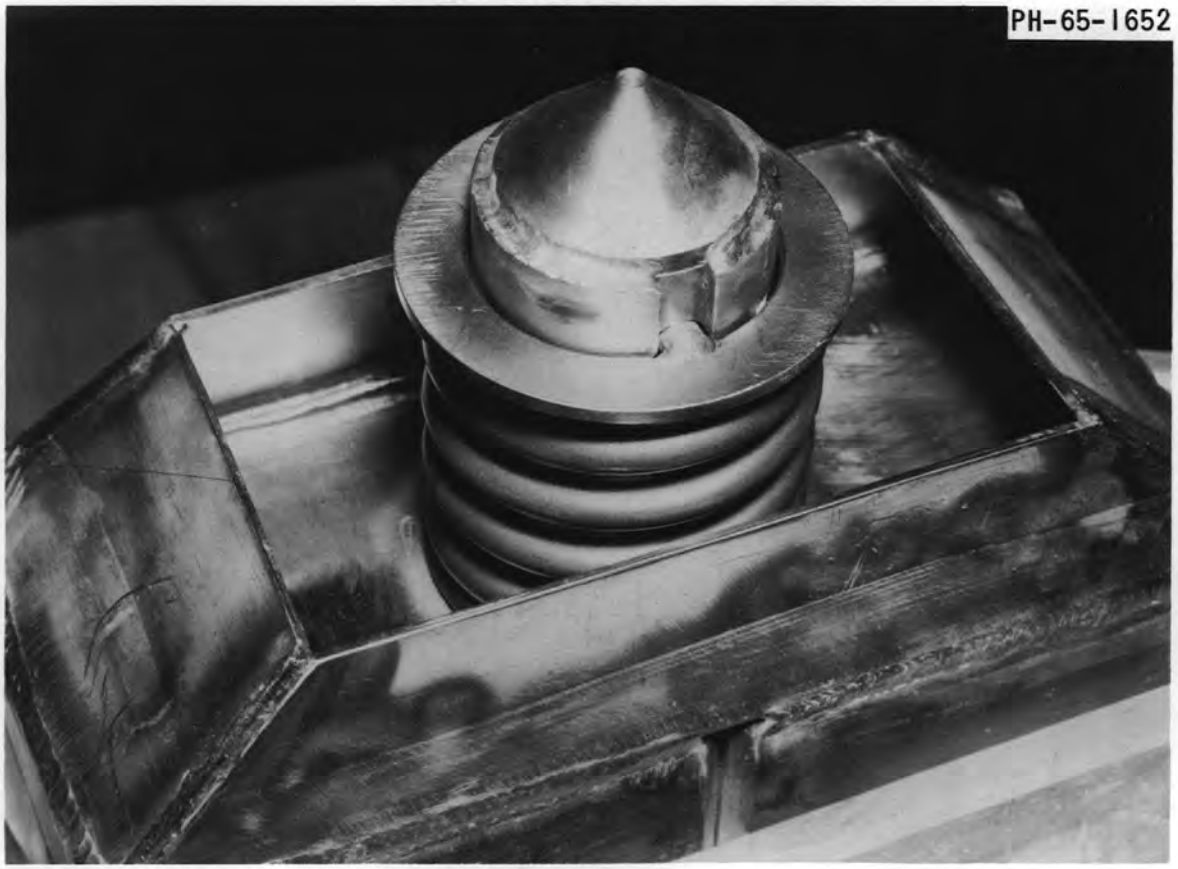


Fig. 34. Completed Assembly of Seat Parts. Note that the original weld bead of the washer tie pin extends past the inside surface and onto the washer face where it would interfere with a flat seat.

Tube Sheet to Standpipe

Both completed subassemblies were integrated in a specially constructed welding fixture for final joining. (This complete fixture is shown in Fig. 35 with the welding completed.) This stiff-framed fixture provided two fixed anchor points for each subassembly to assure correct axial alignment. Two anchor clamps at the midsection, shown in Fig. 36, mate and lock the tube-sheet transition joint. A fixed guide sleeve ring holder, which served to position the bottom of the shell subassembly, is shown in Fig. 37. Figure 38 shows the top standpipe anchor with its sliding gear mechanism. Close-fitting post inserts on this mechanism fitted into the standpipes and trued the axial alignment. Wheels mounted onto the long axis of the frame facilitated positioning by the welder for flat welding.

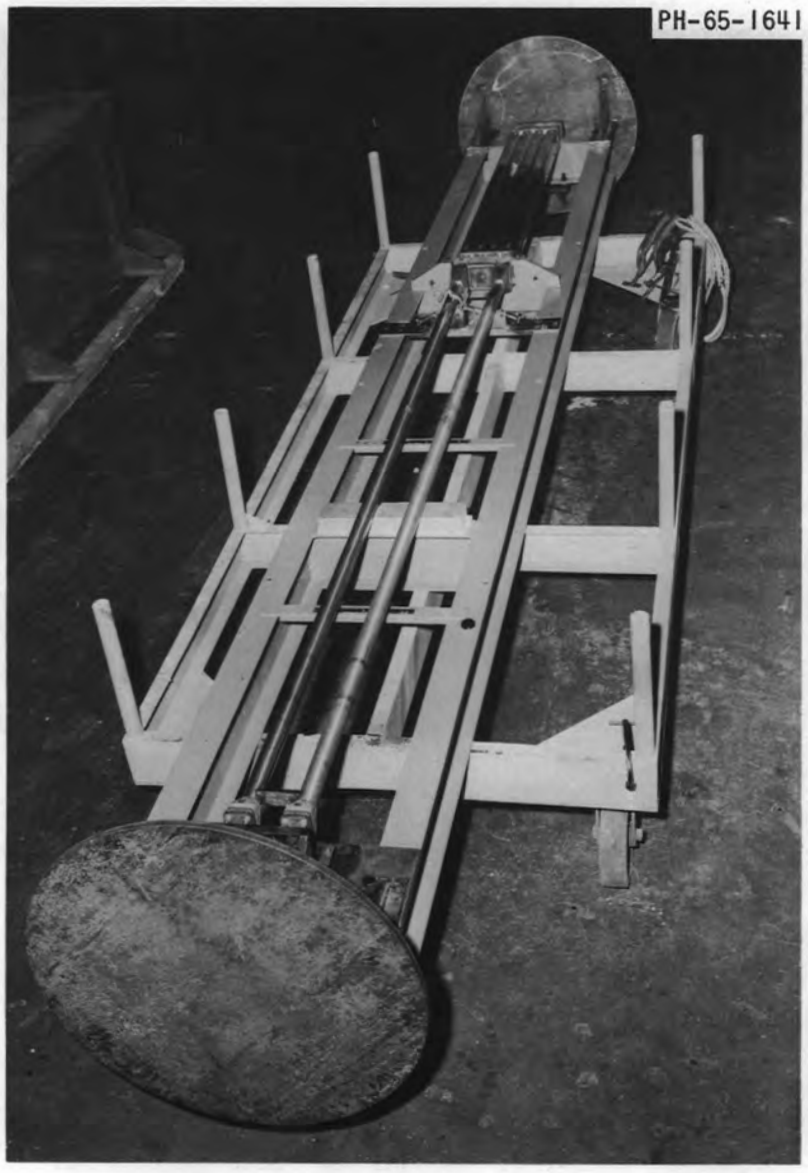


Fig. 35. Overhead View of Fuel Assembly Lying Loosely in the Wheel-Mounted Welding Fixture, Which Is Seated on a Travel Cart.

The two subassemblies were pushed together in the welding fixture after correcting the original transition-liner-to-pressure tube interference by selectively enlarging a few liner holes. Final upper tube-sheet-to-transition welds are shown on Fig. 39. These were welded in accordance with specification UCN-1, Part A. Radiographs of both welds confirmed them to be free of indications of defects as did dye-penetrant tests. Reinforcement crowns were left intact on the edge of the long side but were ground off the short side for meeting envelope dimensions.

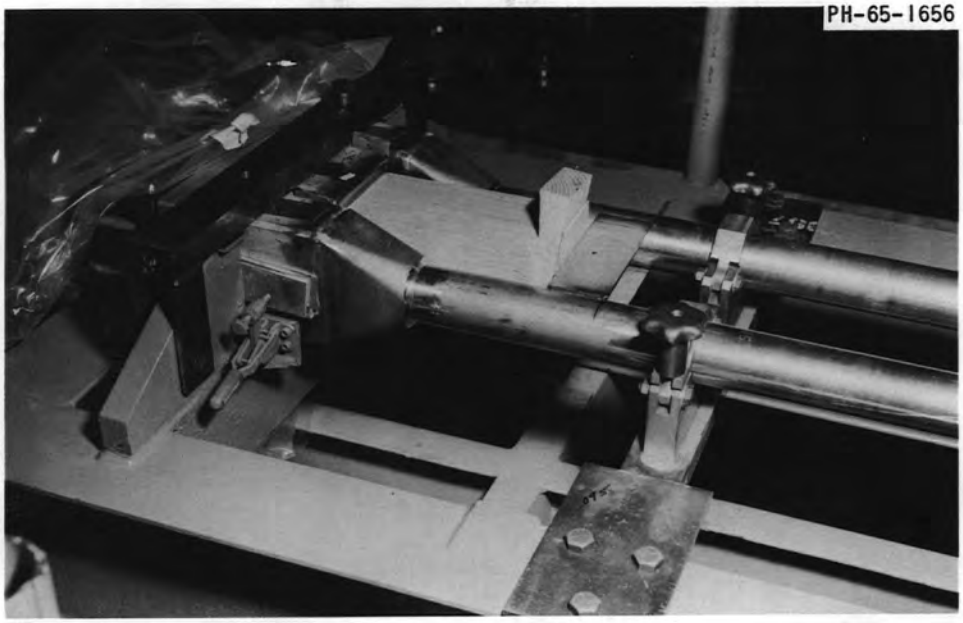


Fig. 36. Fixture and Clamping Devices for Anchoring the Pressure Shell and Standpipe Subassemblies While Welding. In this view the joint weld has been completed and the unit has been shimmed to preclude tube-sheet deformation during leak-test pressuring.

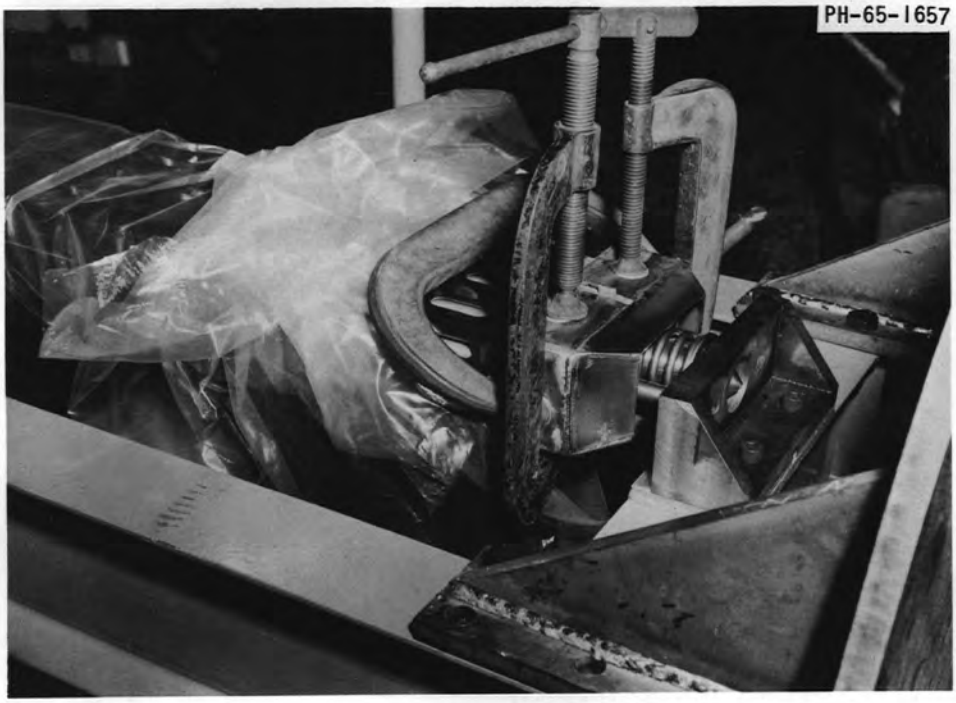


Fig. 37. Lower Tube-Sheet Guide-Sleeve Holder Anchor on the Welding Fixture. Also shown is the clamping method used to prevent the lower-tube-sheet side walls from bulging while undergoing pressure testing.

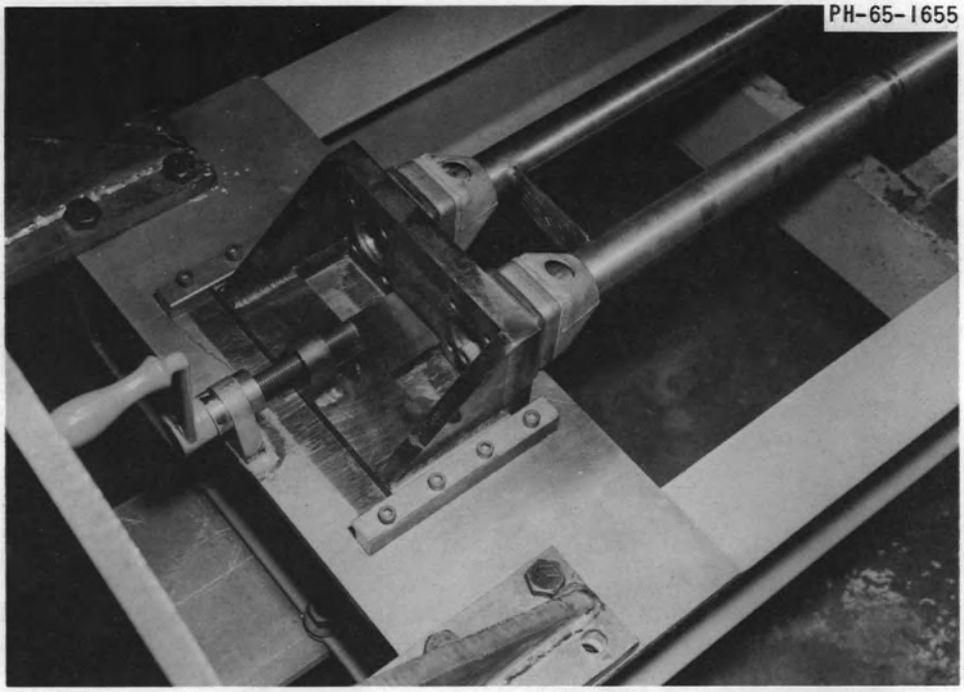


Fig. 38. Sliding Gear Mechanism of the Welding Fixture for Anchoring the Standpipe Flanges.

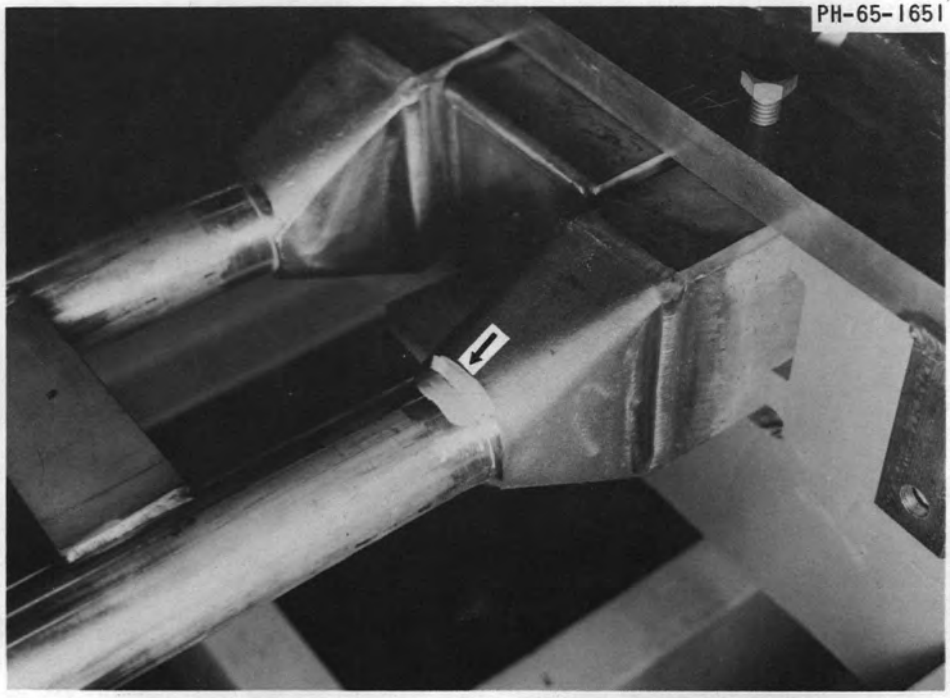


Fig. 39. Final Upper Tube-Sheet-to-Standpipe Weld Joints Showing Lower Anchor Support for Maintaining Dimensional Trueness. The arrow points to a shallow surface defect in the transition casting surface exposed by the dye developer just below the weld joint.

Inspection of Shell Assembly

Original Transition-to-Standpipe Extension Joints

A liquid-penetrant test was conducted on the two original transition-to-standpipe extension welds since stress imposed by the final weld would be concentrated at this assembly joint. One defect was found, as shown in Fig. 39. However, both this defect and the adjacent groove, which appeared to be an undercut, were adjudged below the true weld line. No serious flaw was visible on the radiographs of the joints. This was only a surface defect as proved by the subsequent leak check.

Linear Measurements

The distance between the standpipe flange faces and the lower tube-sheet face measured 16 ft 13/16 in., or 3/16 in. less than the 16-ft 1-in. ± 3/64-in. length required by drawing specifications. Since no measurement had been made of this dimension before cutting the fuel assembly, no exact figures can be assessed to the shortening effected in the rebuilding operation. It can be assumed, however, that as much as 1/8 in. was lost by cutting back the transition casting to expose the transition liner for repair. Minor losses might also be expected from the edge squaring operations and from weld contraction.

A recommendation was made to Combustion Engineering, Inc., through the AEC, to install a 1/4-in.-thick washer-type spacer onto the existing guide washer. It was felt that the additional 1/16 in. of spacer thickness would be practical to compensate for metal contraction in the weld joints made below the lower tube sheet face. The 1/4-in. spacer was approved. It was attached to the original guide washer with a peripheral weld, as shown on Fig. 40. Note that this washer provides a flat seat face for the fuel assembly in the reactor in contrast to the original guide sleeve washer (Fig. 34). The tie-pin-weld bead extended onto the original washer and would have prevented flat seating.

Fig. 40. Modified Assembly Seat with 1/4-in.-Thick Corrective Spacer Incorporated onto the Original Washer.

Pressure Test

Preparatory to running the leak test, stress calculations were conducted of the tube sheets as a pressure vessel. These indicated that the thin-walled sides of the crossover compartments would be overstressed and would be permanently deformed unless reinforcements were supplied. Figures 36 and 37 show the clamping and shim components ultimately used on the upper and lower tube sheets, respectively. With these installed, the unit was pressurized with helium to 300 psi and held at this pressure until all weld joints had been sniff tested. No leaks were detected in any rebuilt joints or original assembly welds.

Figure 41 shows the fuel assembly mounted on the shipping frame ready for restrapping and insertion into the shipping cylinder. The fuel assembly was rolled from the weld fixture onto the shipping frame to prevent bending. The assembly was enclosed in polyethylene, which was seal-welded around the unit before the tiedown straps were locked. The sealed assembly was pushed into the shipping cylinder, where dry air was bled across the unit for 2 hr before closing the container end flanges.

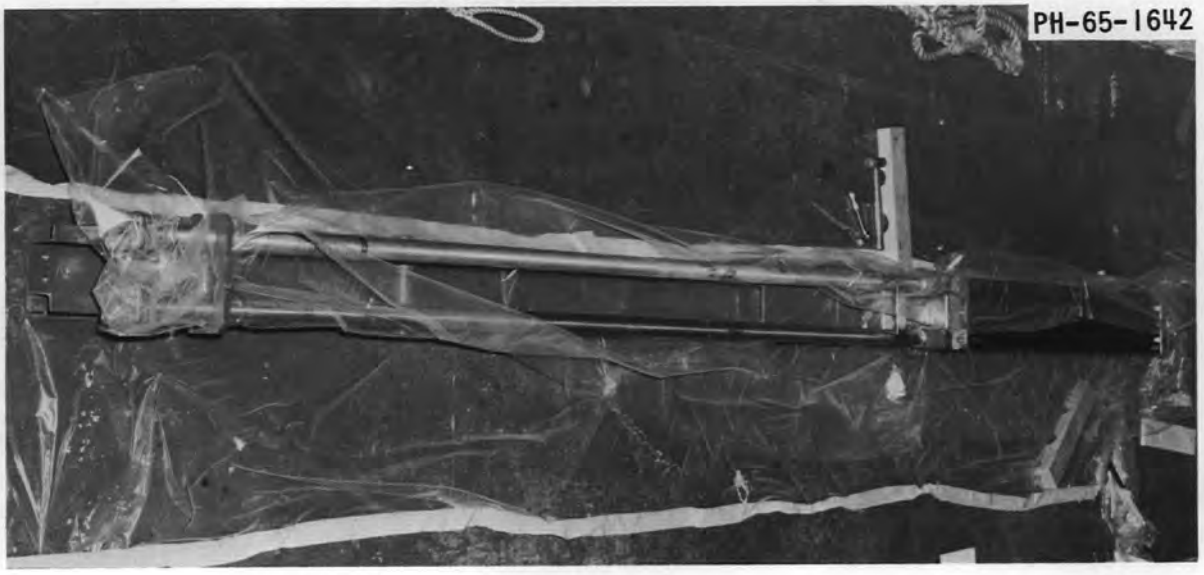


Fig. 41. Unstrapped Fuel Assembly on Original Shipping Frame Ready for the Seal Welding of the Plastic Cover.

Welding and Dimensional Inspection

All assembly joints of the rebuilt fuel assembly were welded by a qualified welder, using a specially adapted weld specification, UCN-1 (Appendix B), that was developed and tested for the job. The welder qualification test records are attached in Appendix B, UCN-1. The composition of filler metals used in making the weld joints was in accordance with ASTM 371-53T, Grade ER-347. Certificates of analyses are included in Appendix C-7 including the one for the box cover plate base metal.

All welding was witnessed by inspectors who gave preliminary approval to the joint setup and its cleanliness and to the purging systems employed. During weld progression, the inspectors approved each bead pass by appearance. Final welds passed the liquid-penetrant test.

Inspectors' reports of each weld are shown in Appendix C-5. Radiographs were made to verify the soundness of the buttered weld extensions onto the upper tube sheet inlet-outlet edges before consummating the cleanup welding. In addition, the final tube sheet transition joints and the original transition standpipe extension joint were radiographed for weld approval. All radiographed welds were accepted as defect-free.

Necessary measurements were made while rebuilding the assembly to be sure that the dimensional tolerances were met. These were categorized into joint details and axial and exterior definitions.

With regard to the first, dimensions of machined parts and areas for agreement with design prints were checked; inspectors reconfirmed that the associated parts properly mated before approving the weld setup. All parts and other joints were remachined to the drawing details. Welding inspectors approved the final fitups of these accepted joints.

Special attention was given to the proper fitting of crossover liners. Preliminary measurements confirmed that the extension of the new coolant tubes from the lower tube sheet base were not excessive. In conformance with specifications, the crossover liner was not forced into the lower tube sheets.

Axial trueness of the rebuilt assembly was obtained with the welding fixture. This unit was designed in strict accordance with drawing

dimensions; measurements confirmed the accuracy of the constructed fixture anchor points. Prior to the attachment welds, both subassemblies were firmly locked in the weld fixture. The clamps were released until the assembly had cooled to room temperature.

Dimensional checks were made to confirm that the rebuilt assembly would fit into the reactor without interference. Basic measurements were made using dimensions adopted for the original fuel fabrication, Appendix C-4. All measurements were within tolerance except at the upper tube-sheet-to-transition joint; the weld reinforcement crowns along the short edges of the tube sheet were found excessive. These were corrected by grinding the weld crowns flush with the base metal.

Leak Test

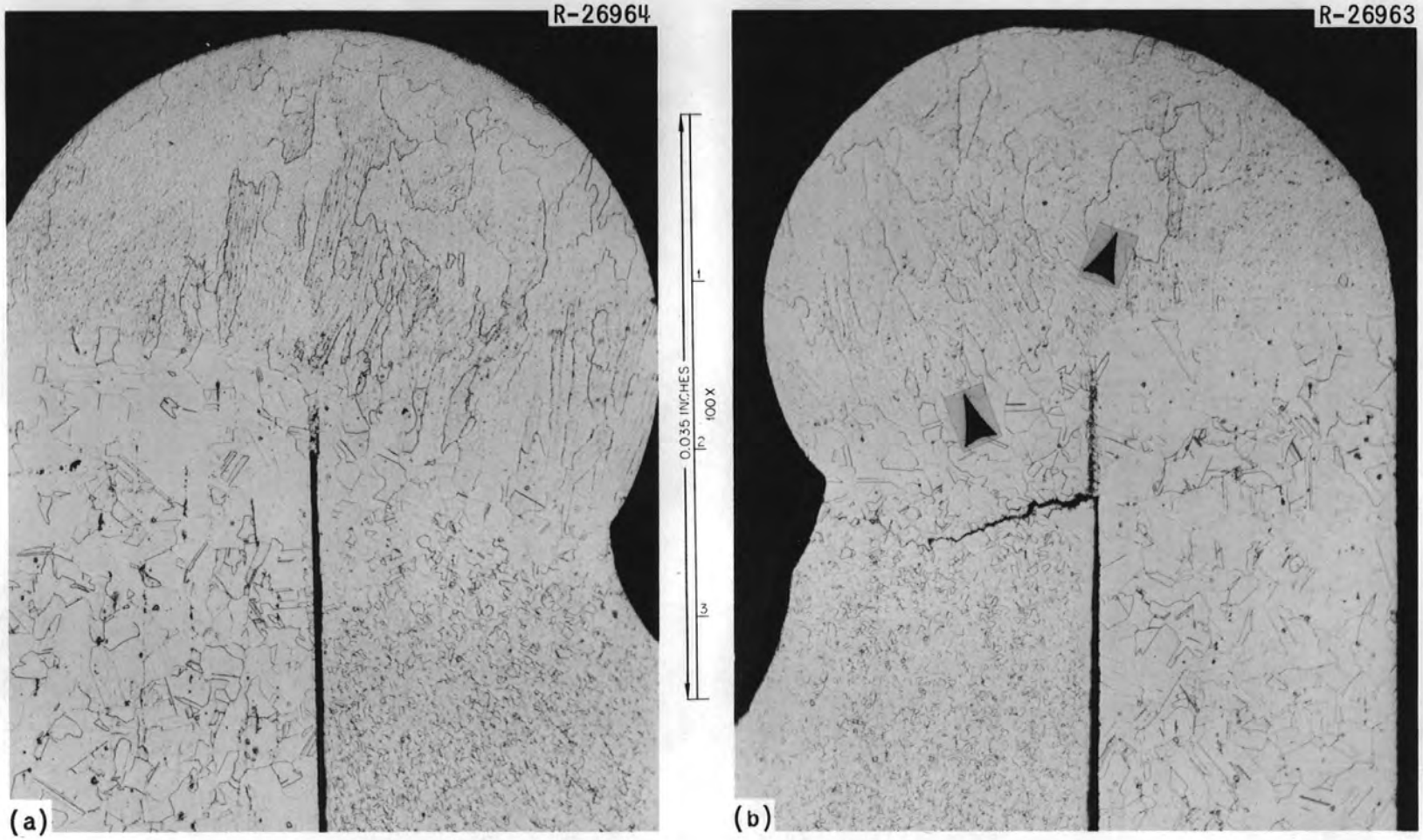
The rebuilt fuel assembly was subjected to a 300-psi helium leak test in accordance with the specifications. All rebuilt weldments and the original standpipe welds were probed, using a CEC Model 24-120A mass spectrometer. All joints were tested, and no leaks were observed.

METALLOGRAPHIC EXAMINATION OF DEFECTS IN THE WELD REGIONS

During the helium leak testing of the replacement fuel rods, minute leaks were found in four. These defects, pinpointed with the aid of dye penetrants and additional helium leak testing, were found to be in the general area of the welds. End caps and a portion of the associated tubing material from two rods were subsequently submitted for metallographic examination. Longitudinal sections were made through the ends of the fuel-rod specimens a few mils away from the defect regions. The sections were then successively reground and polished until the defects were located.

Fuel Rod 0-40

A leak was detected in the upper end cap of fuel rod 0-40 and appeared to be in the immediate vicinity of the weld. By examining several planes of polish, a region was located that contained an intergranular crack, which extended through the lip of the end cap. This region is shown in Fig. 42 along with the same weld but 180° around the fuel rod. As shown



CLADDING END CAP END CAP CLADDING

Fig. 42. Areas from a Longitudinal Section Made Through the Defective End Cap from Fuel Rod 0-40. Both areas shown are from the same weld but 180° apart. Note the intergranular crack in the end cap occurred in the beginning-and-end-of-pass region, as evidenced by the two fusion lines (arrows). Etchant: copper regia.

in this figure, the crack is not in the weld metal but rather along the terminus of the heat-affected zone, as indicated by grain growth in the end cap. Examination of the failed region at a higher magnification revealed a second phase that followed the intergranular crack, as shown in Fig. 43. Three additional observations worth noting were (1) the crack in the end cap occurred at the beginning and end of the weld, as evidenced by the two distinct fusion lines in the weld metal; (2) a lower melting alloy had apparently run out of the weld metal and collected in the gap between the end cap and cladding; and (3) the defective region extended around the end cap less than 1 mil circumferentially, as determined by metallography.

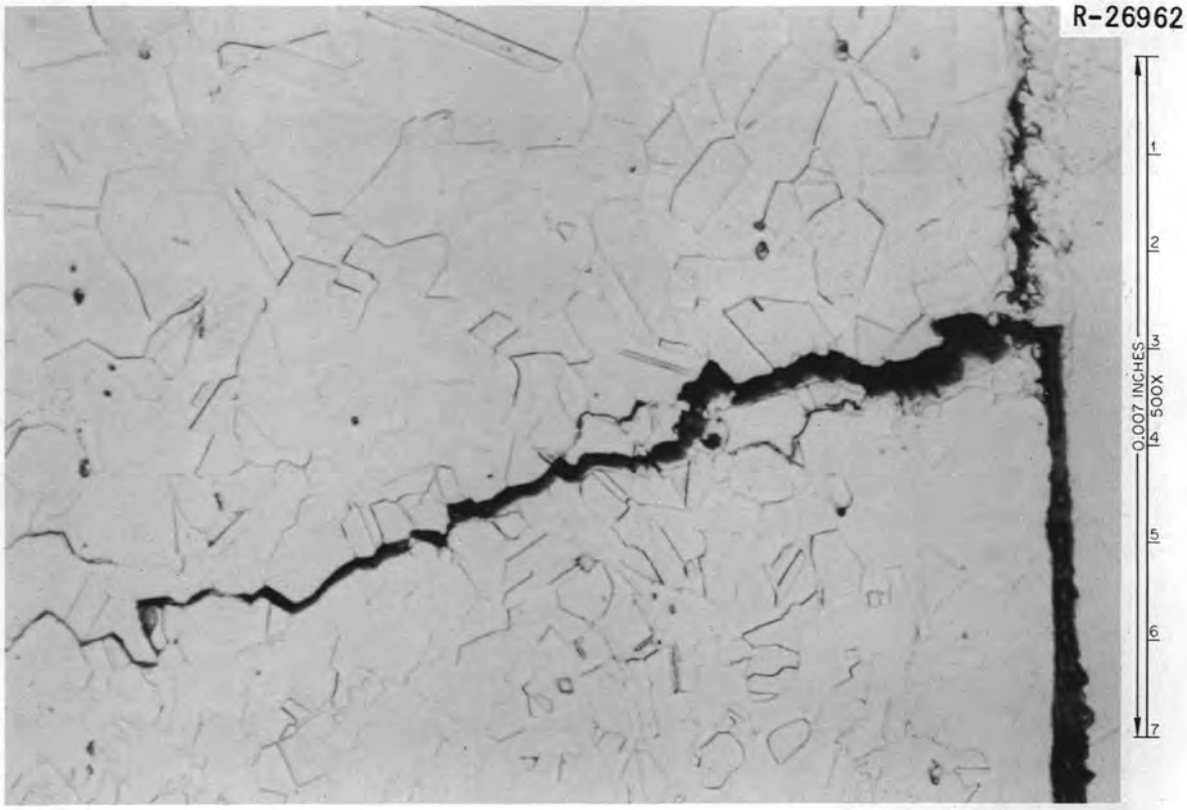


Fig. 43. Appearance of the Failed Region of the End Cap Shown in the Previous Figure but at a Higher Magnification. Etchant: copper regia.

Fuel Rod 0-28

A defect was located in the cladding-weldment interface of the lower end cap of fuel rod 0-28 during nondestructive testing. The end cap was machined off close to the weld in the hope of salvaging this fuel rod. Consequently, only a small amount of cladding was attached to the end-cap weldment for metallography. Examination of a longitudinal section through this specimen disclosed a network of intergranular cracks that extended from the inner surface of the cladding into the weldment, as shown in Fig. 44. Also, a small intergranular crack, found in the end-cap material near the root of the weld, can be seen in this figure. Similar to the defective region in fuel rod 0-28, a lower melting constituent apparently ran out of the weld metal and collected at the cladding-end-cap interface. The cracks were located at the beginning

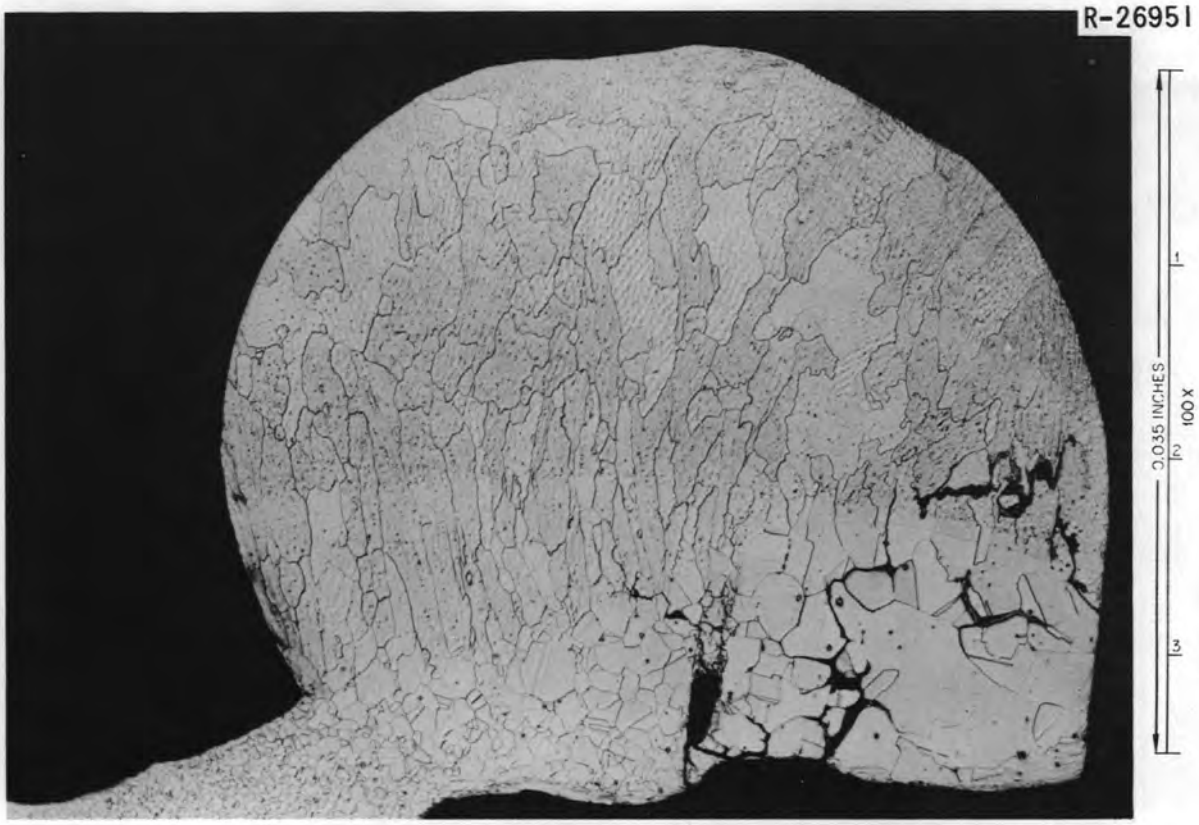


Fig. 44. Appearance of the Defective Region in the Cladding and Weld Metal of the Lower End Cap of Fuel Rod 0-28. Etchant: copper regia.

and-end-of-pass region of the weld; two lines of fusion were seen in the weld metal. Close inspection revealed a second phase that followed along the sides of the cracks.

A new end cap was welded in place in fuel rod 0-28; however, it again failed to pass inspection. A leak was detected in the cladding within a few mils of the weld metal. The defective region was located with the aid of a dye-penetrant test, sectioned longitudinally near the defect, and examined metallographically. Several planes of polish were examined; the first plane that contained any unusual features is shown in Fig. 45. We found in the cladding a network of intergranular cracks that apparently began at the inner surface and continued through the wall of the cladding. After lightly etching the specimen, a wide grain boundary was noted in the end cap material near the weldments, as shown in the following figure.

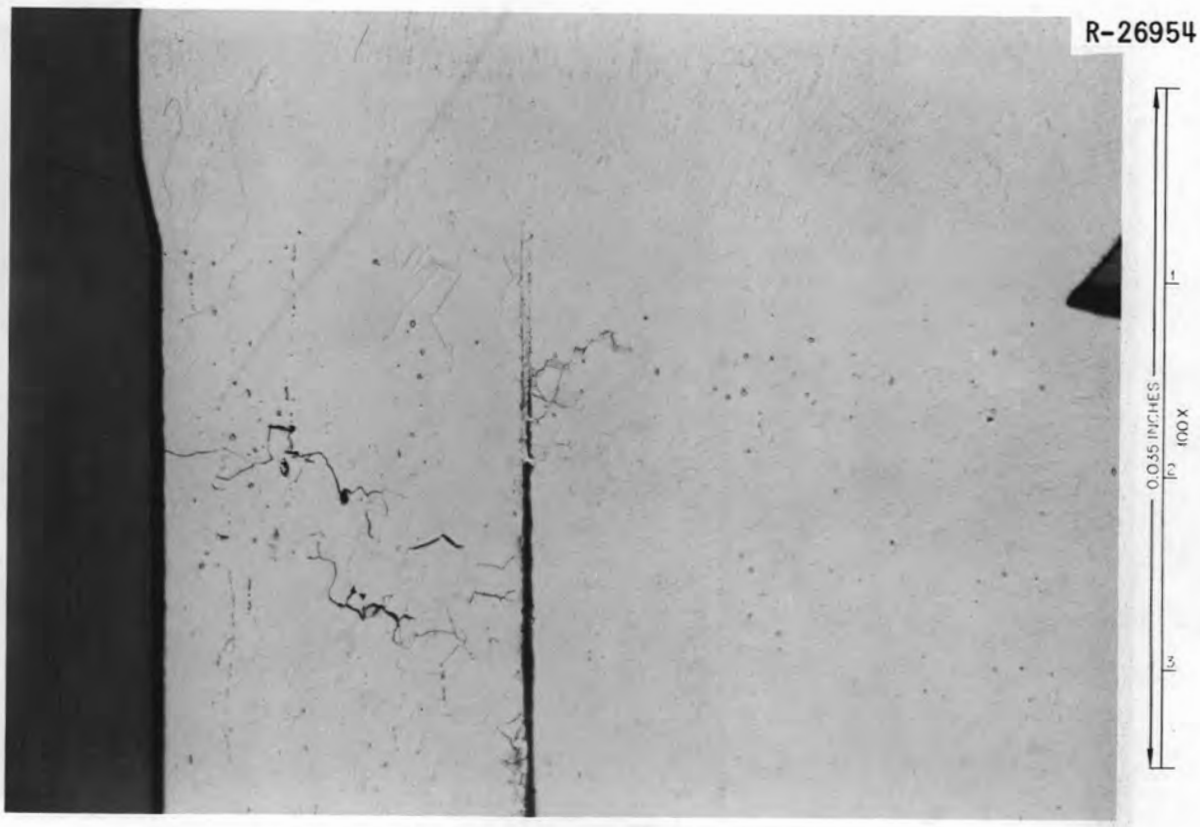


Fig. 45. Appearance of a Longitudinal Section Through the Defective Region of Fuel Rod 0-28. Note the network of intergranular cracks in the cladding and the wide grain boundary in the end cap. Etched lightly with aqua regia.

Also, a low-melting constituent from the weld metal was found along the end-cap—cladding interface. The results of the examination of a plane of polish approximately 1 mil below the one described above are shown in Fig. 46. This plane of polish revealed intergranular cracks in the end-cap material as well as the cladding. The presence of two fusion lines in the weld metal confirmed that the cracks occurred in the beginning-and-end-of-pass region. Examination of the defect region at a higher magnification revealed the low-melting alloy from the weldment apparently ran down the cladding—end-cap interface and wetted a few grain boundaries. The low-melting alloy then apparently penetrated the cladding and end-cap material along grain boundaries, resulting in a hot-short condition that caused cracks in the cladding and end cap. An area showing some of these grain-boundary "rivers" and associated intergranular cracks is shown in Fig. 47. Examination of the same weld, but 180° around the end cap, showed no unusual microstructural features except that a small amount of

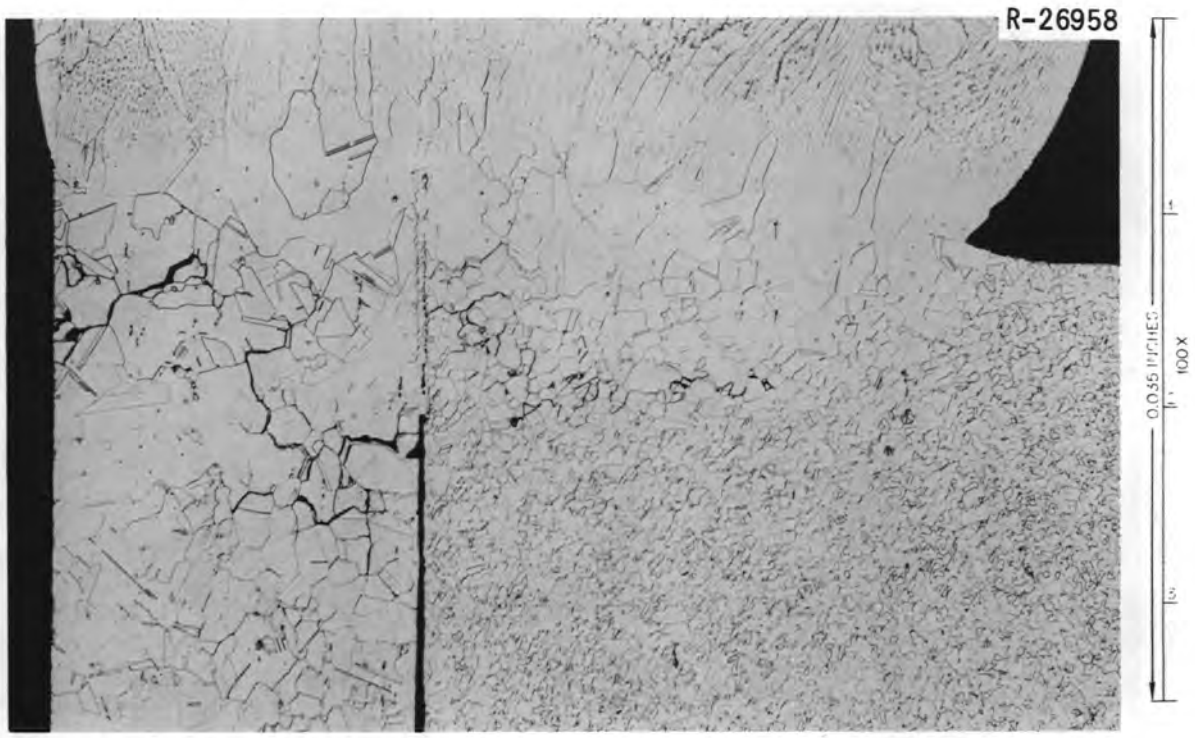


Fig. 46. Intergranular Cracks in Cladding and End Cap Approximately 1 mil Below the Plane Shown in Fig. 45. Etchant: copper regia.

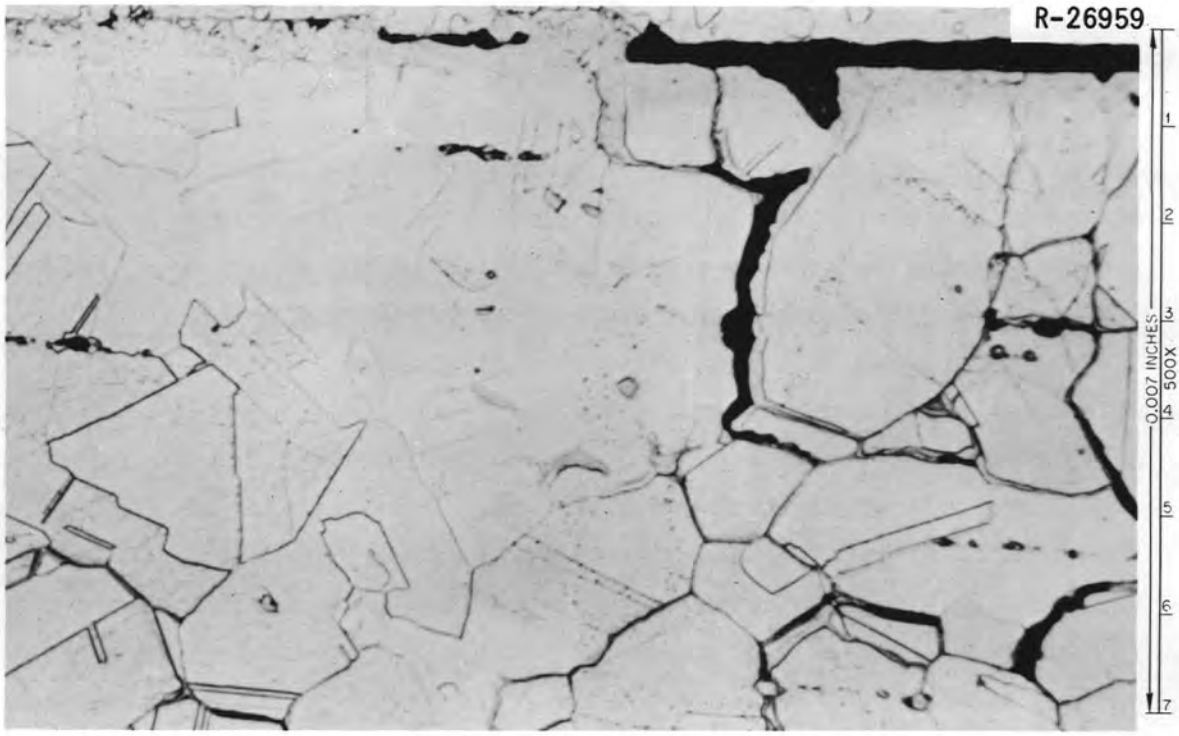


Fig. 47. Intergranular Cracks and Second-Phase "Rivers" in the Cladding. Etchant: copper regia.

material from the weld metal had collected in the space between the cladding and end cap. This specimen was submitted for electron microprobe analysis; the results are discussed in Appendix E.

General Comments

The cause of the weld cracking problem was not completely resolved. However, several interesting facts were noted; that is, a high phosphorous content, much greater than that found in the as-received material, was associated with the cracked regions. Also, this crack always occurred at the beginning-and-end-of-pass region (weld overlap area), suggesting a possible concentration of phosphorous during welding. It appears that the problem is associated with a complex interaction of material composition, weld joint design, and welding procedure.

SUMMARY

BONUS superheater fuel assembly No. 29 was successfully rebuilt at Oak Ridge and has been shipped to the reactor site in Puerto Rico. The design of the fuel rods was changed somewhat from that of the original reactor loading to make them more easily fabricable and more reliable in operation. The socket-type end-closure welds were replaced by edge welds and the vent-hole plug welds were eliminated. Inconel 600 tubing with a 1/4-hard temper was substituted for annealed tubing in order to prevent germinative grain growth, and the brazing cycle was shortened.

The actual fabrication processes were conducted with no undue difficulties except that a weld-cracking problem was encountered in four fuel rods. Thirty-two rods were successfully made and incorporated into the fuel subassembly. The standpipe and shell sections were then completed and the finished unit readily met the required 300-psi helium leak test.

Although studies are currently continuing to determine the cause, the reason for the cracking problem has not been resolved completely. However, we found an abnormally high phosphorous content in the cracked regions.

ACKNOWLEDGMENTS

The authors wish to acknowledge the following for their assistance.

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General planning and technical advice:

G. M. Adamson, Jr., ORNL Metals and Ceramics Division;

J. W. Arendt, ORGDP Engineering Division.

APPENDIX A

Drawings of Core Components for Rebuilt Assembly

Fig. A-1. Fuel Element Components of BONUS Reactor 73
Fig. A-2. Schematic Drawing of Fuel Rod 74
Fig. A-3. Schematic Drawing of Coolant Tube 75
Fig. A-4. Schematic Drawing of Fuel Rod Subassembly 76

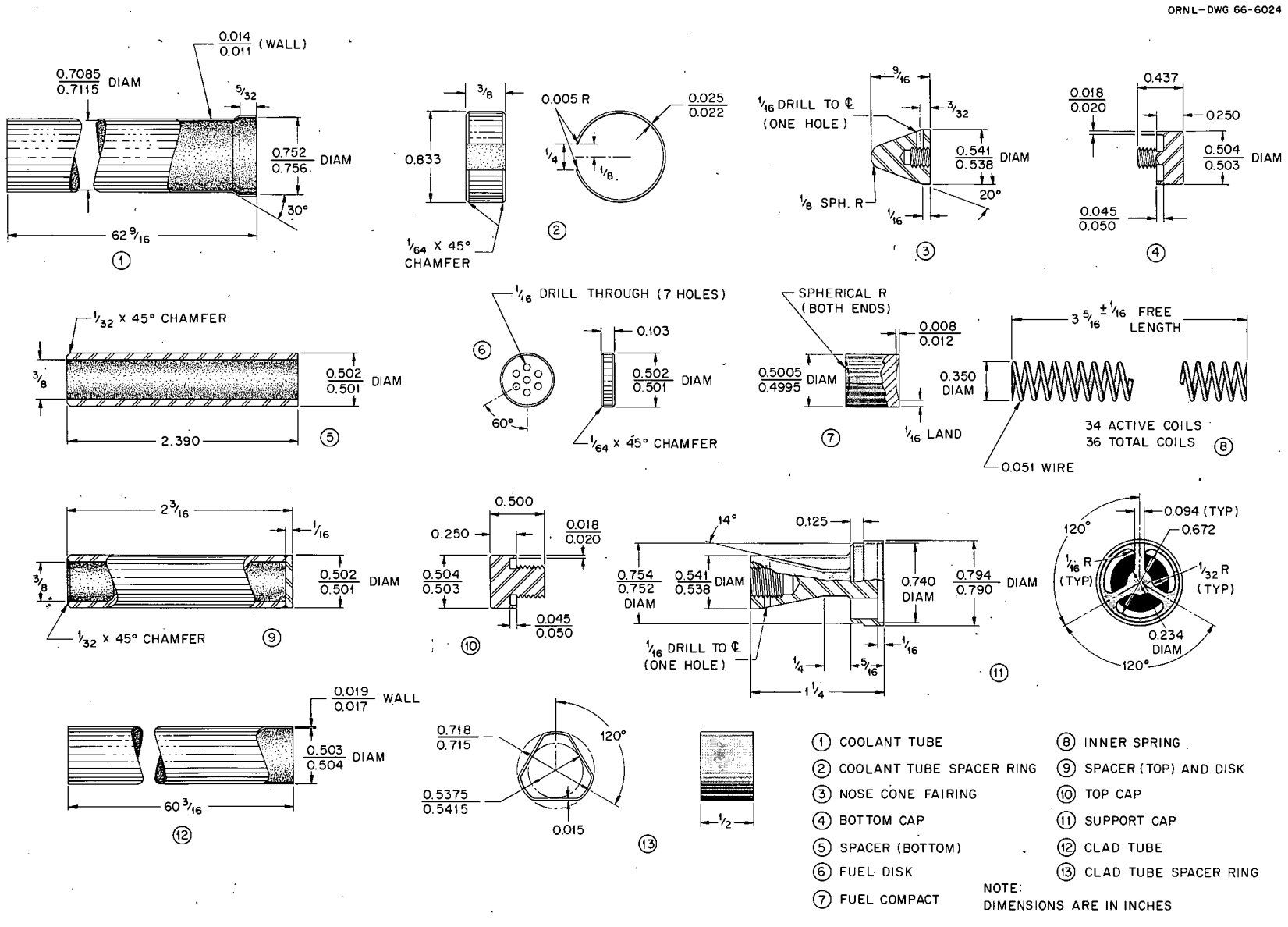

Fig. A-1. Fuel Element Components of BONUS.

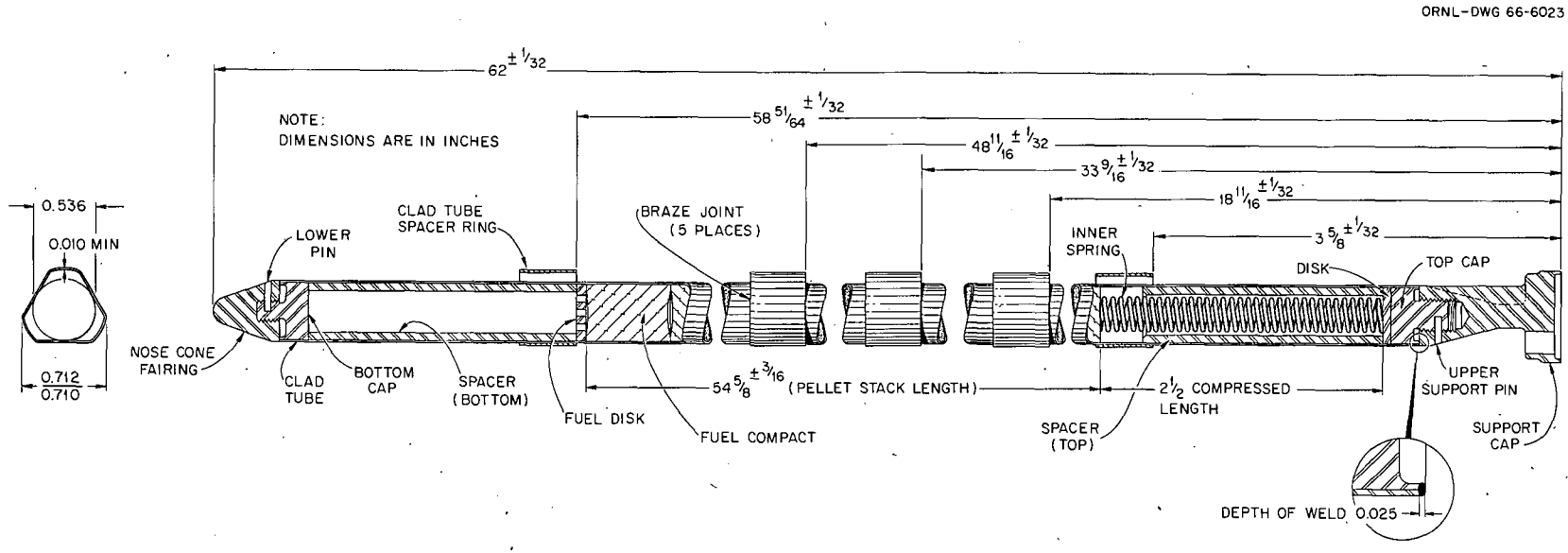

Fig. A-2. Schematic Drawing of Fuel Rod.

ORNL-DWG 66-6022

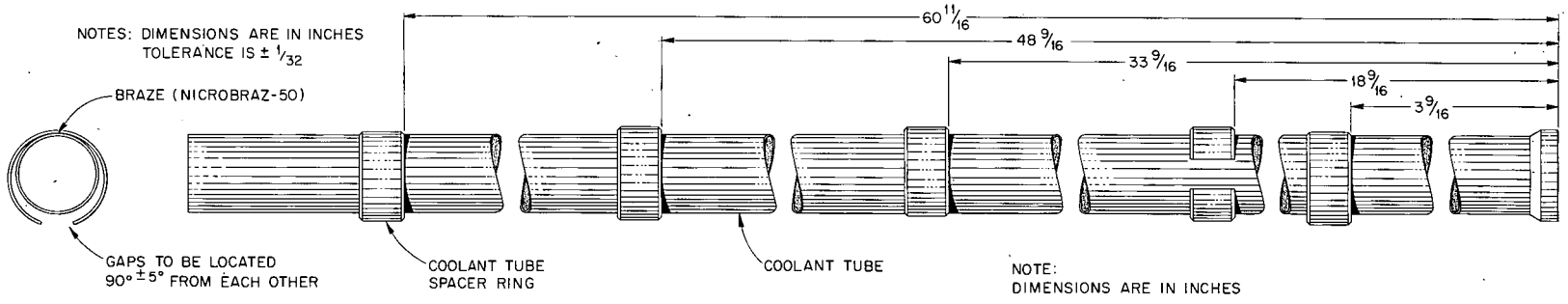

Fig. A-3. Schematic Drawing of Coolant Tube.

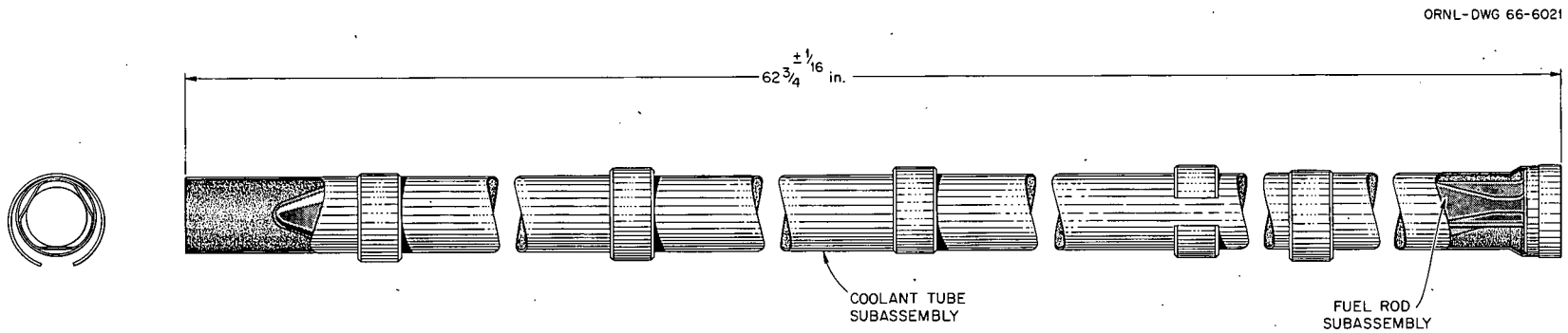

Fig. A-4. Schematic Drawing of Fuel Rod Subassembly.

APPENDIX B

Specifications

NRS-12, Specification for Uranium Dioxide Pellets 79

NRS-13, Specification for Fuel Tubing for BONUS Superheater Element 87

Welding Specification UCN-1 and Welder Qualification Tests 94

NRS-14, BONUS Superheater Fuel Element Brazing Specification 105

NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Union Carbide Corporation
Oak Ridge, Tennessee

Spec: NRS-12
Date: May 18, 1965
Rev. No: Rev. 0
Page: 1 of 8

Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

I. SCOPE:

This specification defines 3.25 enriched fuel pellets made of uranium dioxide, approximately 0.50 OD, 1/2 to one inch long for use in BONUS Super Heater Fuel Elements.

II. MATERIALS:

The Company shall supply to the Seller the uranium hexafluoride to complete the full core loading plus a 25% surplus.

The Seller shall pay for all uranium metal losses.

The Seller shall pay the cost of reprocessing all scrap material to UF_6. This cost shall also include the cost of transportation.

The uranium hexafluoride will be enriched to the specified 3.25 by weight in ^{235}U. The Seller's conversion and fabrication processes shall be such that the isotopic composition of the finished uranium dioxide fuel pellets shall not differ from that of the uranium hexafluoride by more than .05% of the contained amount. Example: If the UF_6 is enriched to 3.25%, then the isotopic analysis may vary from 3.20 to 3.30.

III. REFERENCES:

B-48864, "UO_2 Pellet".

TID-7015, Section I, "ORNL Master Analytical Manual"*

Analytical Chemistry, 32, 610 (1960), "Determination of O/U Ratio in UO_2", H. Kubota.

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*This document is available from the Offices of Technical Services, Department of Commerce, Washington 25, D. C.

Subject: SPECIFICATION FOR URANIUM DIOXIDE PELLETS

IV. MANUFACTURING REQUIREMENTS:

The uranium dioxide pellets shall be manufactured from virgin powder in accordance with Dwg. B-48864, "UO_2 Pellet", and with this specification. Oxidized and reduced used scrap shall be identified as special blend batches. A complete history of the scrap material and process shall be maintained. Acceptance tests which apply to virgin powders shall also apply to special blend batches.

V. CHEMICAL COMPOSITION:

The finished fuel pellets shall conform to the following chemical analysis:

Total Uranium	Not less than 88.0 wt %
Carbon	500 ppm (max)
Nitrogen	100 ppm (max)
Iron	100 ppm (max)
Halides	100 ppm (max)
Fluoride	25 ppm (max)
Calcium, Silicon, & Aluminum	Sum shall not exceed 300 ppm

The sum of the following impurities shall not exceed the equivalent thermal-neutron capture cross section of 20 ppm of boron:

Boron	Gadolinium
Cadmium	Europium
Silver	Samarium

A coefficient of boron equivalent (CBE) may be calculated for the above element as follows:

$$CBE = \frac{(\text{atomic weight boron}) \times (\sigma_a \text{ impurity})}{(\text{atomic weight impurity}) \times (\sigma_a \text{ boron})}$$

σ_a is defined as: Thermal-neutron absorption cross section.

The following list contains boron equivalent coefficients for the high cross-section impurities listed above:

Boron	1.0	Gadolinium	4.191
Silver	8.9×10^{-3}	Eurpoium	0.434
Cadmium	0.325	Samarium	0.524

The oxygen-to-uranium ratio of the finished fuel pellets shall be within the range 2.00 to 2.01.

VI. DENSITY:

The bulk density of the fuel pellet shall be 94-97% of theoretical density for uranium dioxide bodies. Consider theoretical density to be 10.96 g/cm^3.

VII. DIMENSIONAL:

The fuel pellet shall conform to the dimensional tolerances given on Dwg. 48864.

VIII. DRYNESS:

The finished pellets shall be sufficiently dry so that, when run in a CEC No. 29-321A solids moisture analyzer or equal at 300°C for one hour, the weight loss shall not exceed 10 ppm.

IX. SURFACE FINISH AND CONDITION:

A. Chipping

Chipping on the outside cylindrical surface shall not exceed 10% of the outside cylindrical surface area. Chipping on each end of the pellet shall not exceed 25% of the surface area of one end of the pellet. No chip shall be greater than 1/16-in. in laterial dimension nor greater than 1/32-in. in depth. The vendor may submit a visual standard for chipped pellets for the Company's approval to expedite visual inspection. Pellets that are defective based on the above shall be scrapped.

B. Cracks

Radial cracks exceeding 25% of the diameter shall be cause for rejection. Radial cracks are defined as cracks observed at the end or ends of the pellet which are approximately in a radial direction.

Circumferential cracks shall be cause for rejection if the crack is continuous over an arc of 45 deg or more. A circumferential crack is defined as a crack observed at the end of the pellet or on the circumferential surface and which runs approximately parallel to the circumference or perpendicular to a radial direction. A circumferential crack of 180 deg shall be allowed provided no more than one crack per pellet exists and that this crack is located in the center one third of the pellet.

C. Sponginess or Microcracking

Excessive sponginess or microcracking, as illustrated in Fig. 1, shall be cause for rejection.

X. ACCEPTANCE TESTS:

A. Nondestructive

1. Visual. - The fuel pellets shall be subjected to 100% visual inspection to assure conformance with Section IX of this specification. The inspection shall be performed under direct daylight fluorescent illumination of at least 100 footcandles.

2. Dimensional. - One percent of each day's production of pellets, randomly selected, shall be dimensionally inspected to assure conformance to Section VII of this specification. If any of these pellets do not meet dimensional tolerances, the entire day's production shall be 100% dimensionally inspected.

3. Density. - One pellet from each boat of pellets (about 1%), selected randomly, shall be measured and weighed to determine bulk density. If any of these pellets do not meet the density as specified in Section VI of this specification, every pellet from that boat load* shall be subjected to density determination and shall be accepted or rejected accordingly.

4. Dryness. - One percent of the finished pellets shall be selected randomly for dryness tests prior to packaging. The dryness test shall consist of heating the pellets to 300°C for one hour in a CEC No. 26-321A Solids Moisture Analyzer or equal.

If the weight loss for each group of pellets from one dryness testing oven lot does not exceed 10 ppm, all pellets represented by that dryness testing oven lot shall be accepted. If the weight loss of any of the weighing groups in a dryness testing oven lot is greater than 10 ppm, the pellets represented by that dryness testing oven lot shall be rejected unless the Seller is able to demonstrate a 95-95% confidence level that the pellets meet the dryness requirements in Section VIII of this specification. The Seller shall demonstrate this confidence level by conducting sufficient additional dryness tests.

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*A boat load is that quantity of pellets in the sintering zone of the furnace at one time.

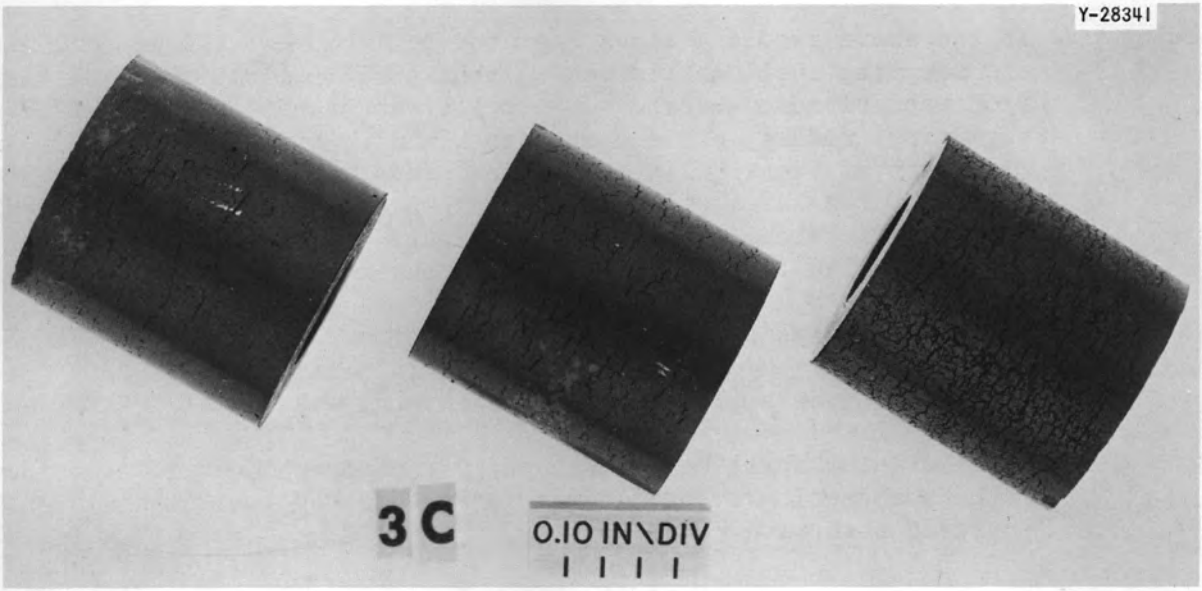


Fig. B-1. Photograph of UO_2 Fuel Pellets Illustrating Excessive Sponginess and Microcracking. The pellet on the left is acceptable. The pellet on the right in the photograph is unacceptable. The pellet in the center is borderline, but is also unacceptable.

B. Destructive

1. Oxygen-to-Uranium Ratio, Total Uranium, Carbon, and Nitrogen

a. Sampling: Two pellets shall be selected randomly from each of the first 10 boat loads for determination for oxygen-to-uranium ratio, total uranium, fluoride, carbon, and nitrogen. At least one analysis shall be performed on each of the two pellets.

If the above sampling shows that the pellets meet the specification, the sampling shall be reduced so that three pellets shall be taken from each blending batch.* One pellet each shall be taken from the beginning, middle, and end of each blending batch. Duplicate samples from each of these pellets shall be sent to the Company for testing. If any of the three pellets from each blending batch fail to meet the specification, sampling shall revert to the original cycle (i.e., 10 consecutive furnace lots shall be sampled).

b. Method of Analysis: The oxygen-to-uranium ratio shall be determined by the polargraphic method referenced in Section III of this specification or by an approved alternate method.

Total uranium shall be determined by the potentiometric or volumetric methods according to procedures recommended by the Company** or by an approved alternate method.

c. Qualification of Seller's Analytical Procedure: Standard samples will be furnished to the Seller by the Company for qualification of the Seller's analytical procedure. This qualification shall be prerequisite pressing of the pellets.

---

*A blending batch is defined as that quantity of uranium dioxide powder that is blended together so that the chemical and isotopic compositions may be assumed to be nearly identical.

**Three suitable methods for the determination of the uranium content of uranium dioxide are found in the ORNL Master Analytical Manual, published as TID-7015, Section I. The methods are:

No. 900719270, Uranium, Volumetric Zinc Amalgam-Potassium Dichromate Method
No. 900719222, Uranium, Potentiometric Ferric Sulfate Method
No. 900719224, Uranium, Automatic Potentiometric Ferric Sulfate Method

d. Acceptance or rejection: If the oxygen-to-uranium ratio and total uranium content do not meet the requirements specified in Section V of this specification, the entire blending batch of sintered pellets shall be rejected unless the Seller performs additional analyses sufficient to assure a 95-95% confidence level that the pellets are within the limits specified.

2. Isotopic and Impurity Analysis

a. Sampling: One finished pellet representing each blending batch of uranium dioxide powder shall be selected randomly for isotopic analysis.

The Seller shall perform impurity analyses on one finished pellet selected randomly from each blending batch of uranium dioxide powder.

An alternate sampling plan may be used in which 5% of the product will be selected for destructive testing. The product to be tested shall be selected so that an equal number of test specimens is selected from each blending batch.

b. Acceptance or Rejection: If the isotopic and impurity analyses do not conform to the limits specified in Sections II and V, respectively, of this specification, all the pellets fabricated from that entire batch of powder shall be rejected unless the Seller performs additional analyses sufficient to assure a 95-95% confidence level that the pellets are within the limits specified.

XI. INSPECTION:

The Seller shall notify the Company five (5) days in advance of date set for production testing in order that the Company's inspector may be present to witness testing.

XII. TEST REPORTS:

Four certified copies of the tests and analytical reports of the requirements in Section X of this specification prior to shipment are required.

The Seller shall be responsible for maintaining a complete record of all materials and process treatments which were used to fabricate these pellets. This information is to include such as the following:

1. Virgin powder surface area
2. Type and amount of binder and lubricant
3. Presinter temperature, gas, time, cooling and heating rate
4. Press pressure
5. Sinter temperature, gas, time, heating and cooling
6. Grinding coolant

Four copies of these material and process treatments used for each batch of material will be sent to the Company upon completion of the order, provided such information is not considered proprietary.

The Seller will supply four copies of a certification of compliance that all the requirements of NRS-12 have been met.

III. PACKING AND SHIPPING:

The Seller will be responsible for shipment of the pellets. The Seller will get all necessary approval for shipment. All pellets in each shipment will be identified according to blending batch.

NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Spec: NRS-13
Date: June 1, 1965
Rev. No:
Page: 1 of 7

Subject: SPECIFICATION FOR FUEL TUBING FOR BONUS SUPER HEATER ELEMENT

I. SCOPE:

This specification defines seamless, cold-drawn nickel-chromium iron tubing with an inside diameter of 0.5035 in. and a wall thickness of 0.018 in. All requirements of ASTM Designation: B 163-64T shall apply in the annealed state except as specifically modified in this specification.

II. MANUFACTURING REQUIREMENTS:

Tubes shall be manufactured in conformance with Dwg. AM-85620-A2, and with this specification.

Tubes shall be extruded or pierced, hot-rolled and cold-drawn, or reduced to size.

III. REFERENCES:

Dwg. AM-85620-A2, "Tube".

ASTM Designation: B 163 - 64T, "Specifications for Seamless Nickel and Nickel Alloy Condenser and Heat Exchanger Tubes".

MET-NDT-4, Rev. 3, "Tentative Methods for Liquid Penetrant Inspection".

AISI, September 1957, "Steel Tubular Products".

ASTM Designation: E 112 - 63, "Standard Method for Estimating the Average Grain Size of Metals".

IV. CHEMICAL COMPOSITION:

Chemical composition of all tubing shall conform to Table 1, "Chemical Composition," of ASTM B 163 - 61T, Nickel-Chromium-Iron-Alloy, with the following modifications:

Nickel, minimum percent	72.0
Cobalt, maximum percent	0.10

Subject: SPECIFICATION FOR FUEL TUBING FOR BONUS SUPER HEATER ELEMENT

V. PHYSICAL PROPERTIES:

The tubing shall be furnished in the hardness range as given below:

Hardness	% Cold Work
Annealed	Less than 10
1/8	10–15
1/4	15–20
1/2	20–25

Samples representing the finished cold worked tubing shall be annealed and tested in accordance with mechanical properties, hardness test, flare test given in ASTM B 163 - 64T. Annealed tubing shall be tested as given above without further heat treatment. The tubing shall conform to ASTM B 163 - 64T when in the annealed state.

For the sellers information, this tubing shall be subjected to a high temperature brazing (about 10 min at 1850°F) operation and it is desired that the grain size be No. 5 or finer as defined in ASTM E 112-63, while at the same time keeping the dimensional distortation to a minimum.

VI. DIMENSIONS AND TOLERANCES:

A. The inside diameter shall be .503 to .504. "Inside Diameter" here does not mean "average inside diameter", but refers to actual diameter at any given plan normal to the axial center line.

B. The wall thickness shall be 0.018 in. ± 0.001. "Wall Thickness" does not mean "average wall thickness", but refers to wall thickness in any plane normal to the axial center line. All dimensional tolerance measurements shall be made after the hydrostatic test is performed.

C. The tubing shall be furnished in accordance with Dwg. A-85620-A2.

D. Corners formed by ends of tubing and longitudinal surfaces shall be square and deburred with a maximum chamfer of 0.005 in.

E. The tubing shall be straight within 0.060 in. per entire ft length as stated in AISI, September 1957, "Steel Tubular Products" and shall be straight within .005 over any 12 inch section as measured by a straight edge.

Subject: SPECIFICATION FOR FUEL TUBING FOR BONUS SUPER HEATER ELEMENT

VII. SURFACE FINISH AND CONDITION:

The tubing shall have a bright surface finish on the inside surfaces and shall be free of scale and oxide film or other foreign materials as determined by visual inspection. The outside surface shall be polished using a belt of 320 grit or finer. Tubing shall be furnished free of seams, cracks, laps, and intergranular attack. All inclusions, pits, gouge marks, and score marks in excess of 10% of the wall thickness shall be cause for rejection.

VIII. ACCEPTANCE TESTS:

A. Nondestructive

1. Liquid Penetrant. - A 100% liquid-penetrant inspection shall be performed by the Seller on the entire outside diameter surface of the finished tubes in accordance with MET-NDT-4 Rev. 3, "Tentative Methods for Liquid Penetrant Inspection".

2. Ultrasonic. - Ultrasonic inspection shall be performed on all tubes.

a. Technical requirements: The tubing shall be inspected at the completion of the manufacturing process. No drawing operation shall be accomplished after the ultrasonic inspection.

b. Inspection equipment: The instruments and accessory equipment shall be of the pulse-reflection type with sufficient sensitivity to distinguish the reference notches as required during calibration.

The transducer employed shall have no dimension greater than 1-in.

Subject: SPECIFICATION FOR FUEL TUBING FOR BONUS SUPER HEATER ELEMENT

VIII. ACCEPTANCE TESTS: (Cont'd)

c. Calibration standards: A calibration standard shall be prepared from tubing taken from the same heat and manufactured by the same processes as the tubing to be inspected and shall be free of defects; the tubing used for the calibration standard shall be the same size as the tubing to be inspected and shall be in the as-polished condition. A longitudinal reference notch, 1/4-in. long and with a maximum depth of 0.0025 in., (the depth shall include the highest point of the metal due to upset, although "deburring" is permitted) shall be machined on the outside and inside surfaces of the standard. The notch may be made by the electric-arc-discharge method. If both reference notches are on the same end of the standard, they shall be at least 120° apart. The included angle of the reference notch shall not exceed 60°.

d. Equipment calibration: Using the calibration standard specified in Section VIII-A-2-c, the equipment shall be adjusted to produce indications as nearly as possible the same height from both the inside and outside reference notches. The rejection alarm shall be adjusted to signal at the indication of the lesser amplitude.

The equipment shall be calibrated at the same circumferential speed and rate of translation (feed helix) which will be used for the inspection of the tube.

The relative translation (feed helix) of the crystal with respect to the tube shall be the lesser of 3/8 in./revolution or one half the crystal or collimator width or diameter.

e. Inspection procedure: The material shall be tested for radial defects in both circumferential directions under conditions which are used for calibration of the equipment.

The equipment shall be recalibrated as specified in Section VIII-A-2-d after the inspection of ten lengths of tubing or when any adjustment to the equipment is made.

When significant adjustment of the equipment is required during the calibration check (any time the inside and outside reference notches do not present a rejectable signal), the preceding ten tubes shall be completely reinspected.

VIII. ACCEPTANCE TESTS: (Cont'd)

f. Defects and rejection: All indications of discontinuities equal to or greater than the lesser indication of the reference notches as described in Section VIII-A-21-d shall be considered as defects and shall be rejected. If the defect is reworkable, it may be removed and reinspected ultrasonically. Reworked material shall conform to the dimensional requirements of this specification.

3. Hydrostatic Test. - Each tube shall be tested by the Hydrostatic Test given in ASTM B 163 - 64T.

4. Dimensional Inspection. -

a. Mechanical measurements of the wall thickness shall be made at 90° intervals or less on each end of each tube (cut to length) to determine compliance with Section VI-B of this specification.

VIII. ACCEPTANCE TESTS: (Cont'd)

b. Each finished tube shall be subjected to an air-gage inspection of the inside diameter along the entire length to determine compliance with Section VI-A of this specification. Diametrical measurements shall be made at intervals of approximately 90 deg.

c. A random 20% sample of the tubes in finished condition and cut to length shall be subjected to an ultrasonic-resonance inspection for wall-thickness determination. The accuracy of the test equipment for use in this measurement shall be established by taking readings at a point near the end of one or more tubes and checking by measurement with a micrometer.

A continuous helical span shall be accomplished on the inspected tubing with a pitch not to exceed 1 in. An acceptable alternate will be circumferential scans on 1-in. centers. If one or more tubes of the 20% sampling are determined not to meet the dimensional requirements as stated in this specification, an additional 20% sampling shall be examined in the same manner. A rejection rate of 10% or more of the tubes shall be cause for 100% inspection of the entire lot.

Tubes not subjected to ultrasonic resonance tests for wall thickness by the Seller are subject to such tests by the Company. The tubes are subject to rejection if the tests by the Company show that the wall thickness does not conform to the dimensional requirements of this specification.

d. The Seller shall perform inspection on each tube for length, end squareness, and straightness to determine compliance with Sections VI-C, VI-D, and VI-E, respectively, of this specification.

5. Visual. - Each tube shall be visually inspected under direct daylight fluorescent lighting of at least 100 footcandles to ensure conformance to Section VII of this specification.

B. Destructive

1. Metallographic examination at 100X of one section of tubing selected at random from each lot shall be prepared to determine complaince with Section V of this specification.

Subject: SPECIFICATION FOR FUEL TUBING FOR BONUS SUPER HEATER ELEMENT

VIII. ACCEPTANCE TESTS: (Cont'd)

2. Metallographic specimens shall be forwarded by the Seller to the Company at time of shipment.

IX. MARKING AND PACKING:

A. Each tube shall be marked by means of a sulfur-free ink with the following:

1. NRS-13

2. Manufacturer's private identification mark

3. Lot number

4. Heat number

B. Each tube shall be packed in such a manner as to prevent damage and to maintain the cleanliness of the tubing during handling and shipment.

X. INSPECTION:

The Seller shall notify the Company five (5) days in advance of the date set for starting of production testing in order that the Company's inspector may be present to witness testing.

XI. TEST REPORTS:

Four certified copies of test reports required by ASTM 163 - 64T and this specification shall be furnished by the Seller to the Company at the time of shipment of each lot of material. At the time of shipment, the Seller shall also furnish to the Company four copies of a Manufacturer's certification of compliance to this specification.

WELDING SPECIFICATION

STANDARD REFERENCE INFORMATION

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
ORGDP, OAK RIDGE, TENNESSEE - PADUCAH, KENTUCKY

NUMBER	UCN-1
DATE	12-30-65
REVISED	
PAGE	1 of 5

SUBJECT

BONUS SUPERHEATER REPAIR WELDING

SCOPE

This standard covers the welding procedures and performance tests necessary for the reassembly welding of the BONUS Superheater Fuel Assembly No. 29 and incorporates the performance test results.

SPECIFICATION

BONUS Assembly Specifications 66-10, Rev. 1, Paragraphs 3.1.3.4 and 3.3.3.4.

GENERAL

All welding shall be done in the flat 1G position using the TIG process. Torches shall be energized with direct current and connected for reverse polarity (DCRP). Filler metal shall be mill-certified 348 stainless steel wire.

Components of the assembly shall be precleaned with chlorine-free alcohol. White, lint-free gloves shall be worn for all handling and fit-up work to avoid fingerprint contamination.

JOINT APPLICATION

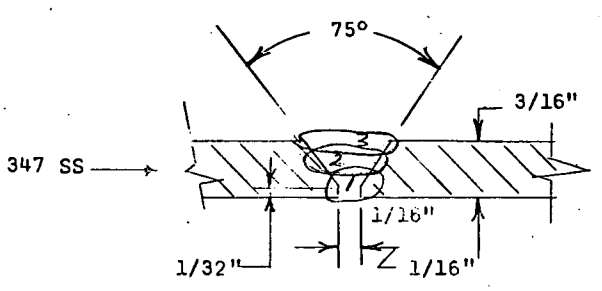
Parts A, B, and C below specify the details pertaining to the specific joints.

PART A

JOINT

Inlet-Outlet Standpipe Transition Components to Upper Tube Sheet.

TEST WELD



APPROVED BY: J. W. Cannon

NUMBER	STANDARD REFERENCE INFORMATION
UCN-1	
DATE 12-30-65	
REVISED	SUBJECT
PAGE 2 of 5	BONUS SUPERHEATER REPAIR WELDING

QUALIFICATION TESTS AND EVALUATION

Make three 6-in.-long vee butt weldments with 4 x 6 x 3/16-in. 347 stainless steel plate. (1) Perform tensile and guided bend tests in accordance with ASME Boiler and Pressure Vessel Code, Section IX, and (2) radiograph in accordance with Code paragraph UW-51.

WELDER: R. H. Duncan, Badge No. 19375 - Date Tested June 2, 1965

WELD PARAMETERS

Pass No.	Bead Type	Tungsten Size (in.)	Filler Size (in.)	Amps	Volts	Argon Flow	
						Torch	Purge
1	Straight	1/16	1/16	47	11	35	40
2-3	Weave	3/32	1/16	86	12	35	30

TENSILE COUPONS

Sample No.	Yield Point (psi)	Tensile Strength (psi)	Remarks
TR-1	47,000	89,300	Base metal fracture
TR-2	46,800	89,000	Base metal fracture

Guided bend coupons for Samples DR1-1 (face type); DR1-2 (root type); TR2-1 (face type); and TR2-2 (root type) showed no defects.

Radiographic checks showed that Samples DR1, DR2, and TR1 were acceptable per Code.

APPROVED BY: _____

STANDARD REFERENCE INFORMATION

NUMBER	UCN-1
DATE	12-30-65
REVISED	
PAGE	3 of 5

SUBJECT

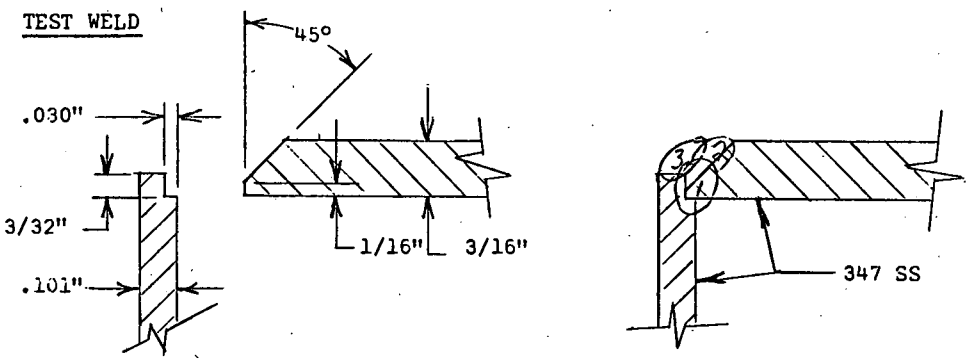
BONUS SUPERHEATER REPAIR WELDING

PART B

JOINTS

Upper Cover Plate to Upper Tube Sheet; Lower Cover Plates to Lower Tube Sheet; and Crossover Liner Pins to Cover Plates.

TEST WELD



QUALIFICATION TEST AND EVALUATION

Make four corner test welds from 2-in.-long x 2-in.-wide coupons. Visual and metallographic approval required.

WELDER: R. H. Duncan, Badge No. 19375 - Date Tested October 5, 1965

WELD PARAMETERS

Pass No.	Bead	Tungsten Size (in.)	Filler Size (in.)	Amps	Volts	Argon Flow (cfh)	
						Torch	Backing
1	Fusion	1/16		75	10-12	20	25
2	Weave	1/16	.035	75	10-12	20	25
3	Weave	1/16	1/16	75	10-12	20	25

APPROVED BY: _____

NUMBER UCN-1	STANDARD REFERENCE INFORMATION
DATE 12-30-65	
REVISED	SUBJECT BONUS SUPERHEATER REPAIR WELDING
PAGE 4 of 5	

METALLOGRAPHIC CHECK - 100X

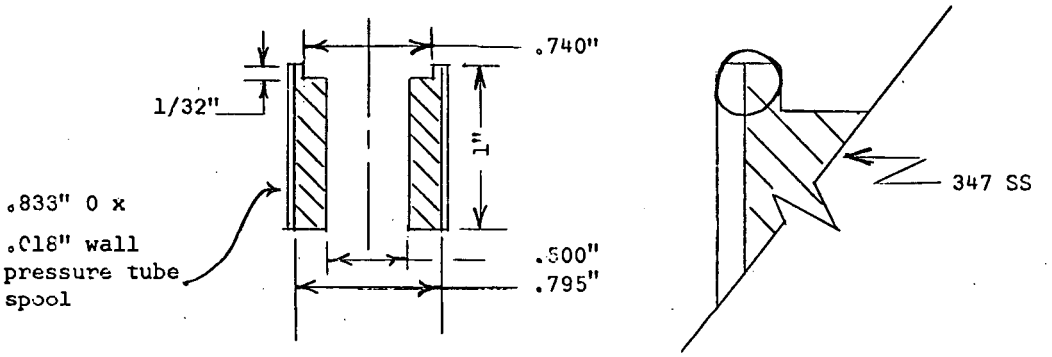
Sample No.	Penetration (100%)	Cracks	Inclusion	Pores (.002" max)
6B	OK	None	None	OK
7B	OK	None	None	OK
8B	OK	None	None	OK
9B	OK	None	None	OK

PART C

JOINT

Support Cap to Pressure Tube.

TEST WELD



QUALIFICATION TEST AND EVALUATION

Make four prctotype edge welds at the corner tube position using a 2 x 4 x 3-in.-deep handicap box, simulating the actual welds to be made in the tube sheet. Metallographic evaluation is to be made at 100X.

APPROVED BY: _____

STANDARD REFERENCE INFORMATION

NUMBER	UCN-1
DATE	12-30-65
REVISED	
PAGE	5 of 5

SUBJECT

BONUS SUPERHEATER REPAIR WELDING

WELDER: R. H. Duncan, Badge No. 19375 - Date Tested August 9, 1965

WELD PARAMETERS*

Pass No.	Tungsten Size (in.)	Amps	Volts	Argon Flow (cfh)
Fusion	.040	15	10	35

*Ceramic cup - Size No. 4.

METALLOGRAPHIC CHECK - 100X

Sample No.	Cracks	Inclusion	Cold Laps	Pores (.002" max)
8T	None	None	None	None
9T	None	None	None	None
10T	None	None	None	None
11T	None	None	None	None

We certify that the above qualification tests and test results stipulated in Parts A, B, and C are correct, and that the welder, R. H. Duncan, is hereby qualified to conduct all repair welding on the rebuilt assembly.

K-25 Engineering Division

12/30/65
(Date)

E. C. Kirstowsky
E. C. Kirstowsky
Welding Engineering Department

APPROVED BY: _____

K-25 RECORD OF WELDER QUALIFICATION TESTS

SAFETY AND PROTECTION DIVISION

Operator R. H. Duncan Badge No. 19375 Dept. No. 1080

Procedure No. UCN-1 - Part A Date Started 6-2-65 Stencil or Test No. _____

Material 347 SS (Kind & Specification No.) Thickness 3/16" Filler Metal 347 SS (Rod or Electrode & Spec. No.)

Weld Process Heliarc (Arc, Gas, Heliarc, etc.) Weld Positions 1G Type of Test Performance Qualification (First, Double, Retest)

Record test results below giving a brief description of defects. Record silver brazing tests on back side.

COUPON NUMBERS	FACE BEND TESTS: Passed [X] Failed [ ]
1	No defects - Test plate - DR-1
2	No defects - Test plate - DR-2
3	
4	
	ROOT BEND TESTS: Passed [X] Failed [ ]
1	No defects - Test plate - DR-1
2	No defects - Test plate - DR-2
3	
4	
	TENSILE ~~SIDE BEND OR NICK BREAK TESTS~~ (Indicate Which Method) Passed [X] Failed [ ]
1	TR-1 - 89,300 - Base metal fracture
2	TR-2 - 89,000 - Base metal fracture
3	
4	
FILM NUMBER	RADIOGRAPHS: Passed [X] Failed [ ] Prior to Bend Tests [X] Renewal of Qualification [ ]
1	TR - Scattered, minimum sized pores - Exceeds ASME Sec. III Standards
2	DR-1 - Scattered, minimum sized pores - Exceeds ASME Sec. III Standards
3	DR-2 - Scattered, minimum sized pores - Exceeds ASME Sec. III Standards
4	

The above operator is qualified to weld under the following:

Procedure No. UCN-1 - Part A Positions 1G Effective 6-7-65

INSPECTOR E. C. Kirstowsky DATE 6-2-65 6-7-65

APPROVED E. C. Kirstowsky DATE 6-7-65

WCX-2081, Mech. Insp. Dept. K25RC (2-56)

K-25 RECORD OF WELDER QUALIFICATION TESTS

SAFETY AND PROTECTION DIVISION

Operator R. H. Duncan Badge No. 19375 Dept. No. 1080

Procedure No. UCN-1 - Part B Date Started 10-5-65 Stencil or Test No. _____

Material 347 SS (Kind & Specification No.) Thickness 1/8 to 3/16" Filler Metal 347 SS (Rod or Electrode & Spec. No.)

Weld Process TIG (Arc, Gas, Heliarc, etc.) Weld Positions 1G Type of Test Performance Qualification (First, Double, Retest)

Record test results below giving a brief description of defects. Record silver brazing tests on back side.

COUPON NUMBERS	FACE BEND TESTS: Passed ☐ Failed ☐
1	
2	
3	
4	
	ROOT BEND TESTS: Passed ☐ Failed ☐
1	
2	
3	
4	
	SIDE BEND OR NICK BREAK TESTS: (Indicate Which Method) Passed ☐ Failed ☐
1	
2	
3	
4	
FILM NUMBER	METALLOGRAPHIC ~~RADIOGRAPHIC~~ Passed [X] Failed ☐ Prior to Bend Tests [X] Renewal of Qualification ☐
X 6B	Acceptable per attached metallographic examination
X 7B	Acceptable per attached metallographic examination
X 8B	Acceptable per attached metallographic examination
X 9B	Acceptable per attached metallographic examination

The above operator is qualified to weld under the following:

Procedure No. UCN-1 - Part B Positions 1G Effective 10-20-65

INSPECTOR E. C. Kirstowsky DATE 10-19-65

APPROVED E. C. Kirstowsky DATE 10-20-65

UNION CARBIDE

INTERNAL CORRESPONDENCE

NUCLEAR DIVISION

POST OFFICE BOX P, OAK RIDGE, TENNESSEE 37831

To (Name) Mr. E. C. Kirstowsky (2)
Company
Location K-1400

Date October 28, 1965
Originating Dept. Metallurgy
Answering letter date

Copy to Mr. J. W. Arendt
Mr. W. S. Dritt
File (NoRC)

Subject Qualification Welds - Type 348 Stainless Steel

Introduction

The stainless steel qualification welds you submitted have been examined to determine the weld quality. The welds (sample numbers 6B, 7B, 8B, and 9B) were prepared by R. H. Duncan to prove the integrity of top cover-to-upper tube sheet corner welds in the BONUS reactor. The welds were prepared by TIG welding 3/16-inch thick bevel plate to 1/8-inch thick vertical plate in the horizontal position using the UCN-1 auxiliary welding procedure. Type 348 stainless steel filler wire was used in making the welds.

Results

Metallographic examination showed that full penetration and complete fusion were accomplished with no undercutting of the base metal adjacent to the weld. No defects were found greater than 0.002 inch in major dimension.

C. E. Weaver

C. E. Weaver

Plant Equipment Problems
Metallurgy Department
Technical Division

CEW:emck

K-25 RECORD OF WELDER QUALIFICATION TESTS

SAFETY AND PROTECTION DIVISION

Operator R. H. Duncan Badge No. 19375 Dept. No. 1080

Procedure No. UCN-1 - Part C Date Started 8-9-65 Stencil or Test No.

Material 347 to 348 SS (Kind & Specification No.) Thickness .018 to .027" Filler Metal None (Rod or Electrode & Spec. No.)

Weld Process TIG (Arc, Gas, Heliarc, etc.) Weld Positions 1G Type of Test Performance Qualification (First, Double, Retest)

Record test results below giving a brief description of defects. Record silver brazing tests on back side.

COUPON NUMBERS	FACE BEND TESTS: Passed ☐ Failed ☐
1	
2	
3	
4	
	ROOT BEND TESTS: Passed ☐ Failed ☐
1	
2	
3	
4	
	SIDE BEND OR NICK BREAK TESTS: (Indicate Which Method) Passed ☐ Failed ☐
1	
2	
3	
4	
FILM NUMBER	METALLOGRAPHIC ~~XXXXXXXXX~~: Passed [X] Prior to Bend Tests [X] Failed ☐ Renewal of Qualification ☐
X 8T	Acceptable per attached metallographic examination
X 9T	Acceptable per attached metallographic examination
X10T	Acceptable per attached metallographic examination
X11T	Acceptable per attached metallographic examination

The above operator is qualified to weld under the following:

Procedure No. UCN-1 - Part C Positions 1G Effective 8-16-65

INSPECTOR E. C. Kirstowsky DATE 8-9-65

APPROVED E. C. Kirstowsky DATE 8-16-65

WCX-2081, Mech. Insp. Dept. K25RC (2-56)

UNION CARBIDE

INTERNAL CORRESPONDENCE

NUCLEAR DIVISION

POST OFFICE BOX P, OAK RIDGE, TENNESSEE 37831

To (Name) Mr. E. C. Kirstowsky (2)
Company
Location K-1400

Date October 28, 1965
Originating Dept. Metallurgy
Answering letter date

Copy to Mr. J. W. Arendt
Mr. W. S. Dritt
File (NoRC)

Subject Qualification Welds - Type 348 Stainless Steel

Introduction

The stainless steel qualification welds you submitted have been examined to determine the weld quality. The fusion welds (sample numbers 8T, 9T, 10T, and 11T) were prepared by R. H. Duncan to simulate the pressure tube-to-support cap welds for the repair welding of BONUS fuel assembly number 29. The welds were made in the flat position using a simulated handicap jig.

Results

Metallographic examination showed that complete fusion was accomplished with no undercutting of the base metal adjacent to the weld. All welds were free of cracks and porosity exceeding 0.002 inch in maximum dimension.

C. E. Weaver
C. E. Weaver

Plant Equipment Problems
Metallurgy Department
Technical Division

CEW:emck

UCN-1 PART C.

R. H. Duncan's Qualification Welds

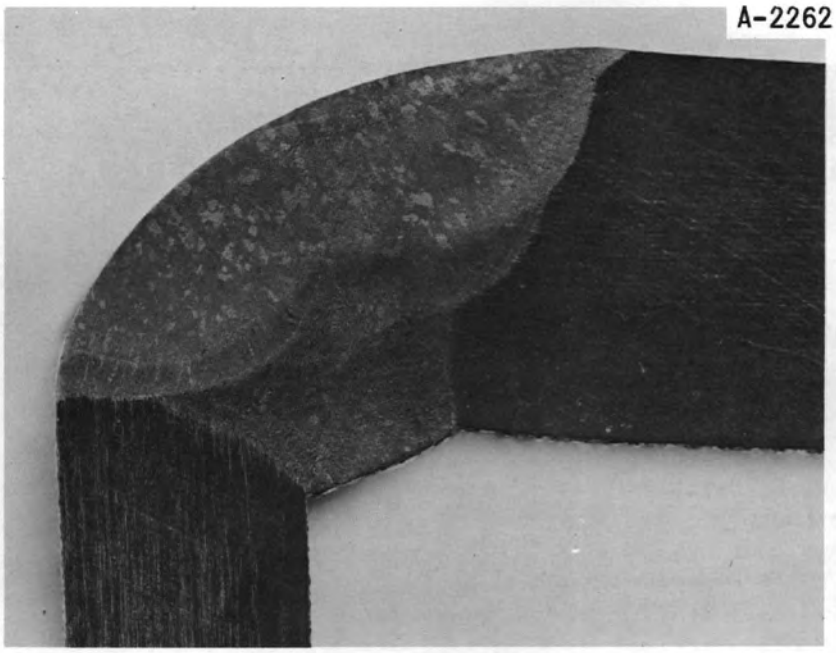


Fig. B-2. UCN-1, Part B Box Cover-to-Tube Sheet Weldment. Full weld penetration was achieved by reducing the tube sheet edge to 3/32 in. high. 348 stainless steel to 348 stainless steel. 9×.

Fig. B-3. UCN-1, Part C Pressure Tube-to-Support Cap Weld. 348 stainless steel to 348 stainless steel. 75×.

NUCLEAR REACTOR SPECIFICATION
METALS AND CERAMICS DIVISION
OAK RIDGE NATIONAL LABORATORY

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Spec: NRS-14
Date: August 4, 1965
Rev. No.: 0
Page: 1 of 2

Subject: BONUS SUPERHEATER FUEL ELEMENT BRAZING SPECIFICATION

I. SCOPE

This specification is a process specification which defines the attachment, by brazing with Nicrobraz -50, of spacers to the clad tubes and to the coolant tube of the BONUS Superheater Fuel Element in a continuous hydrogen furnace.

II. PROCEDURE

A. The Seller shall let the furnace run empty for a period of four hours at a minimum of 1900°F before the brazing run to insure a clean hydrogen atmosphere. A clean Dexo Electro Dryer or equal shall be put in service at the start of the run.

B. A control sample and a thermocouple shall be run through the furnace before any brazing is performed. A survey shall be taken by recording the temperature of the thermocouple every minute and by recording its total time above 1600°F. The time above 1600°F shall not exceed 10 minutes and the temperature shall not exceed 1850°F. The brazing temperature shall be 1830 ± 20°F. If the survey is in an acceptable range and if the control sample is brazed successfully (See Section III), the production brazing may begin. The process must be repeated if either the sample did not braze or the survey was out of specification.

C. After the temperature survey the controls of the furnace shall remain at the same setting (belt speed, temperature, etc.) until after the braze run. A lot shall consist of all the subassemblies that were run through the furnace at one time with the same setting (belt speed, temperature, etc.).

D. Tubing and spacers shall be supplied in accordance with drawings 10398 R 001 D and DM-85620-A3. The spacers; the brazing alloy, Nicrobraz -50; and the stop-off, in the case of the coolant, shall be put in place by the Seller. The coolant spacer may be spot welded in place but spot welding shall not be used on the clad tube.

E. After production brazing, a temperature survey shall be run as defined in Section II, paragraph B of this specification.

F. Two rebraze cycles may be used on the clad tubes. The coolant tubes may be rebrazed once. The same procedure (furnace clean up, survey before and after the control sample, etc.) must be used for each rebraze

run. The serial number of each subassembly which is rebrazed shall be recorded.

III. VISUAL INSPECTION

All subassemblies shall be visually examined under direct daylight fluorescent illumination of at least 100 foot candles. The brazed joints on the clad tubes shall be continuous uniformly filled joints. The brazed joints on the coolant tube shall be continuous uniformly filled joints extending for a minimum distance of 3/8 inches along each side of the spacer.

IV. INSPECTION

The Company shall have an Inspector and/or an Engineer to witness all operations covered by this specification. The Seller shall be responsible for notifying the Company 24 hours in advance of assembling and brazing so that a representative may be present.

V. RECORDS

The Seller shall provide the following records:

A. The two furnace surveys for each braze lot and rebraze lot.

B. The instrument trace from the furnace control thermocouple for each brazing lot.

C. The serial number of each tube that was rebrazed.

VI. SHIPMENT

The Seller shall be responsible for packing the subassemblies to insure against shipping and handling damage.

APPENDIX C

Inspection Data and Fabrication Comments

C-1. Fuel Inspection (Certificates of Chemical Analysis) 109

C-2. Cladding Tube Spacer Fabrication Comments 114

C-3. Helium Leak Test Data on Fuel Rods 115

C-4. Dimensional Inspection of BONUS Fuel Rods 117

C-5. Shell Subassembly Inspection Reports (Weld Reports) 119

C-6. Envelope of Superheater Fuel Assembly 133

C-7. Metal Analysis Certificates 135

C-8. Procedures for Fabrication of Cladding Tube Spacers 143

C-1. FUEL INSPECTION (Certificates of Chemical Analysis)

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material Enriched UO_2 Pellets

Date August 18, 1965

Customer Union Carbide Corporation
P.O. Box P
Oak Ridge, Tennessee

Date Shipped August 7, 1965

Bill of Lading No. 1966

Purchase Order No. 28X-9766

Sales Order No. 3306

ELEMENT	Batch No. 2	ANALYSIS, ppm				
		Total Uranium		O/U		Carbon
1		88.11		2.002		11
2		88.08		2.004		11
3		88.09		2.004		11
4		88.06		2.005		30
5		88.06		2.005		59
6		88.11		2.004		14
7		88.10		2.004		12
8		88.06		2.004		11
9		88.10		2.004		12
10		88.11		2.002		27
11		88.06		2.005		86
12		88.11		2.002		39
Average		88.09		2.004		27
% U-235		3.3100				
		Nitrogen		Chloride		Fluoride
1		32		< 25		< 10
2		41		< 25		< 10
3		10		< 25		< 10
4		10		< 25		< 10
5		28		< 25		15
6		22		< 25		< 10
7		17		< 25		< 10
8		23		< 25		< 10
9		28		< 25		17
10		23		< 25		< 10
11		28		< 25		< 10
12		37		< 25		< 10
Average		25		< 25		11

Certified By: K.D. Hensley
Quality Control Department
K.D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material Enriched UO_2 Pellets

Date August 18, 1965

Customer Union Carbide Corporation
P.O. Box P
Oak Ridge, Tennessee

Date Shipped July 30, 1965

Bill of Lading No. 1947

Purchase Order No. 28X-9766

Sales Order No. 3306

ELEMENT	Batch No. 1	ANALYSIS, ppm				
	Total	Uranium		O/U		Carbon
1		88.07		2.002		29
2		88.04		2.002		32
3		88.07		2.003		82
4		88.07		2.003		19
5		88.06		2.002		38
6		88.05		2.002		19
7		88.08		2.001		53
8		88.07		2.002		53
9		88.07		2.003		34
10		88.08		2.002		19
11		88.08		2.002		33
12		88.09		2.001		44
13		88.03		2.005		27
14		88.10		2.001		12
15		88.06		2.002		29
16		88.08		2.002		40
17		88.09		2.001		12
18		88.09		2.001		10
19		88.10		2.001		28
20		88.09		2.001		15
21		88.08		2.003		11
22		88.06		2.001		12
23		88.06		2.001		29
Average		88.07		2.002		30
% U		3.24				

Certified By: K.D. Hensley
Quality Control Department
K.D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material Enriched UO_2 Pellets

Date August 18, 1965

Customer Union Carbide Corporation
P.O. Box P
Oak Ridge, Tennessee

Date Shipped July 30, 1965

Bill of Lading No. 1947

Purchase Order No. 28X-9766

Sales Order No. 3306

ELEMENT	Batch No. 1	ANALYSIS, ppm				
		Nitrogen		Chloride		Fluoride
1		74		< 25		< 10
2		51		< 25		< 10
3		40		< 25		< 10
4		37		< 25		< 10
5		32		< 25		19
6		28		< 25		22
7		69		< 25		22
8		55		< 25		< 10
9		55		< 25		< 10
10		46		< 25		< 10
11		20		< 25		20
12		65		< 25		19
13		32		< 25		16
14		50		< 25		< 10
15		60		< 25		< 10
16		92		< 25		< 10
17		42		< 25		< 10
18		60		< 25		< 10
19		60		< 25		< 10
20		18		< 25		< 10
21		60		< 25		< 10
22		46		< 25		< 10
23		68		< 25		< 10
Average		50		< 25		13

Certified By: K.D. Hensley
Quality Control Department
K.D. Hensley

NUCLEAR FUEL SERVICES, INC.
A Subsidiary of W. R. Grace & Co.
Erwin, Tennessee

CERTIFICATE OF ANALYSIS

Material Enriched UO_2 Pellets — Date August 18, 1965

Customer Union Carbide Corporation
P.O. Box P
Oak Ridge, Tennessee

Date Shipped
Bill of Lading No.

Purchase Order No. 28X-9766 — Sales Order No. 3306

ELEMENT	ANALYSIS, ppm				
Batch		#1			#2
Iron		< 50			341
Calcium		< 20			50
Silicon		20			125
Aluminum		3			8
		Boron Equivalents			Boron Equivalents
Boron	< 0.20	0.20000		< 0.20	0.20000
Cadmium	< 0.10	0.03120		< 0.10	0.03120
Silver	< 0.10	0.00084		< 0.10	0.00084
Gadolinium	< 0.01	0.04190		< 0.01	0.04190
Europium	< 0.02	0.00812		< 0.02	0.00812
Samarium	< 0.20	0.10660		< 0.20	0.10660
Total		0.38866			0.38866
Density:	Greater than 10.30 g/cc -- Less than 10.63 g/cc				
Dryness:		< 40 ppm			
Dimensional:		The UO_2 fuel pellets produced for UCNC's Purchase Order Number 28X-9766 conform to the dimensional tolerances given on Drawing No. 48864.			

Certified By: K.D. Hensley
Quality Control Department
K.D. Hensley

C-2. CLADDING TUBE SPACER FABRICATION COMMENTS*

The following comments discuss some of the features of the explosive forming:

1. The die was not hard enough.

2. The sealing system for the inner tube was not good, particularly since Tygon tubing was used.

3. To prevent damage to the die from water leaks and to increase production rate, shoot tooling in air with water in the tube.

4. Tool weight was about as much as was convenient to handle.

The following suggestions are made on how these parts would be made if ordered again in the future:

1. The preform would be shaped on mechanical tools rather than explosive tools. This allows a larger round preform, 0.650 ± 0.002-in. OD, 0.0195 ± 0.001-in.-wall thickness, and 0.50 in. long, to be made from 0.75-in. Inconel tubing. This size was limited before by the collapse in the explosive sizing tools. This reduces the amount of stretch required and eliminates the initial annealing.

2. Anneal the preform for 1 hr at 900°C in vacuum to soften and provide optimum corrosion resistance.

3. Tumble 24 hr in stainless steel shot to break all edges.

4. Explosive size in one shot about 20 parts at one time in good vacuum. The tools would be designed differently. The steel would be heat-treated harder. The die would be shot in air with water in the tube. This would prevent water inleakage inside the die. The die would be hand-lapped routinely to keep up the surface finish. The liner would be rubber, not Tygon. The explosive would be MDF 10A in rubber liner to space explosive better and protect die.

5. All parts would be inspected on a go no-go gage.

6. Any oversized parts would be ground on the outside surface. Depending upon the quantities involved, this might be cheaper than reworking the tools.

---

*Information supplied by W. T. Carey, Y-12 Plant.

C-3. HELIUM LEAK TEST DATA ON FUEL RODS

Equipment: CEC MODEL 24-120

A	B	C	D	E	F	G			Net for Rod				
Rod Number	Chamber Pressure Microns of Hg	Instrument Background Meter Div.	Empty Chamber (Background) Meter Div.	Rod & Chamber Meter Div.	Std. Leak & Empty Chamber Meter Div.	Std. Leak, Rod, & Chamber Meter Div.	Std. Leak (5×10^{-9}) Col.F-D Meter Div.	Sensitivity Std.cc/sec.	Col.G-F Meter Div.	Col.E-D Meter Div.	Leak Rate Std.cc/sec.	Pumping Time Minutes	Date
	2.8	0	11		91		80	6.25×10^{-11}				30	10/22/65
0-11	2.8			11		91			0	0	0	30	
0-30	2.8			11		68			-23	0	0	30	
	2.8		11		71		60	8.33×10^{-11}				25	
0-21	2.8			11		70			-1	0	0	30	
	2.8		10		67		57						Checked Acc.V. & Reset Zero
0-20	2.8			10		66			-1	0			
	2.2		5		56		51	9.8×10^{-11}				7	10/23/65
0-25	2.8	0		5		51			-5	0	0	30	
0-41	3.0	0		5		51			-5	0	0	30	
0-10	3.0	-1		5		51			-5	0	0	30	Reset Zero
	3.0	0	5		52		47	10.63×10^{-11}				25	Reset Acc. V.
	2.8	0	5		56		51	9.8×10^{-11}				20	
0-38	3.0	0		16		62			+6	+11	1×10^{-9}	30	
0-31	3.0	0		5		54			-2	0	0	30	
0-43	3.0	0		5		53			-3	0	0	30	
	3.0	0	5		56		51	9.8×10^{-11}				25	
0-1	3.0	0		5		54			-2	0	0	30	
0-35	3.0	0		5		54			-2	0	0	30	
0-36	3.0	0		5		60			+4	0	0	30	
	3.0		5		60		55	9.09×10^{-11}				25	
	2.5	1	8		76		68	7.35×10^{-11}					10/25/65
0-2	2.8	-1		8		71			-5	0	0	30	Reset Zero
0-42	3.0	0		7		70			-6	-1	0	30	
0-28	30.0			>100,000						>100,000	$>1 \times 10^{-5}$		
0-15	2.5			6									Filament went out-Changed instruments
0-15	3.0	0		10		83			-2*	-2*	0	45	*Based on subsequent sensitivity check
	3.0	0	12		85		73	6.84×10^{-11}				45	
0-27	3.0	0		11		84			-1	-1	0	45	

Appendix C-3 (continued)

A	B	C	D	E	F	G							
Rod Number	Chamber Pressure Microns of Hg	Instrument (Background) Meter Div.	Empty Chamber (Background) Meter Div.	Rod & Chamber Meter Div.	Std. Leak & Empty Chamber Meter Div.	Std. Leak Rod, & Chamber Meter Div.	Std. Leak (5×10^{-9}) Col.F-D Meter Div.	Sensitivity Std.cc/sec.	Net for Rod Col.G-F Meter Div.	Net for Rod Col.E-D Meter Div.	Leak Rate Std.cc/sec.	Pumping Time Minutes	Date
0-4	3.0	0		12		84			-1	0	0	45	
0-13	3.0	0		12		84			-1	0	0	45	
	3.0	0	12		84		72	6.8×10^{-11}				45	
0-37	3.0	0		11		84			0	-1	0	45	
0-40	30.0			>100,000						>100,000	$>1 \times 10^{-5}$		
	3.2	1	9		86		77	6.47×10^{-11}					10/26/65
0-5	3.2	1		8		84			-2	-1	0	70	
0-9	3.2	1		9		83			-3	0	0	70	
	3.0	0	4		80		76	6.56×10^{-11}					10/27/65
0-33	3.2	0		4		80			0	0	0	55	
0-24	3.2	0		5		81			+1	+1	0	50	
0-32	3.2	0		5		81			+1	+1	0	55	
	3.2	0	5		82		77	6.49×10^{-11}				60	
0-8	3.2	0		5		82			0	0	0	60	
0-19	3.2	0		5		82			0	0	0	60	
0-27	3.2	0		5		82			0	0	0	60	
	3.0	0	4		80		76	6.56×10^{-11}					10/28/65
0-17	3.0	0		5		80			0	+1	0	75	
0-14	30.0			>100,000						>100,000	$>1 \times 10^{-5}$		
	3.2	1	16		100		84	5.94×10^{-11}					
0-34	3.2	1		13		93			-7	-3	0	60	
0-44	3.2			11		93			-7	-5	0	60	
	3.2	0	5		84		79	6.33×10^{-11}					10/29/65
0-40R	3.2	0		5		84			0	0	0	45	
	3.0	0	6		66		60	8.33×10^{-11}					11/1/65
0-3	3.2	0		4		62			-4	-2	0	45	
0-28R	30.0			>100,000						>100,000	$>1 \times 10^{-5}$		

Column B is the test chamber pressure in microns of Hg. at the time the leak rate meter was read.

Column C is the instrument "zero" reading taken with the filament ON but with the manifold system valved off.

Sensitivity = $\frac{\text{Standard leak}}{\text{Leak rate meter reading of standard leak}} = \frac{5 \times 10^{-9}}{\text{Column F - Column D}}$

"Net for Rod" is obtained in two ways: (1) with the standard leak in the system (2) without any external source of helium in the system (Column E - D)

Note: One of the two listings of rod 0-27 is a mistake and should be 0-22.

C-4. DIMENSIONAL INSPECTION OF BONUS FUEL RODS

Rod No.	Weld Diameter Top End Min.-----Max.	Weld Diameter Bottom End Min.--------Max.	Rod Length Weld to Weld	Rod Length Tip to Tip	Clad Diameter Min.----------Max	
0-1					0.5394	0.5404
0-2	0.541 - 0.545	0.543 - 0.546	60.152	60.608		
0-3	0.541 - 0.543	0.545 - 0.546	60.170	60.617		
0-4	0.545 - 0.545	0.546 - 0.552	60.161	60.614		
0-5	0.543 - 0.544	0.543 - 0.545	60.169	60.624		
0-8	0.543 - 0.549	0.542 - 0.547	60.160	60.614		
0-9	0.546 - 0.549	0.543 - 0.552	60.157	60.619		
0-10	0.541 - 0.542	0.543 - 0.545	60.163	60.609		
0-11	0.542 - 0.544	0.541 - 0.545	60.147	60.593		
0-13	0.542 - 0.544	0.543 - 0.547	60.152	60.625		
0-15	0.541 - 0.544	0.542 - 0.545	60.150	60.597		
0-17	0.542 - 0.546	0.542 - 0.543	60.160	60.616		
0-19	0.544 - 0.548	0.542 - 0.544	60.149	60.616	0.5395	0.5398
0-20	0.543 - 0.545	0.540 - 0.540	60.155	60.611		
0-21	0.546 - 0.546	0.544 - 0.546	60.147	60.606		
0-22	0.543 - 0.545	0.544 - 0.548	60.155	60.609		
0-24	0.542 - 0.543	0.541 - 0.542	60.164	60.629		
0-25	0.543 - 0.545	0.538 - 0.541	60.164	60.618		
0-27	0.541 - 0.546	0.541 - 0.544	60.153	60.622		
0-30	0.542 - 0.547	0.542 - 0.546	60.158	60.608		
0-31					0.5398	0.5405
0-32	0.548 - 0.553	0.542 - 0.546	60.154	60.621	0.5395	0.5404
0-33	0.543 - 0.547	0.543 - 0.544	60.153	60.605		
0-34	0.542 - 0.547	0.543 - 0.547	60.150	60.624	0.5395	0.5405
0-35						
0-36	0.542 - 0.544	0.542 - 0.544	60.153	60.621		
0-37	0.543 - 0.547	0.542 - 0.546	60.139	60.612		
0-40	0.542 - 0.543	0.541 - 0.543	60.044	60.561		
0-41	0.542 - 0.544	0.543 - 0.546	60.155	60.603		
0-42	0.541 - 0.542	0.541 - 0.545	60.165	60.636		
0-43						
0-44	0.542 - 0.543	0.542 - 0.547	60.160	60.640		

C-5. SHELL SUBASSEMBLY INSPECTION REPORTS

(Weld Reports)

X983

WELD INSPECTION REPORT

Report No.

DISTRIBUTION:

DRAWING NUMBER: 66M-47

WORK ORDER NUMBER: M 32466-07

DATE: 11-1-65

COMPONENT TITLE: BONUS SUPERHEATER TRANSITION LINER

WELD NUMBER: —

WELDING SPECIFICATION: 4.3.26

WELDING PROCESS: TIG

TYPE JOINT: SURFACE FILL

INSPECTION SPECIFICATION: U.C.N 1

INSPECTION SCHEDULE: VISUAL & Dye check

BASE MATERIALS			FILLER METAL		
TYPE	347 SS		TYPE	347 SS	
IR			IR		
HEAT			HEAT	X 56081	
MFG.			MFG.	ARCOS	
LOT NO.			ITEM		
FORM	Sheet		SIZE	.035	
ITEM	4				
PIECE	Flow liner	(66-M-47-4)			
SIZE					

WELDER

WELDER'S NAME: R. H. DUNCAN

FITTER'S NAME:

BACK-UP GAS: A ✓ He

COVER GAS: A ✓ He

INSPECTION

	DISPOSITION	APPROVED
CLEANLINESS	OK	REB
FIT-UP	NONE	—
ROOT PASS	OK	—
PENETRANT: DEFECTS Root	NONE	REB
INTERMEDIATE PASSES	—	—
PENETRANT: DEFECTS	—	—
FINAL PASSES	—	—
PENETRANT: DEFECTS	—	—
RADIOGRAPHY	—	—
ULTRASONIC	—	—
WELDING VARIABLES	VOLTS / AMPS 15-18	INTER PASS TEMP.

REMARKS: Repairs to transition liner, surface cuts. Mill nicks from severance cut.

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
R E Bumley	11-1-65	E. C. Kistowski	11-1-65

UCN-1149A (2 12-61)

✓ J547 ,

WELD INSPECTION REPORT

Report No.

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M32466-07

DATE: 12-2-3-65

COMPONENT TITLE: SUPERHEATER FUEL SUB ASSEMBLY No. 29

WELD NUMBER:

WELDING SPECIFICATION: 4.3-26

WELDING PROCESS: TIG

TYPE JOINT: FUSION

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	347	C 8FC	TYPE	NONE	
IR			IR		
HEAT			HEAT		
MFG.			MFG.		
LOT NO.			ITEM		
FORM	(66-M-48-3)	(66-M-46-14)	SIZE		
ITEM	PRESSURE TUBE SUPPORT CAPS.				
PIECE	TO PRESSURE TUBES				
SIZE					

WELDER

WELDER'S NAME: R. H. DUNCAN

FITTER'S NAME:

BACK-UP GAS: A He

COVER GAS: A ✓ He

INSPECTION

	DISPOSITION		APPROVED
CLEANLINESS	OK		JTB
FIT-UP	—		
ROOT PASS	—		
PENETRANT: DEFECTS	—		
INTERMEDIATE PASSES	—		
PENETRANT: DEFECTS	—		
FINAL PASSES	OK		JTB
PENETRANT: DEFECTS	—		
RADIOGRAPHY	—		
ULTRASONIC	—		
WELDING VARIABLES	VOLTS	AMPS	INTER PASS TEMP.

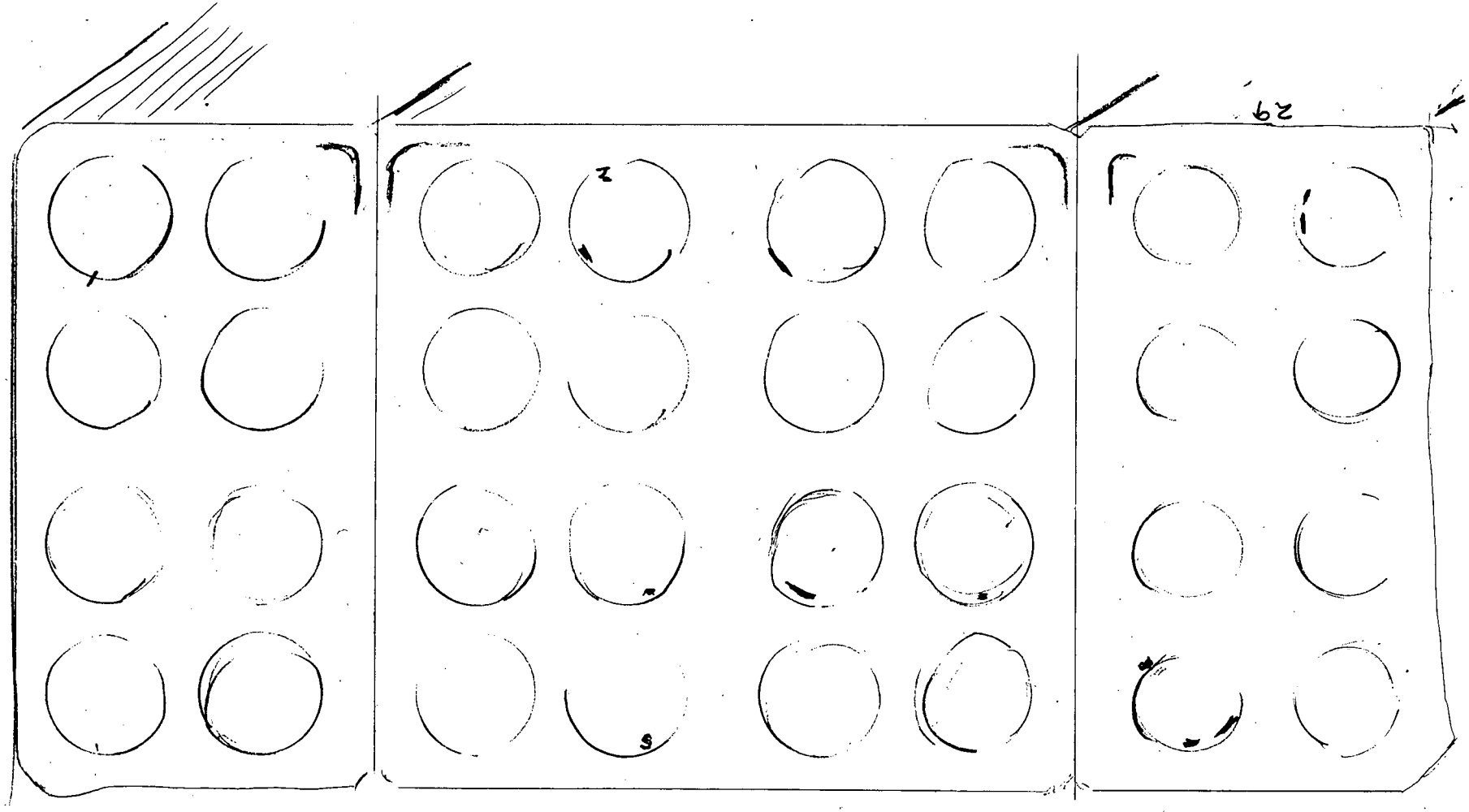
REMARKS:
12 TUBE REPAIRS WERE MADE, ALL BEING CONSIDERED SATISFACTORY AFTER VISUAL INSPECTION

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
[illegible]		E. C. Kristonsky	12-29-65

UCN-1 [illegible]
(2 ✓ 12 [illegible])

INSPECTION #1

Top



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Bottom

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WELD INSPECTION REPORT

Report No. 2

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M-32466-07

DATE: 12-7-65

COMPONENT TITLE: SUPERHEATER SHELL COMPONENTS

WELD NUMBER:

WELDING SPECIFICATION: 4-4-26

WELDING PROCESS: TIG

TYPE JOINT: GROOVE-PLUG

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	SPEC. 66-10	A-167-63 348	TYPE	347	
IR			IR		
HEAT		X33684-2	HEAT	X-56056 W05672	
MFG.		G D CARLSON	MFG.	Arcoly	
LOT NO.			ITEM		
FORM	UPPER CROSSOVER FLOW LINER	PLATE	SIZE	.035 .0625	
ITEM	66-M-47-1	66-M-47-5			
PIECE					
SIZE		4.279x4.096x.188			

WELDER

WELDER'S NAME: DUNCAN R.H. 19375

FITTER'S NAME:

BACK-UP GAS: A 45 CFPH He

COVER GAS: A 35 CFPH He

INSPECTION

	DISPOSITION		APPROVED
CLEANLINESS	OK		
FIT-UP	OK		
ROOT PASS	—		—
PENETRANT: DEFECTS	—		—
INTERMEDIATE PASSES	—		—
PENETRANT: DEFECTS	—		—
FINAL PASSES	satisfactory		
PENETRANT: DEFECTS	[illegible]		
RADIOGRAPHY	not required		
ULTRASONIC			
WELDING VARIABLES	VOLTS	AMPS	INTER PASS TEMP.

REMARKS:

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
J. Bunal	12-7-65	E.C. Kistowsky	12-28-65

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✓ J-547

WELD INSPECTION REPORT

Report No. 3

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M-32466-07

DATE: 12-7-65

COMPONENT TITLE: SUPEHEATER SHELL COMPONENTS

WELD NUMBER:

WELDING SPECIFICATION: 4-W-26

WELDING PROCESS: TIG

TYPE JOINT: GROOVE

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	SPEC. 66-10 PAR. 4.5	A-167-63 348	TYPE	347	
IR			IR		
HEAT		X33684-2	HEAT	X5608L W05672	
MFG.		G.D. CARLSON	MFG.	Arcos	
LOT NO.			ITEM	4	
FORM	UPPER TUBE SHEET	PLATE	SIZE	.035 .0625	
ITEM	66M-48 -1	66M-47 - 5			
PIECE					
SIZE	9-272 x 4.391 x 3/8	4.229 x 4.096 x 188			

WELDER

WELDER'S NAME: DUNCAN, R.H. 19375

FITTER'S NAME:

BACK-UP GAS: A 45 CFPH He

COVER GAS: A 35 CFPH He

INSPECTION

	DISPOSITION		APPROVED
CLEANLINESS	—	OK	JB
FIT-UP	✓	OK	JB
ROOT PASS	✓	OK	JB
PENETRANT: DEFECTS	none		JB
INTERMEDIATE PASSES	✓		
PENETRANT: DEFECTS			
FINAL PASSES	satisfactory	OK	JB
PENETRANT: DEFECTS	none		JB
RADIOGRAPHY	none required		
ULTRASONIC	"	"	
WELDING VARIABLES	VOLTS	AMPS	INTER PASS TEMP.

REMARKS:

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
J Bend	12-7-65	E.C. Kirstensen	12-20-65

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WELD INSPECTION REPORT

Report No. 4

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M-32466-07

DATE: 12-11-65

COMPONENT TITLE: SUPERHEATER SHELL COMPONENTS

WELD NUMBER:

WELDING SPECIFICATION: 4-4-26

WELDING PROCESS: TIG

TYPE JOINT: GROOVE & PLUG

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	SPEC 6.6.10 PAR 4.5	A-167-63 348	TYPE	347	
IR			IR		
HEAT		X33624-2	HEAT	X-5608L W05672	
MFG.		G.D. CARLSON	MFG.	Arcos	
LOT NO.			ITEM		
FORM	LOWER TUBESHEET	PLATES (2)	SIZE	.035 .0625	
ITEM	66-M-48-2	66-M-47-6			
PIECE					
SIZE	4.22 x 9.21 x 3 3/4	4.268 X 3.995 x .250			

WELDER

WELDER'S NAME: DUNCAN, R.H. 19375

FITTER'S NAME:

BACK-UP GAS: A 45 CFPH He

COVER GAS: A 35 CFPH He

INSPECTION

	DISPOSITION	APPROVED
CLEANLINESS	OK	
FIT-UP	OK	
ROOT PASS	OK	
PENETRANT: DEFECTS	none	
INTERMEDIATE PASSES	OK	
PENETRANT: DEFECTS	none	
FINAL PASSES	OK	
PENETRANT: DEFECTS	none	
RADIOGRAPHY	not required	
ULTRASONIC	"	
WELDING VARIABLES	VOLTS / AMPS	INTER PASS TEMP.

REMARKS:

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
J. Berch	12-13-65	E. C. Kristensky	12/28/65

UCN-1149A (2/12-61)

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WELD INSPECTION REPORT

Report No. 5

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M-32466-07

DATE: 12-11-65

COMPONENT TITLE: SUPERHEATER SHELL COMPONENTS

WELD NUMBER:

WELDING SPECIFICATION: 4-4-26

WELDING PROCESS: TIG

TYPE JOINT: GROOVE-PLUG

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	SPEC. 6.6.10 PARA 1.6	A-167 63 348	TYPE	347	
IR			IR		
HEAT		X-33584-2	HEAT	X-5608L W05672	
MFG.		G.A. CARLSON	MFG.	[illegible]	
LOT NO.			ITEM		
FORM	LOWER CROSSOVER FLOW LINER	PLATES (2)	SIZE	.035 .0625	
ITEM	66-M-47 ITEM 2	66-M-47 ITEM 6			
PIECE					
SIZE					

WELDER

WELDER'S NAME: DUNCAN, R.H. 19375

FITTER'S NAME:

BACK-UP GAS: A 45 CFH He

COVER GAS: A 35 CFH He

INSPECTION

	DISPOSITION		APPROVED
CLEANLINESS	✓		[illegible]
FIT-UP	OK		[illegible]
ROOT PASS	OK		[illegible]
PENETRANT: DEFECTS	none		[illegible]
INTERMEDIATE PASSES	—		—
PENETRANT: DEFECTS	—		—
FINAL PASSES	OK		[illegible]
PENETRANT: DEFECTS	none		[illegible]
RADIOGRAPHY	not required		
ULTRASONIC	"	"	
WELDING VARIABLES	VOLTS	AMPS	INTER PASS TEMP.

REMARKS:

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
[illegible]		E.C. Kistowski	12/28/65

UCN-1149A (12-61)

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WELD INSPECTION REPORT

Report No. 6

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M-32466-07

DATE: 12-13-65

COMPONENT TITLE: SUPERHEATER FUEL ASSEMBLY

WELD NUMBER:

WELDING SPECIFICATION: 4-4-26

WELDING PROCESS: TIG

TYPE JOINT: Fillet

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	AS PURCHASED	A-167-63 347	TYPE	347	
IR			IR		
HEAT		X-33684-2	HEAT	X 56084 W05627	
MFG.		C.D. CARLSON	MFG.	Arcoly	
LOT NO.			ITEM		
FORM			SIZE	.035 .0625	
ITEM	66-M-49-4	66-M-47 ITEM 6			
PIECE	GUIDE SLEEVE	PLATES (2)			
SIZE					

WELDER

WELDER'S NAME: DUNCAN, R.H.

FITTER'S NAME:

BACK-UP GAS: A He

COVER GAS: A He

INSPECTION

	DISPOSITION		APPROVED
CLEANLINESS	✓		[illegible]
FIT-UP	OK		[illegible]
ROOT PASS	—		—
PENETRANT: DEFECTS	—		—
INTERMEDIATE PASSES	—		—
PENETRANT: DEFECTS	—		—
FINAL PASSES	OK		[illegible]
PENETRANT: DEFECTS	—		[illegible]
RADIOGRAPHY	not required		[illegible]
ULTRASONIC	" "		
WELDING VARIABLES	VOLTS	AMPS	INTER PASS TEMP.

REMARKS:

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
[illegible]	12-13-65	L.C. Pistowsky	12/20/65

UCN-1149A (2) 12-61)

✓ J-547

WELD INSPECTION REPORT

Report No. 7

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M-32466-07

DATE: 12-15-65

COMPONENT TITLE: SUPERHEATER FUEL ASSEMBLY

WELD NUMBER:

WELDING SPECIFICATION: 4-4-26

WELDING PROCESS: TIG

TYPE JOINT: FILLET

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	AS FURNISHED	AS FURNISHED	TYPE	347	
IR			IR		
HEAT			HEAT	X56086 W056722	
MFG.			MFG.	Arcoly	
LOT NO.			ITEM		
FORM			SIZE	.035 .0625	
ITEM	66-M-49 ITEM 4	66-M-49 ITEM 17			
PIECE	GUIDE SLEEVE	SLEEVE END			
SIZE	1 3/4 x 3 45/32	1.735			

WELDER

WELDER'S NAME:

BACK-UP GAS: A He

FITTER'S NAME:

COVER GAS: A He

INSPECTION

	DISPOSITION		APPROVED
CLEANLINESS	✓		R.
FIT-UP	OK		B.
ROOT PASS	—		—
PENETRANT: DEFECTS	—		—
INTERMEDIATE PASSES	—		—
PENETRANT: DEFECTS	—		—
FINAL PASSES	OK		B.
PENETRANT: DEFECTS	—		B.
RADIOGRAPHY	not required		
ULTRASONIC	"	"	
WELDING VARIABLES	VOLTS	AMPS	INTER PASS TEMP.

REMARKS:

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
J. Bond	12-15-65	E. C. Kristovsky	12/29/65

UCN-1149A (12-61)

J-547

WELD INSPECTION REPORT

Report No. 8

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M-32466-07

DATE: 12-15-65

COMPONENT TITLE: SUPERHEATER FUEL ASSEMBLY

WELD NUMBER:

WELDING SPECIFICATION: -4-4-26

WELDING PROCESS: TIG

TYPE JOINT: GROOVE

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	AS FURNISHED	TUBESHEET AS FURNISHED	TYPE	347	
IR		BOX TUBE A-167-43 348	IR		
HEAT			HEAT	X56082L W05672	
MFG.			MFG.		
LOT NO.			ITEM		
FORM			SIZE	.035" .0625"	
ITEM	2/66 66-M-49 ITEM 1	66-M-48-7			
PIECE	FUEL ASSEMBLY GUIDE	LOWER TUBE SHEET & BOX COVER			
SIZE					

WELDER

WELDER'S NAME: DUNCAN, RH 19375

FITTER'S NAME:

BACK-UP GAS: A He

COVER GAS: A He

INSPECTION

	DISPOSITION		APPROVED
CLEANLINESS	—		
FIT-UP	OK		
ROOT PASS	—		—
PENETRANT: DEFECTS	—		—
INTERMEDIATE PASSES	—		—
PENETRANT: DEFECTS	—		—
FINAL PASSES	OK		
PENETRANT: DEFECTS	—		
RADIOGRAPHY	not required		
ULTRASONIC			
WELDING VARIABLES	VOLTS	AMPS	INTER PASS TEMP.

REMARKS:

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
J. Bird	12-15-65	E.C. Kristowsky	12/28/65

UCN-1149A (2-12-61)

✓ V-542

WELD INSPECTION REPORT

Report No. 9

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M-32466-07

DATE: 12-17-65

COMPONENT TITLE: SUPERHEATER FUEL ASSEMBLY

WELD NUMBER:

WELDING SPECIFICATION: 4-4-26

WELDING PROCESS: TIG

TYPE JOINT: GROOVE

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	AS FURNISHED	AS FURNISHED	TYPE	347	
IR			IR		
HEAT			HEAT	X-56082 W05672	
MFG.			MFG.		
LOT NO.			ITEM		
FORM	REDUCER	SHELL ASSEMBLY	SIZE	.035 .0625	
ITEM	#66-M-47 ITEM-3	66-M-45 ITEM-1			
PIECE					
SIZE					

WELDER

WELDER'S NAME: DUNCAN, RH 19375

FITTER'S NAME:

BACK-UP GAS: A 45 CFH He

COVER GAS: A 35 CFH He

INSPECTION

	DISPOSITION		APPROVED
CLEANLINESS	OK		JB
FIT-UP	OK		JB.
ROOT PASS	OK		JB.
PENETRANT: DEFECTS	none		JB.
INTERMEDIATE PASSES	—		—
PENETRANT: DEFECTS	—		—
FINAL PASSES	OK		JB
PENETRANT: DEFECTS	None		JB
RADIOGRAPHY	OK		JB.
ULTRASONIC	not required		
WELDING VARIABLES	VOLTS	AMPS	INTER PASS TEMP.

REMARKS:

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
J. Burch	12-20-65	E. C. Kirstosky	12/20/65

UCN-1149A
(2 (12-61)

✓ J-547

WELD INSPECTION REPORT

Report No. 10

DISTRIBUTION:

DRAWING NUMBER: 66-M-44

WORK ORDER NUMBER: M-32466-07

DATE: 12-23-65

COMPONENT TITLE: SUPERHEATER FUEL ASSEMBLY

WELD NUMBER:

WELDING SPECIFICATION: 4-4-26

WELDING PROCESS: TIG

TYPE JOINT: GROVE

INSPECTION SPECIFICATION:

INSPECTION SCHEDULE:

BASE MATERIALS			FILLER METAL		
TYPE	AS FURNISHED	A-167-63 348	TYPE	347	
IR			IR		
HEAT		X-33684-2	HEAT	X-5608 L	
MFG.		C.D. CARLSON	MFG.		
LOT NO.			ITEM		
FORM	GUIDE WASHER	SPACER GUIDE WASHER RING	SIZE	.635 .0625	
ITEM	66-M-49 ITEM 2				
PIECE					
SIZE		3" DIA. x 1/4"			

WELDER

WELDER'S NAME: DUNCHY, RH 19325

FITTER'S NAME:

BACK-UP GAS: A He

COVER GAS: A 35 CFH He

INSPECTION

	DISPOSITION		APPROVED
CLEANLINESS	OK		
FIT-UP	OK		
ROOT PASS	—		—
PENETRANT: DEFECTS	—		—
INTERMEDIATE PASSES	—		—
PENETRANT: DEFECTS	—		—
FINAL PASSES	OK		
PENETRANT: DEFECTS	none		
RADIOGRAPHY	not required		—
ULTRASONIC			—
WELDING VARIABLES	VOLTS	AMPS	INTER PASS TEMP.

REMARKS:

INSPECTOR'S SIGNATURE	DATE	FINAL ACCEPTANCE	DATE
J. Bunch	12-23-65	E. C. Kristowsky	12/28/65

UCN-1149A (2 12-61)

ORGDP PLANT ENGINEERING INSPECTION REPORT

Test Performed by Physical Test Dept Date 12/20/65

for U.S A.E.C. Bonus Reactor ESO No.

W. O. No. M32466-07

Report No.

JOB TITLE Superheater Fuel Assembly and Connector Pipe Arrangement Sheet of

The Assembly

was subjected to A leak test while pressurized at 300 psig with an He media

with the following results: No leaks were found on the assembly during probing procedure using a CEC Model 24-120A, Single Channel Mass Spectrometer.

References: Drawing No 66M40

Accepted ~~on Rejected~~.

Witnessed by:

J Burch

E. C. Kristovsky

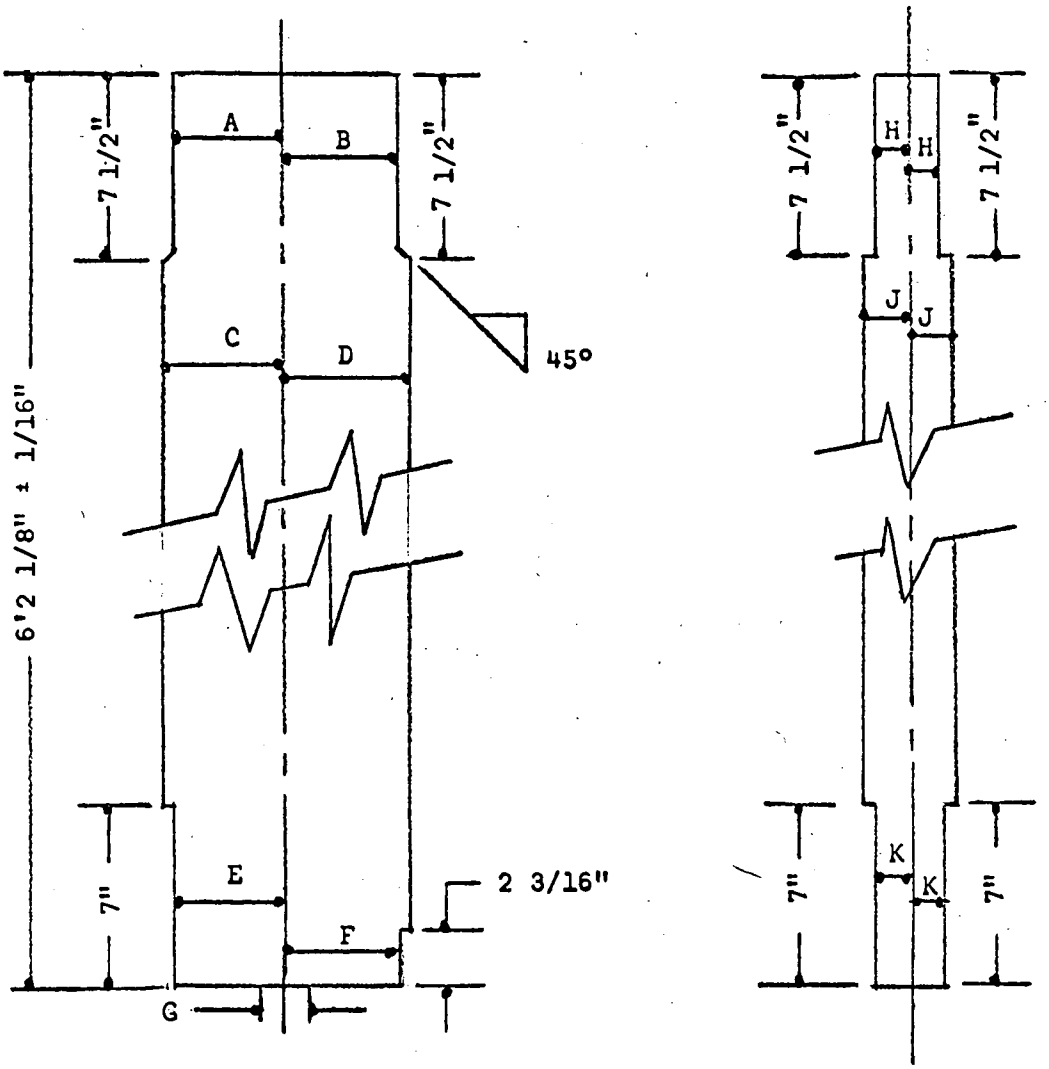
12-28-65

cc:

PE-11 (1 5-61)

C-6. ENVELOPE OF SUPERHEATER FUEL ASSEMBLY

C-6. ENVELOPE OF SUPERHEATER FUEL ASSEMBLY



A	4.553 / 4.548	F	4.781 / 4.776
B	4.832 / 4.827	G	2.005 / 2.003
C	4.625 / 4.553	H	2.234 / 2.229
D	5.103 / 5.047	J	2.281 / 2.229
E	4.553 / 4.548	K	2.226 / 2.221

Per GNEC Sketch 066-SK-477

C-7. METAL ANALYSIS CERTIFICATES

E.C. Kirstowsky

ARCOS CORPORATION

50th & PASCHALL AVENUE
PHILADELPHIA 43, PA.

October 25, 1961

Research and Engineering Department

Date.....

CHEMICAL ANALYSIS CERTIFICATE

UNION CARBIDE NUCLEAR CO.
P. O. BOX P
OAK RIDGE, TENN.
MARK: ORNL

ATTN: MR. NORMAN ROSS

Customer's Order No. 65X-78850
Arcos S. O. No. SE 11842
Shipping Date 10/19/61

Size	.035"
Grade	CHROMENAR 19/9Cb
Alloy No.	X5608L347
Process No.	
Weight	32# 10 oz.
Chemical Analysis	WELD METAL
Carbon	.074
Manganese	1.36
Silicon	.40
Sulfur	.016
Phosphorus	.017
Chromium	20.36
Nickel	9.73
Molybdenum	.18
Columbium	.78
Tungsten	

Y.S. 67000 TS. 89800 EL. 34 RA. 49.1

FREE FACE BENT - SOUND, ELONGATION 32% GUIDED SIDE BEND - SOUND

Cobalt - 550 - 1650 ppm
Boron - 2 ppm
Tantalum - 50 ppm

As per 617/618 - 11-1-65

ARCOS CORPORATION

Signed
Quality Control Supervisor

Mass

SPECTROGRAPHIC REPORT

MATERIAL TYPE	DATE	REQUESTER	BATCH NUMBER	REQUISITION NUMBER
347 Steel	11/1/65	Kristowsky	X5608 L	

REPORTING UNIT

- [ ] %
- [x] ppm
- [ ] Other
- [ ] µg/ml
- [ ] Total µg

REPORTING BASIS

- [ ] Sample as Received
- [x] Metal Basis
- [ ] Other
- [ ] Dry Basis
- [ ] Ash Basis

PLATE SHEET NO.

617
618

Ag		Al		Au		B	2.0	Ba		Be		Bi	
Ca		Cd		Co	550–1650	Cr		Cs		Cu		Fe	
Hf		K		Li		Mg		Mn		Mo		Na	
Nb		Ni		P		Pb		Pd		Pt		Rb	
Sb		Si		Sn		Ta	N50	Th		Ti		U	
V		W		Zn		Zr							
Ce		Dy		Er		Eu		Gd		Ho		Lu	
Nd		Pr		Sm		Tb		Tm		Y		Yb	

UCN-2379
(23 7-64)

ALLOY RODS COMPANY
Division of Chemetron Corporation

Certificate of Analysis 07-576-3841

☐ Weld Deposit Analysis ☒ Base Wire Analysis

Union Carbide Nuclear
P. O. Box Y Plant Y 12
Oak Ridge, Tenn.
P. O. 658 1152
Rel. 65Y 58

Specification AWS 5.9 ASTM A371
Grade Type ER 347
Customer Order No. 542 M 324
Alloy Rods Co. Order No. 992718
Shipped October 3, 1963

This material conforms to specification referenced above.

Trade Name: Arcaloy Welding Wire 347 x 36

Size: (60 lbs.) 1/16"

Lot Number:

Heat Number:	W06572
Carbon	.05
Manganese	1.70
Chromium	19.59
Nickel	9.75
Silicon	.38
Columbium	
Molybdenum	
Tungsten	
Copper	
Titanium	
Phosphorus	.019
Sulphur	.014
Columbium + Tantalum	.63

Cobalt - <0.2%
Boron - <0.002%
Tantalum - <0.1%
Per K-25 analysis No. 9502 5-18-65

State of Penna.)
County of York) SS

Subscribed and sworn to before me this 3rd day of October 19 63

SEAL [signature]
Notary Public

My commission expires: 2/28/65

The undersigned certifies that this report is correct and that no significant change has been made in any of the elements described in the qualification approval.

ALLOY RODS COMPANY
Division of Chemetron Corporation

BY [signature]
R. Freireich

ALLOY RODS COMPANY
Division of Chemetron Corporation

07-576-3551

Certificate of Analysis

☐ Weld Deposit Analysis

☒ Bare Wire Analysis

Union Carbide Nuclear
P.O. Box P Plant K 25
Oak Ridge, Tenn.
Order 65 S 1152
Rel 65K 40

Grade: Type ER 347
Customer Order No. 542-M-201
Alloy Rods Co. Order No. 062606
Shipped July 3, 1964

This material conforms to specification AWS 5.9 ASTM A371

1152
65 K 40
(092)

Trade Name:	Arcaloy 347 Welding Wire
Size:	3/32"
Lot Number:	
Heat Number:	W06572
Carbon	.05
Manganese	1.70
Chromium	19.59
Nickel	9.75
Silicon	.38
Columbium	.63
Tungsten	
Copper	
Titanium	
Phosphorus	.019
Sulphur	.014
Ferrite	
Vanadium	

Cobalt - <0.2%
Boron - <0.002%
Tantalum - <0.1%

Per K-25 analysis No. 9302 - 5-18-65

State of Penna)
County of York) SS

Subscribed and sworn to before me this 3rd day of July 1964

SEAL Penna M. Kelley
Notary Public

My commission expires: 2/23/65

The undersigned certifies that this report is correct and that no significant change has been made in any of the elements described in the qualification approval.

ALLOY RODS COMPANY
Division of Chemetron Corporation

BY R.E. Wolfe
R.E. Wolfe

JOCN 5901
(1) 5 64

WORKS LABORATORY ANALYSIS REPORT

1503

18703 18697 18698 18697 18694

SPECTROCHEMICAL REPORT

Ag	Ir	Sr
Al	K	Te <0.1
As	Li	Tc
Au	Mg	Te
B <0.002	Mn	Th
Ba	Mo	Ti
Be	Na	Tl
Bi	Ni	U
Ca	Os	V
Cb	P	W
Cd	Pb	Zn
Co <0.2	Pd	Zr
Cr	Pr	
Cs	Rb	
Cu	Re	
Fe	Rh	
Ga	Ru	
Ge	Sb	
Hf	Sc	
Hg	Si	
In	Sn	

☐ QUAL. ☐ SEMIQUANT. ☐ QUANT.

NUMBERS = 0/0 ON A Sample BASIS

" " MEANS "SOUGHT BUT NOT FOUND"

CHARGE A-85620-01	DATE 5-18-65	NO. 9302
SENDER K. Zirkle		DATE ANALYSIS NEEDED
CLASS	MATERIAL CODE	SAMPLED FROM ARCALOY PT WO6572 / CONTAINER NO.
REQUEST NO.	PRECISION	GROSS
MATERIAL DESCRIPTION 347 Stainless Welding Wire		TARE
INSTRUCTIONS		NET

REQUESTED ANALYSIS	UNITS	RESULT(S)
Ta, Co, B		

RESULT APPROVED BY [illegible]

DATE 5-19-65

140

999
NEGOTIABLE

BIR-11-9115 (2)
SALES TERRITORY

G.O.CARLSON Inc.

Producers of Stainless Steel

THORNDALE • PENNSYLVANIA

TEST REPORT

Je 6/2/65
DATE

SOLD TO
Union Carbide Corporation
Nuclear Division
P. O. Box M
Oak Ridge, Tennessee 37831

INVOICE
P. O. Box P

SHIP TO
United States Atomic Energy Commission
c/o Union Carbide Corporation
Plant K23
Oak Ridge, Tennessee

ROUTING (ACTUAL)
A. Dule Pyle % United Airlines
PREPAID

OOG 59683

CUST. NO. 735-16544

MARK 735-16544
RELEASE 73K04

NOTARIZED TEST REPORTS
3 CHEMICALS &
MECH. PROPS.

B/N TO CUST. 2

B/N TO CONS

CHEMICALS AND OR PHYSICALS

DATE OF SHMT. 5/28

NO. COPIES 3

ATTN. Pur. Dept.

TYPED BY
JJH

TYPE 348 HRAP EXCEPT 1.65 MAX. Mn .
ASTM A-167-63

SHIPPING SCHEDULE
5/28 or sooner

QT. ORD.		ITEM	QT. SHPD.	WEIGHT (LBS.)	PRICE	AMOUNT
1	9/32 x 24 x 24 (Bdl)	1	1	48		

004

CHEMICAL ANALYSIS

Item	Qt.	Heat No.	C	Mn	P	S	Si	Cr	Ni	Cb	Ta	Mo	Ti	Cu	Co	Misc.
.1	1	X33684-2	.064	1.65	.022	.025	.45	18.71	11.35	.76	.03					

MECHANICAL TESTS GA.	HEAT NO.	YIELD STR. P.S.I. 2% OFFSET	TENSILE STR. P.S.I.	% ELONG. IN 2"	% RED. OF AREA	BRINELL HARDNESS	BEND TEST
9/32	X33684-2	42,400	89,600	45.0	53.1	163	OK

SWORN TO AND SUBSCRIBED BEFORE ME THIS 2 DAY OF June, 1965

Notary Public, Coatesville, Pa. Co. Pa.
My Commission Expires June 17, 19

I HEREBY CERTIFY THESE TESTS ARE CORRECT TO THE BEST OF MY KNOWLEDGE AND BELIEF.

G. O. CARLSON, Inc.

Mildred M. Carlson

Box Cover Material

~~SSL~~ MCW SPECTROGRAPHIC REPORT

MATERIAL TYPE	DATE	REQUESTER	BATCH NUMBER	REQUISITION NUMBER
348 S.S	2-11-66	Kiratmaky	A-167-63	Mt. # X-33684-2

REPORTING UNIT	REPORTING BASIS	PLATE SHEET NO.
☐ % ☐ µg/ml ☑ ppm ☐ Total µg ☐ Other	☐ Sample as Received ☐ Dry Basis ☑ Metal Basis ☐ Ash Basis ☐ Other	826

Ag		Al		Au		B	2.8	Ba		Be		Bi	
Ca		Cd		Co	322.0	Cr		Cs		Cu		Fe	
Ht		K		Li		Mg		Mn		Mo		Na	
Nb		Ni		P		Pb		Pd		Pt		Rb	
Sb		Si		Sn		Ta		Th		Ti		U	
V		W		Zn		Zr							
Ce		Dy		Er		Eu		Gd		Ho		Lu	
Nd		Pr		Sm		Tb		Tm		Y		Yb	

UCN-2379
(23 7-64)

C-8. PROCEDURES FOR FABRICATION OF CLADDING TUBE SPACERS

Step Number	Description	Procedures	
		Initial	Final
1	Stock — Inconel from ORNL Stores	5/8-in. diameter by 1/16-in. wall thickness	5/8-in. diameter by 1/16-in. wall thickness
2	Preform machined from tubing	0.620 ± 0.002-in. OD, 0.0195 ± 0.0005 in. wall thickness	0.620 ± 0.002-in. OD, 0.0195 ± 0.0005 in. wall thickness
3	Anneal preform in vacuum	900°C, 1 hr, 5×10^{-6} torr	900°C, 1 hr, 5×10^{-6} torr
4	Explosive form tools, ET-56010		
	First Shot		
	Lining	5/8 in. Tygon tubing	5/8 in. Tygon tubing
	Vacuum	<29 in. Hg (no leak)	<15 in. Hg (leaked)
	Explosive	MDF 5A	MDF 5A in rubber tube
	Second Shot		
	Lining	5/8 in. Tygon tubing	5/8 in. Tygon tubing
	Vacuum	<29 in. Hg (no leak)	<15 in. Hg (leaked)
	Explosive	MDF 10A	MDF 5A in rubber tube
	Third Shot		
	Lining	5/8 in. Tygon tubing	5/8 in. Tygon tubing
	Vacuum	<29 in. Hg (no leak)	<15 in. Hg (leaked)
	Explosive	MDF 10A	MDF 5A in rubber tube
	Fourth Shot		(About 1/8 of parts)
	Lining		5/8 in. Tygon tubing
	Vacuum		<15 in. Hg (leaked)
	Explosive		MDF 5A in rubber tube
5	Inspection with No-Go Gage	Checked inside diameter spacer generally snug	Checked inside diameter spacer generally snug
6	Cleaned	Solvent	Solvent
7	Tumbled 24 hr	Alumina grit followed by stainless steel	Not tumbled
8	Outer surface ground to fit gage	Not ground	Placed on mandrel

APPENDIX D

Fuel Element Fabrication Data

Table D-1. Fuel Weights 147

Table D-2. Analyses of Inert Gas Present in Atmosphere Chamber During Fuel Rod Welding 148

Table D-3. Fuel Rods and Corresponding Coolant Tubes 149

Table D-1. Fuel Weights

Tube Number	UO_2 Weight (g)	Tube Number	UO_2 Weight (g)
0-1	1810.0994	0-24	1808.9504
0-2	1802.2708	0-25	1801.8549
0-3	1802.4828	0-27	1808.4456
0-4	1804.3137	0-30	1801.6986
0-5	1800.5170	0-31	1801.8283
0-8	1811.4366	0-32	1803.4091
0-9	1800.2268	0-33	1810.7643
0-10	1813.7166	0-34	1806.3327
0-11	1800.6740	0-35	1804.4523
0-13	1816.6190	0-36	1818.6080
0-15	1801.8428	0-37	1809.0045
0-17	1807.8048	0-40	1800.0618
0-19	1804.1631	0-41	1800.9414
0-20	1801.5537	0-42	1802.5699
0-21	1823.4693	0-43	1800.4087
0-22	1800.1878	0-44	1802.4576

Table D-2. Analyses of Inert Gas Present in Atmosphere Chamber During Fuel Rod Welding

Welding Batch Number	Fuel Rod Number	Chamber Vacuum Before Filling	Helium Bottle Number	Gas Sample Analysis Number	Mass Spectrometer Gas Analysis						
					H_2 (ppm)	He (%)	H_2O (ppm)	N_2 + CO (ppm)	O_2 (ppm)	Ar (ppm)	CO_2 (ppm)
		$\times 10^{-5}$									
1	0-1	3.5	X-973		5	99.997	1	17	5	3	1
	0-31			6176	<3	99.995	9	27	7	5	2
	0-35										
	0-43										
2	0-22	3	R-631A		2	99.998	2	13	1	1	2
	0-33			6177	<3	99.997	6	14	2	4	2
	0-34										
	0-24										
3	0-36	3.8	R-631A								
	0-27			6195	4	99.995	5	23	5	10	
	0-10										
4	0-40	2.4	R-631A								
	0-41			6196	4	99.996	6	16	3	7	2
	0-21										
	0-5										
	0-25										
5	0-9	4	H-189953		2	99.996	5	13	1	16	1
	0-8			6197	6	99.994	8	20	5	18	1
	0-4										
	0-13										
6	0-44	4.2	H-189953								
	0-32			6203	4	99.991	11	35	5	36	1
	0-19										
	0-37										
	0-17										
7	0-20	2.2	H-189953								
	0-11			6204	6	99.996	6	9	1	21	<1
	0-42										
	0-2										
	0-15										
	0-30										
	0-3										

Table D-3. Fuel Rods and Corresponding Coolant Tubes

Fuel Rod Number	Coolant Tube Number	Fuel Rod Number	Coolant Tube Number
0-1	1501	0-24	1391
0-2	1393	0-25	1491
0-3	1502	0-27	1499
0-4	1504	0-30	1289
0-5	1500	0-31	1377
0-8	1389	0-32	1362
0-9	1295	0-33	1506
0-10	1419	0-34	1374
0-11	1513	0-35	1386
0-13	1495	0-36	1490
0-15	1379	0-37	1376
0-17	1493	0-40	1293
0-19	1380	0-41	1387
0-20	1498	0-42	1381
0-21	1288	0-43	1390
0-22	1297	0-44	1497

APPENDIX E

Electron Microprobe Analysis of the Defective Region in Fuel Rod 0-28

ELECTRON MICROPROBE ANALYSIS OF THE DEFECTIVE REGION IN FUEL ROD 0-28

G. Hallerman

The longitudinal section through the defective region in fuel rod 0-28 described in the previous section, was submitted for electron microprobe analysis. The region of interest was in the heat-affected zones in the end cap and cladding near the weldment. Intergranular cracks were observed in both the end cap and cladding material in this region. The microprobe was used to observe concentration changes of elements present in the defective regions.

For all elements investigated, a 20-kv accelerating potential and a specimen current of 0.02 μa were used. The analyses were made with the MAC model 400 microprobe using flow-proportional detectors and pulse-height discrimination. The estimated electron probe diameter was 1–2 μ. For each of the minor elements analyzed (Al, Si, S, P, K, Nb), a minimum of three 100-sec counts were made on each of the areas of interest and on standards. For Ni, Cr, and Fe, counts of shorter duration were used. Background measurements were also made on each of the areas of interest and on the standards by defocusing the spectrometers. Specific conditions used for the analysis are shown in Table E-1.

Table E-1. Conditions of Analysis

Element Analyzed	Standard Used	Characteristic Line	Analyzing Crystal
Al	Pure Al	Kα	KAP
Si	Pure Si	Kα	KAP
S	FeS_2	Kα	ADP
P	InP	Kα	ADP
K	KOH	Kα	ADP
Nb	Pure Nb	Lα	KAP
Ni	Pure Ni	Kα	LiF
Cr	Pure Cr	Kα	LiF
Fe	Pure Fe	Kα	LiF

An area of the specimen adjacent to the weld is shown in Fig. E-1. The numbered arrows identify areas and phases in the cladding tube, end cap, and interface analyzed with the static electron beam. The results of semiquantitative analysis of these areas are tabulated in Table E-2. The values shown are intensity ratios. These ratios, to the first approximation, are weight percent concentrations with no corrections for x-ray absorption of fluorescence. These ratios were obtained by dividing the count rates of x ray produced by an element in the specimen by the count

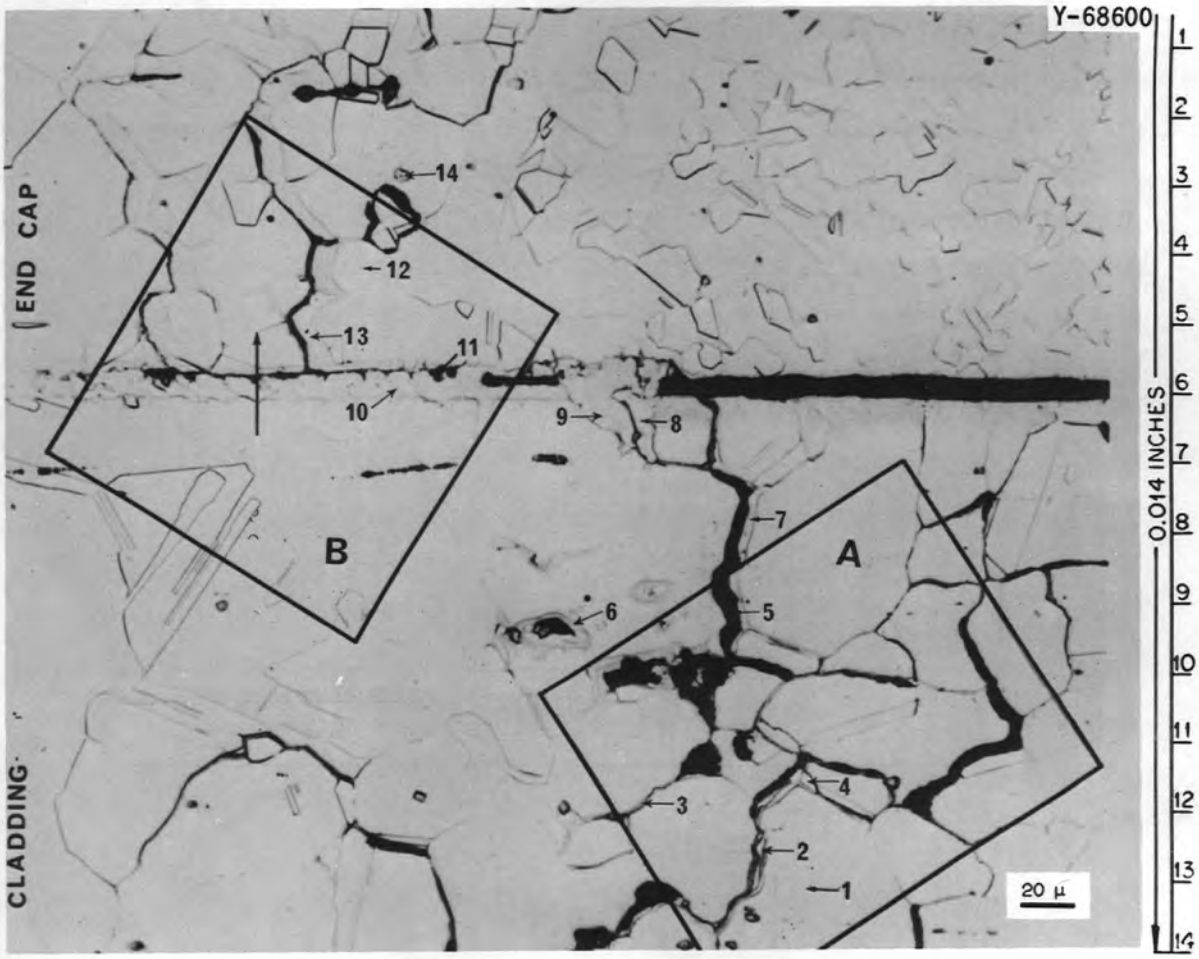


Fig. E-1. Defective Region in Fuel Rod 0-28 Analyzed with the Aid of the Electron Microprobe. Etchant: copper regia. 400×. Original reduced 10%.

Table E-2. Concentration of Elements (Semiquantitative)

Analyzed Area	Aluminum	Silicon	Sulfur	Phosphorus	Potassium	Niobium
1	<0.1	<0.1	<0.1	<0.1	0	0.4
2	<0.1	<0.1	<0.1	3.1	0	1.4
3	<0.1	<0.1	<0.1	0.7	0	(a)
4	<0.1	<0.1	<0.1	1.4	0	(a)
5	4.0	<0.1	<0.1	0.4	0	(a)
6	<0.1	<0.1	<0.1	5.2	0	3.7
7	<0.1	<0.1	<0.1	0.5	0	(a)
8	<0.1	<0.1	<0.1	1.3	0	0.6
9	<0.1	<0.1	<0.1	0.7	0	0.8
10	<0.1	<0.1	<0.1	0.4	0	1.8
11	<0.1	<0.1	<0.1	2.3	0	(a)
12	<0.1	<0.1	<0.1	<0.1	0	1.8
13	<0.1	<0.1	<0.1	0.4–3.3	0	(a)
14	<0.1	<0.1	<0.1	<0.1	0	13.5

[a]Not investigated.

rates of a pure standard. Where a pure element standard was not available, as in the case of phosphorus (where InP was used), the count rate of x rays generated in the sample was divided by the known concentration of the element in the standard. The values should include corrections for background and for instrument drift. Under these conditions the values shown are only semiquantitative.

In addition to the elements shown in Table E-2, concentration checks were also made for the major elements, nickel, chromium, and iron. No significant changes in concentrations were detected. The concentrations of aluminum, silicon, and sulfur were less than 0.1%, with the exception of high concentration of aluminum in area 5. This area is actually a crack and the presence of aluminum was attributed to aluminum oxide particles associated with the metallographic preparation of the specimen. Concentration of potassium was below the limit of detectability of the microprobe.

Phosphorus was distributed heterogeneously, as shown in Table E-2. The concentration in some areas was difficult to establish because of large concentration gradients; therefore, the data in Table E-2 show only average concentration. We will show later that the concentration of phosphorus in some areas is higher than indicated in Table E-2.

The distribution of phosphorus is shown in Fig. E-2. Figure E-2a and b are oscilloscope photographs of the area A in Fig. E-1. Figure E-2c and d represent area B in Fig. E-1. In the specimen current presentation the contrast varies with average atomic number. The dark areas were

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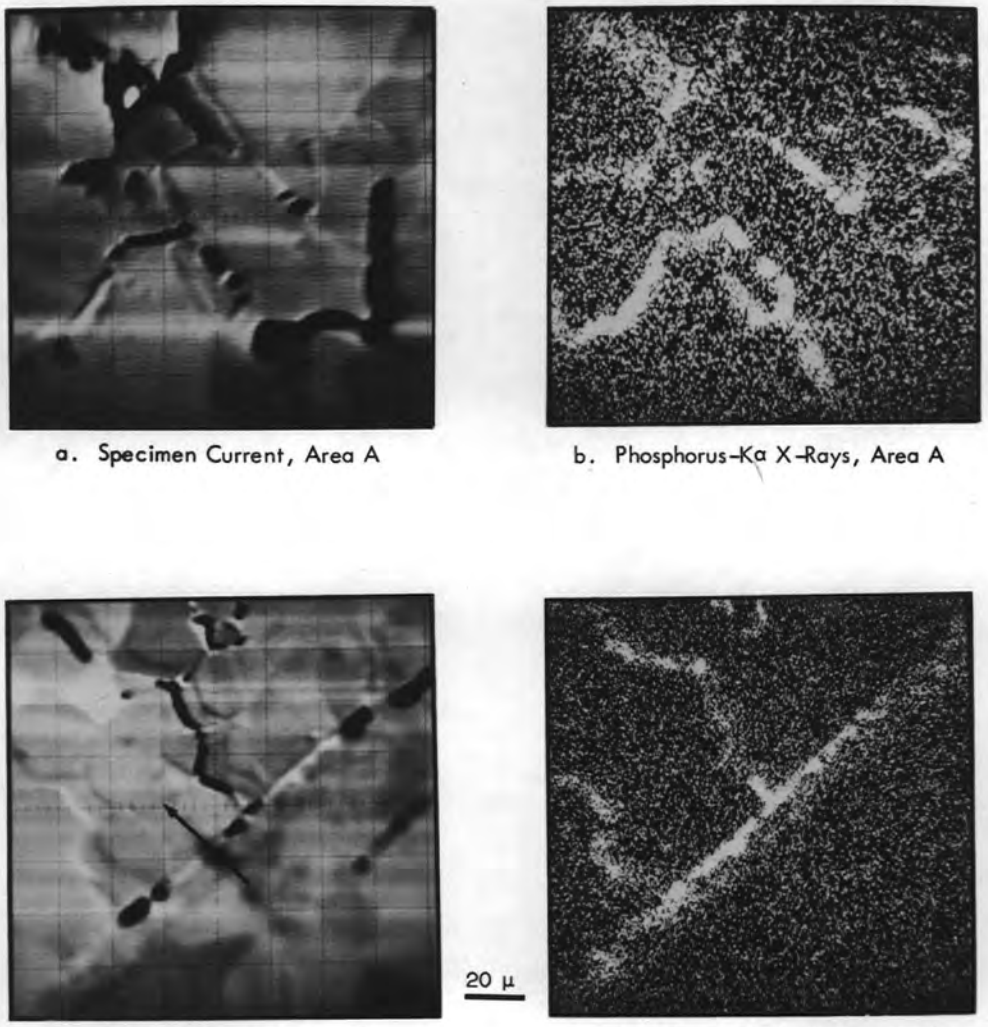

a. Specimen Current, Area A

b. Phosphorus-Kα X-Rays, Area A

c. Specimen Current, Area B

d. Phosphorus-Kα X-Rays, Area B

Fig. E-2. Oscillographic Photographs of Areas A and B shown in Fig. E-1.

cracks and voids. The bright areas on the photograph represent areas on the specimen with average atomic numbers lower than the surrounding matrix. The heterogeneous distribution of phosphorus is evident from Fig. 2b and d.

In addition to point-count analysis using a static beam and x-ray mapping method, using a beam sweep to form a rectangle, phosphorus concentration was also determined by using a static beam and moving the sample in a stepwise motion across the cladding–end-cap interface. The concentration profile was obtained in the area and direction indicated by a long arrow in area B in Fig. E-1. The same area is also depicted in Fig. E-2. The results are tabulated in Table E-3 and plotted in Fig. E-3.

Table E-3. Concentration of Phosphorus Across Cladding–End Cap Interface

Distance (μ)	Concentration (wt %)	Distance (μ)	Concentration (wt %)
0	0.03	38	1.13
5	0.03	39	2.41
10	0.03	40	4.42
15	0.03	41	5.76
20	0.02	42	8.33
25	0.03	43	8.59
28	0.05	44	6.50
30	0.10	45	1.94
32	0.24	46	0.14
33	0.28	48	0.05
34	0.27	50	0.04
35	0.27	55	0.04
36	0.32	60	0.03
37	0.45	70	0.04
		80	0.03

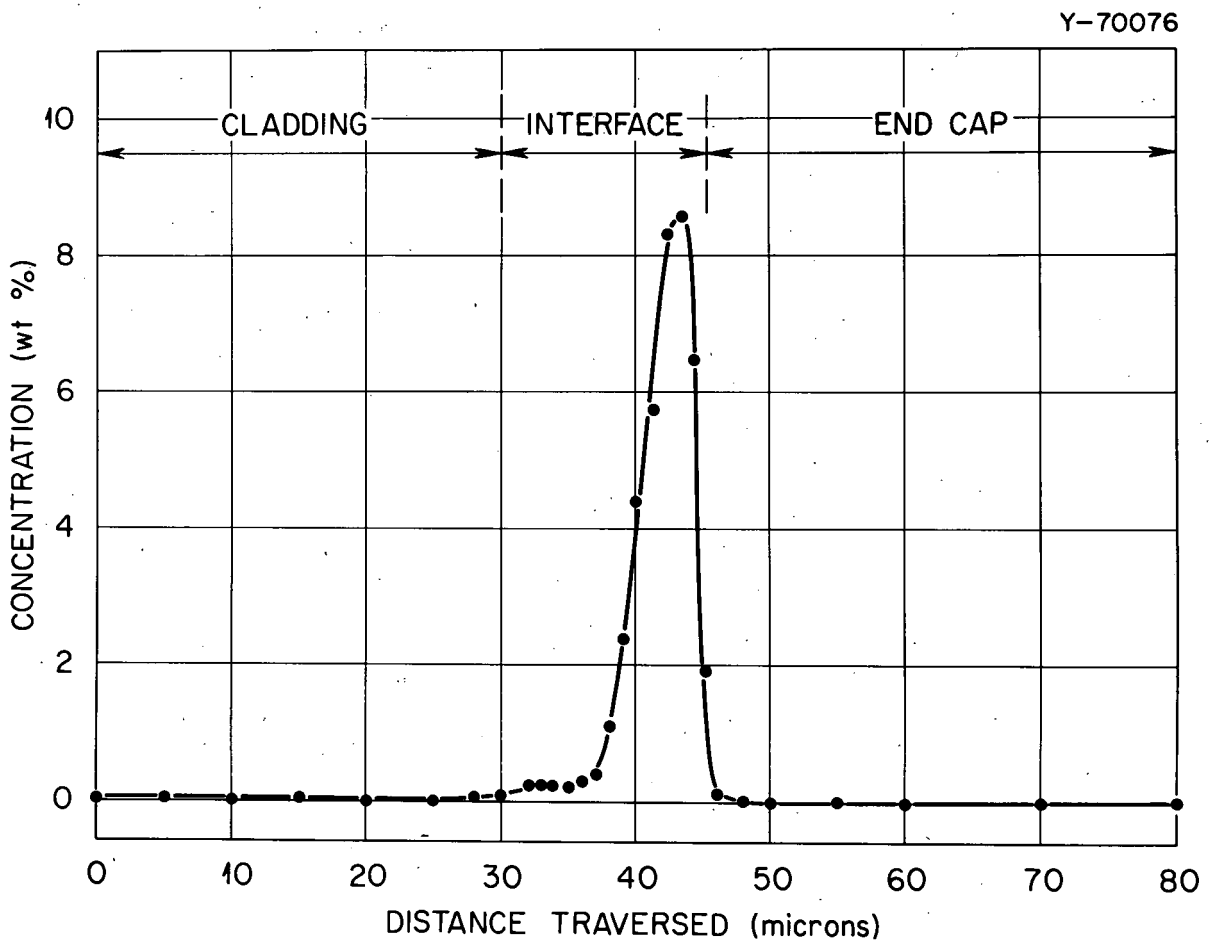

Fig. E-3. Phosphorus Concentration Profile Across Cladding–End Cap Interface.

It is evident from Fig. E-3 and Table E-3 that the concentration of phosphorus in the interface material (area 10 of Fig. E-1) was approximately 10 times as high as that of the matrix. Furthermore, the concentration of phosphorus increased approximately three hundredfold in areas such as area 11 in Fig. E-1; this area appeared as a crack. Closer metallographic examination, however, showed it to consist of a string of cracks and a glassy, slag-like phase. The makeup of this string of cracks and slag-like phase was clearly evident from the specimen current image, Fig. E-2. The high concentration of phosphorus decreases sharply at the interface of the slag-like phase and the end-cap material.

The same weld, but 180° from the defective region, was subjected to a microprobe analysis; this region showed no evidence of intergranular

cracking in either the cladding or end-cap material. The cladding—end-cap interface material of this region was compared to that in the defective region of the fuel rod for phosphorus concentration. The average phosphorus concentration was 0.3% in the defective region and 0.03% in the opposite side of the fuel rod. Heterogeneous distribution of phosphorus was noted in both regions analyzed. Chemical analysis, by conventional techniques, showed that the cladding and end-cap material contained 50 and 40 ppm P, respectively.

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