Report No. ACNP-63023

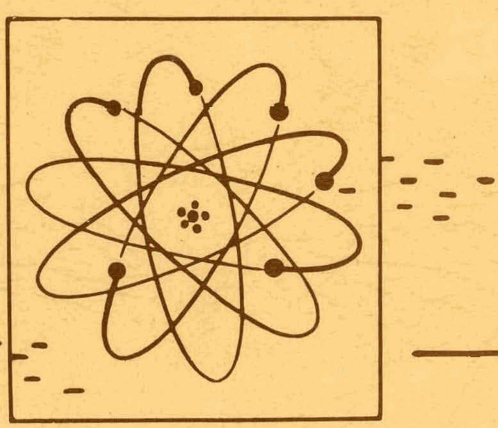
PATHFINDER ATOMIC POWER PLANT

END CLOSURE DEVELOPMENT FOR LOW ENRICHMENT SUPERHEATER FUEL RODS

U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY
and
CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY
ATOMIC ENERGY DIVISION
Milwaukee 1, Wisconsin



Ref: AEC Contract No. AT(11-1)-589

DISCLAIMER

ACNP-63023

PATHFINDER ATOMIC POWER PLANT

END CLOSURE DEVELOPMENT FOR LOW ENRICHMENT SUPERHEATER FUEL RODS

By R. A. Boschke and R. J. Wiggins

Submitted to

U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY
and
CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY

Under
Agreement dated 2nd Day of May 1957, as Amended
between
Allis-Chalmers Mfg. Co. & Northern States Power Co.
under
AEC Contract No. AT(11-1)-589

July 30, 1963

Classification – UNCLASSIFIED

Reviewed by [signature]
Authorized Classifying Official

Facsimile Price $ 4.60
Microfilm Price $ 1.49
Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

Approved: [signature]
C. B. Graham
Manager
Nuclear Power Dept.-Greendale

Approved: [signature]
Hibbert Hill
Vice President-Engineering

ALLIS-CHALMERS MANUFACTURING COMPANY
ATOMIC ENERGY DIVISION
MILWAUKEE 1, WISCONSIN

NORTHERN STATES POWER COMPANY
15 SOUTH FIFTH STREET
MINNEAPOLIS 2, MINNESOTA

PATHFINDER ATOMIC POWER PLANT

END CLOSURE DEVELOPMENT FOR LOW ENRICHMENT SUPERHEATER FUEL RODS

DISTRIBUTION

USAEC, Chicago operations Office -- 9800 South Cass Avenue, Argonne, Illinois.	5
USAEC, Division of Reactor Development -- Washington 25, D.C..	8
USAEC, OTIE -- Oak Ridge, Tennessee ... OFFSET MASTER PLUS.	20
Northern States Power Company and CUAPA.	26
Allis-Chalmers Manufacturing Company	39
Total	98

FOREWORD

One of a series of reports on research and development in connection with the design of the Pathfinder Atomic Power Plant, this particular report deals with the welding process developed for the end closure of low enrichment superheater fuel rods. The Pathfinder plant will be located at a site near Sioux Falls, South Dakota, and is scheduled for operation in 1963. Owners and operators of the plant will be the Northern States Power Company of Minneapolis, Minnesota. Allis-Chalmers is performing the research, development, and design as well as being responsible for plant construction.

The U.S. Atomic Energy Commission, through Contract No. AT(11-1)-589 with Northern States Power Company, and Central Utilities Atomic Power Associates (CUAPA) are sponsors of the research and development program. The plant's reactor will be of the Controlled Recirculation Boiling Reactor type with Nuclear Superheater.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - Con't

1.0 INTRODUCTION

A research and development program was initiated to develop a low enrichment fuel element for the Pathfinder integral nuclear Superheater. The design includes the use of ceramic UO_2 fuel containing 3.5 w/o U235 which is clad with thin walled stainless steel tubes. The fuel assemblies consist of seven fuel rods with a 1/4 in. diam. and a length of 6 ft arranged in a circular bundle of approximately 1 in. diam. (Fig. 1). The development program covers three major areas:

1. Rod fabrication
2. End closures
3. Assembly attachments.

2.0 OBJECTIVE

The object of this report is to describe work that was accomplished to develop methods for consistently producing high integrity fuel-rod-end closures that meet the severe environmental and stress conditions imposed by a nuclear superheater.

3.0 CONCLUSION

The conclusions arrived at in this report provide a clearer understanding of many fundamental welding principles as applied to components which combine relatively large and small masses at the weld joint. The following general conclusions can be drawn from this study:

1. Design is one of the major considerations for welding components which have large mass differences. Proper attention to heat balance of components at the design stage can mean the difference

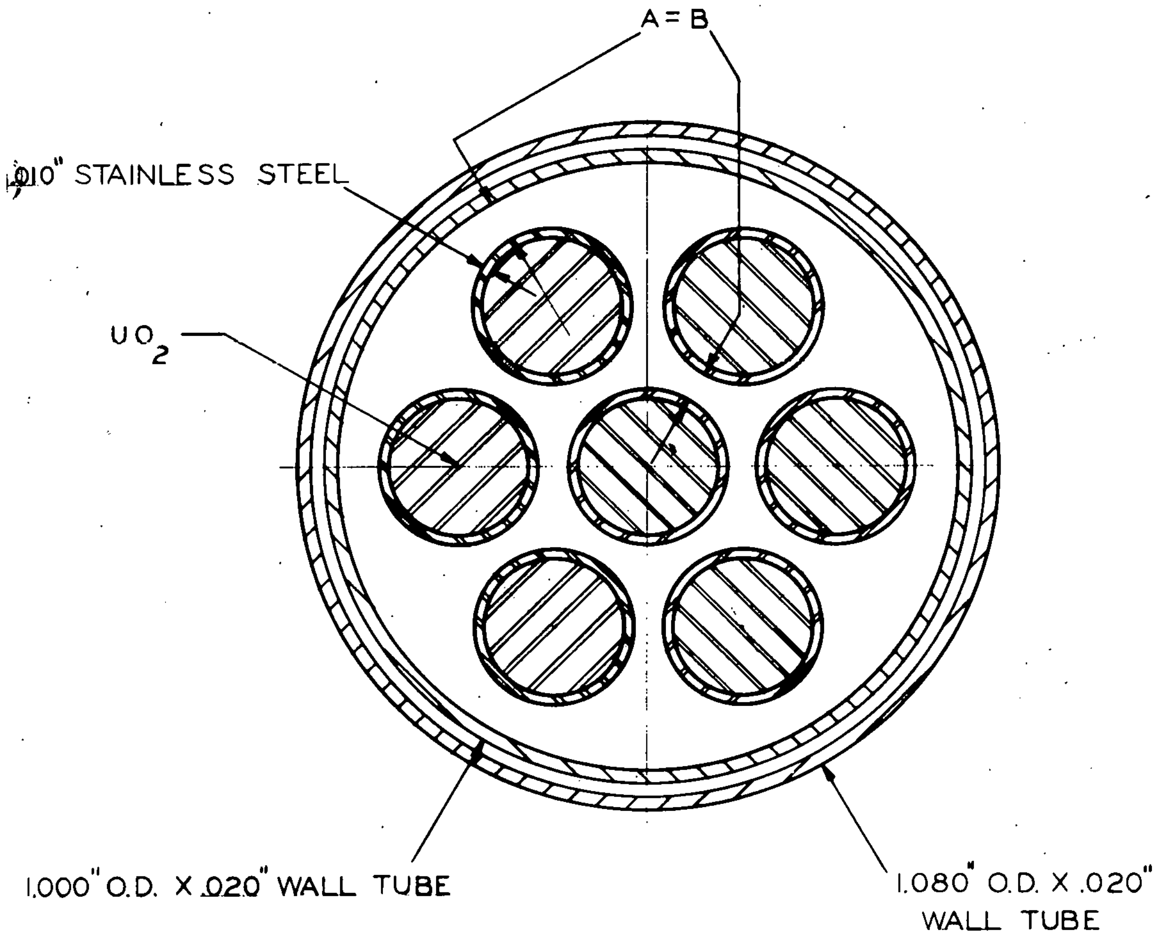


Fig. I... Low Enrichment Superheater Fuel (43-024-085) between a process which is hypercritical to parameter variation and one which provides a practical latitude for production application.

2. Weld puddle geometry and weld microstructure can be greatly improved with the proper use of chills on the fuel tube. An integral chill which rotates with the tube during welding is the most effective.

3. Entrapped air or gas between the end plug and fuel can cause serious weld defects if heat buildup becomes great during welding. This can be minimized by venting, increasing weld speed or reducing the welding mass by end cap design. The most satisfactory method was found to be a combination of speed and design.

4. Preheat and decay cycles change outer appearances, but do not significantly affect weld penetration in the range studied (0.5 to 1.5 rev.) in the case of this material and this geometry.

5. Satisfactory welds can be made on Pathfinder-type fuel rods by using straight plug caps with vent holes, reduced shoulder caps or cup caps. The plug caps, however, are the most sensitive to welding parameters.

6. Both the reduced shoulder and the cup-cap end closures are relatively insensitive to process variations. From a design standpoint the reduced shoulder cap is most desirable for Pathfinder.

All possible variations of end closure welding were not tried.

4.0 EQUIPMENT

The basic power source selected for use consisted of an ac-dc welder with a special low power tap for amperage (as low as 2 amp.). A motor-driven variable rheostat was provided for controlling preheat and decay cycles.

A glass lathe was adapted to turn the fuel rod during the welding operation. A welding chamber and mounting for a conventional welding torch were installed on the lathe in the appropriate position. The welding chamber permitted atmospheric control of the weld. Instruments for recording weld amperage and voltage were provided (Fig. 2 and 2A).

Preliminary experiments with the setup showed that a more versatile welding torch was necessary to provide remote operation and accurate electrode positioning. Since no equipment of this type was available commercially, a special torch was designed and built. This unit (Fig. 3) permitted accurate adjustment of the arc gap by using a split-collar adjusting screw and it also allowed replacement of electrodes from outside the welding chamber without removing the torch. The torch provided excellent control and reproducibility of arc gap plus torch angle, and was used for all subsequent experiments in the welding program.

5.0 PRELIMINARY EXPERIMENTS

A qualitative type experiment to determine performance of the welding equipment and to obtain a feel for welding behavior of Pathfinder

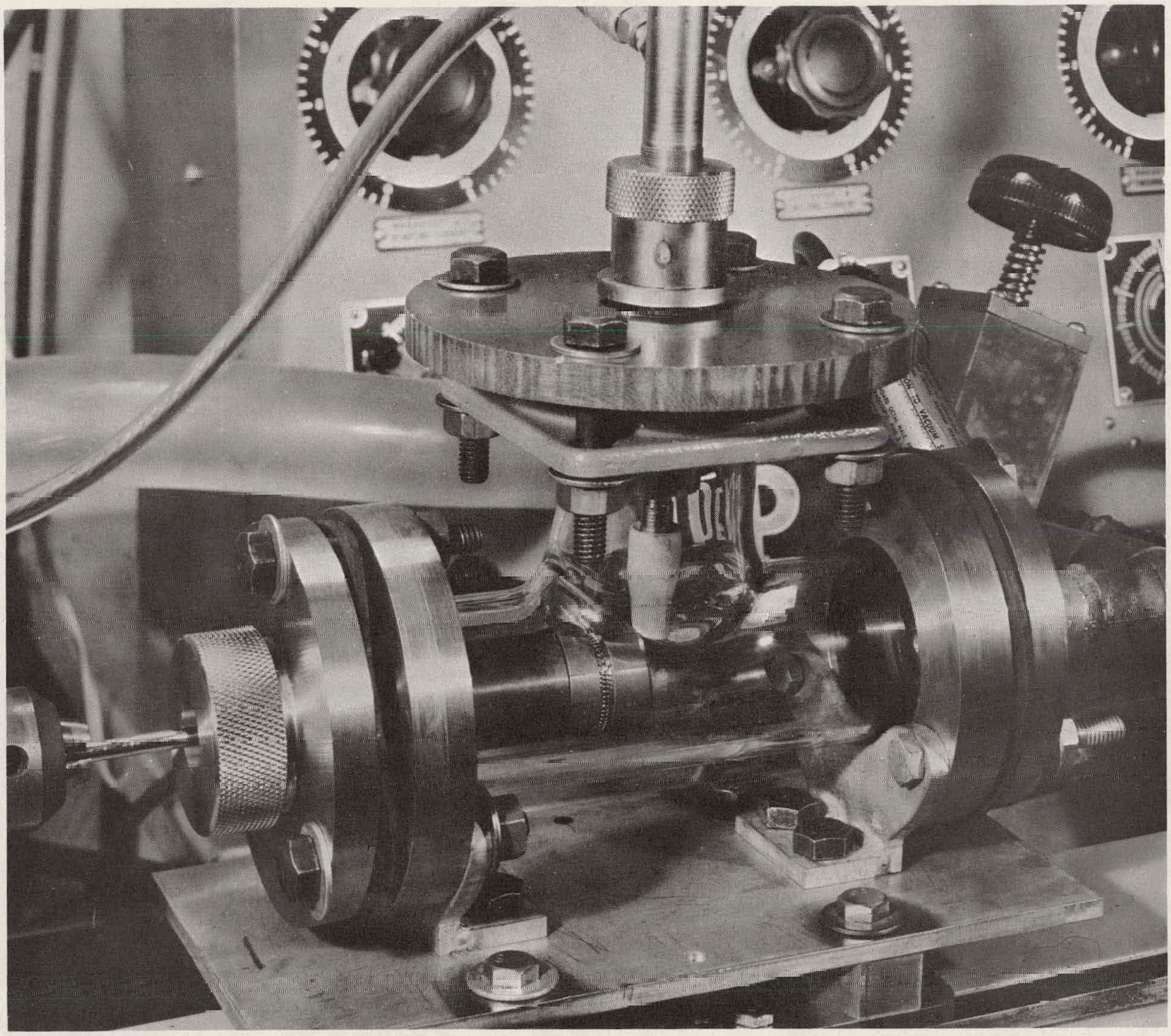


Fig. 2... Inert Gas Welding Torch and Chamber

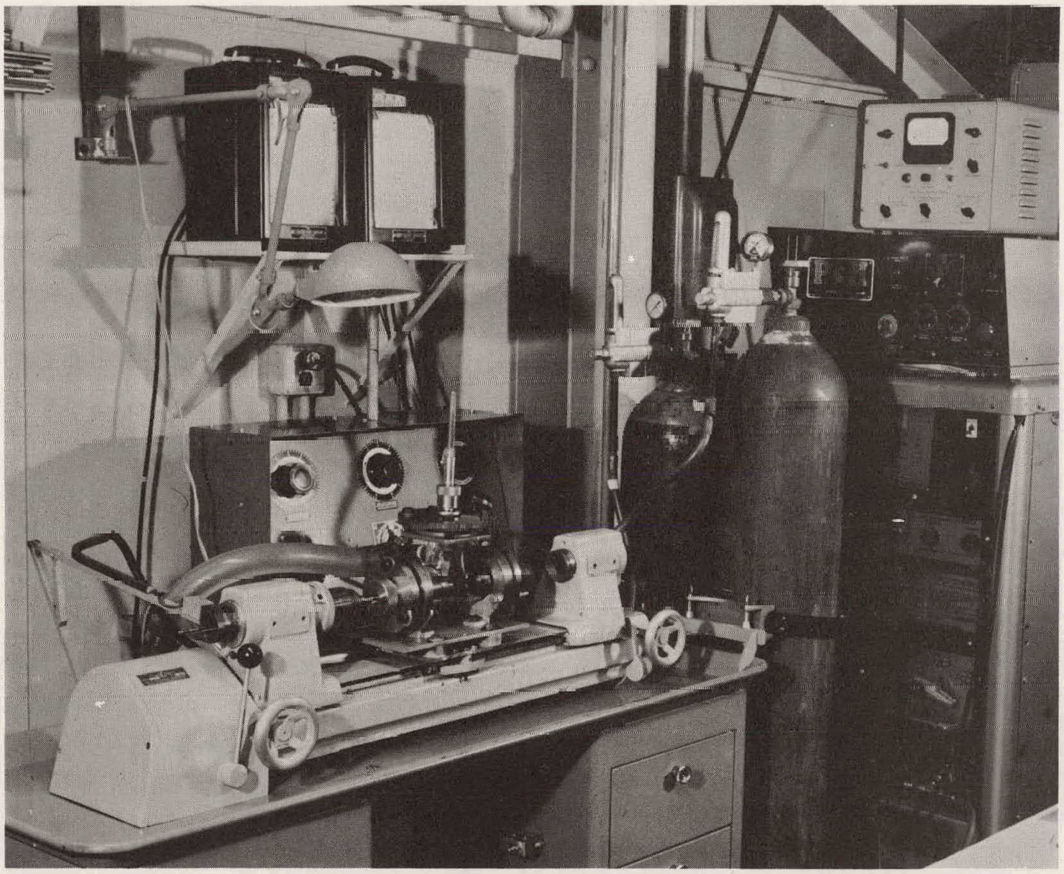


Fig. 2A... End Cap Welding Equipment for
Pathfinder Development

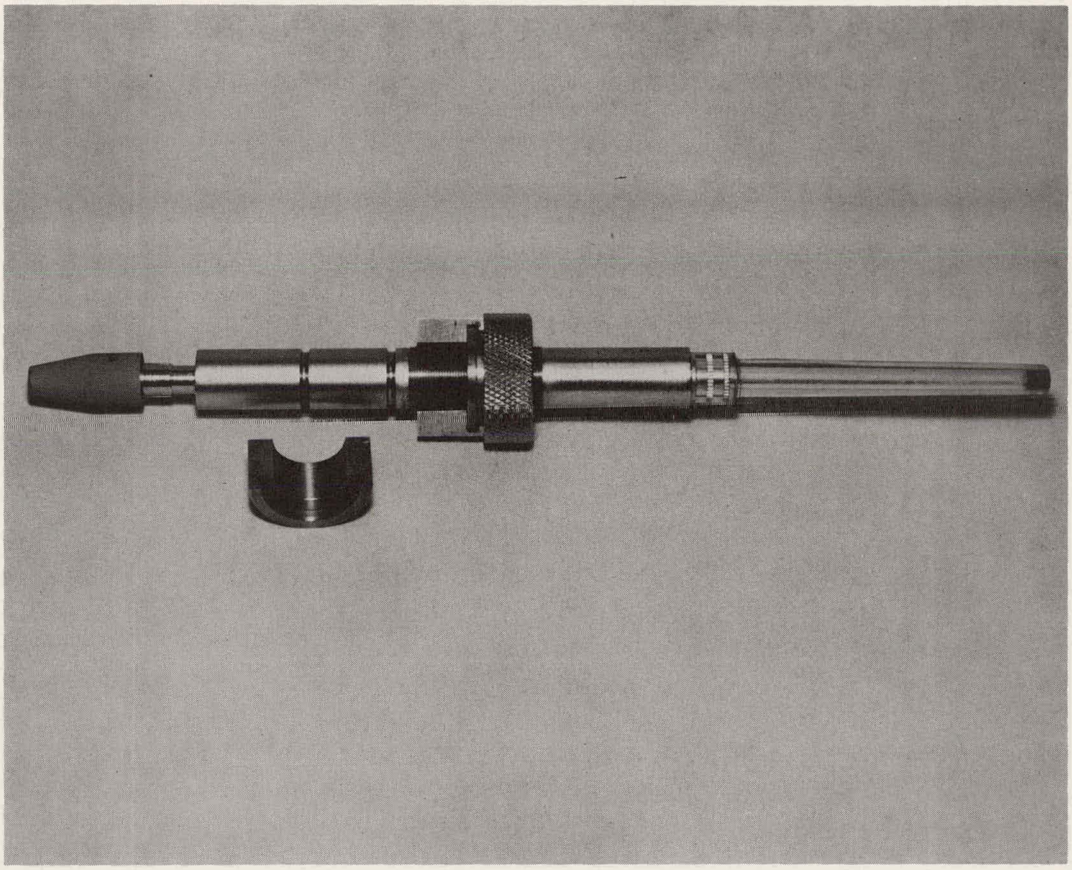


Fig. 3... Special Allis-Chalmers Design Welding Torch for Remote Welding

fuel rods was conducted. A series of welds was made using 0.010 in. wall 0.220 in. OD Type 316 Stainless Steel tubes with a straight-plug type end cap (Fig. 4). Welds were made at 7 in/min using a 12 amp current for 1-1/4 revolutions. The resulting samples were qualitatively evaluated for reproducibility, joint integrity and weld penetration.

Equipment performance was satisfactory but end cap weld quality was erratic. Some welds were externally satisfactory while others, welded under the same conditions, had severe peel-back defects (Fig. 5). Metallographic examination of welds that appeared sound externally were of minimum quality (Fig. 6).

Results from this series of welds indicated that the substantial difference in mass between the stainless steel cladding tube and the end cap produced a heat balance which made the weld very sensitive to the major variables (Table I). Since all of the apparently sound welds were of minimal quality it was indicated that a comprehensive study of primary welding variables and their interaction was required.

6.0 MAJOR WELD VARIABLES

The major variables that significantly affected physical and metallurgical weld quality in Pathfinder fuel rod end closures were reviewed. Constants based on accumulated data and design requirements were established wherever possible. Factorial and sequential type experiments were then set up and performed for evaluation of each of the remaining major variables. A summary of the variables considered and the applicable constants is presented in Table I.

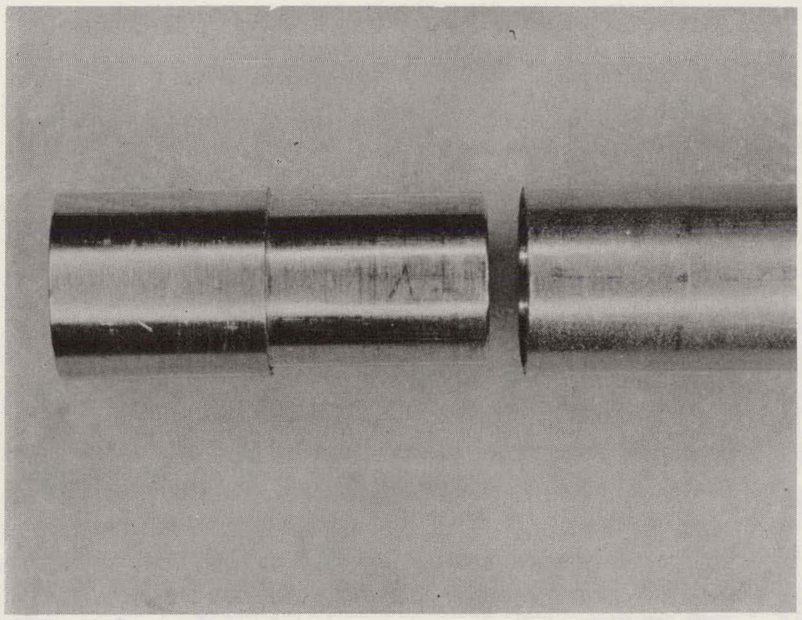


Fig. 4... Typcial Plug Type End Cap and Tube
(Tube .220 OD - .200 ID)

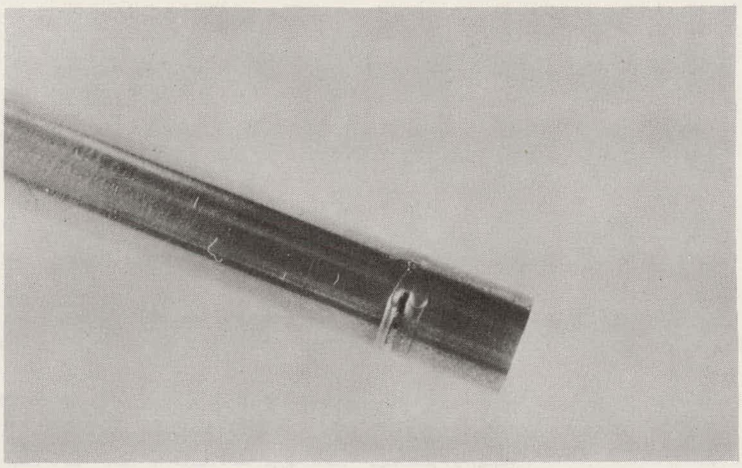


Fig. 5... Peel Back Type Defect on Thin Wall Plug Type Weld

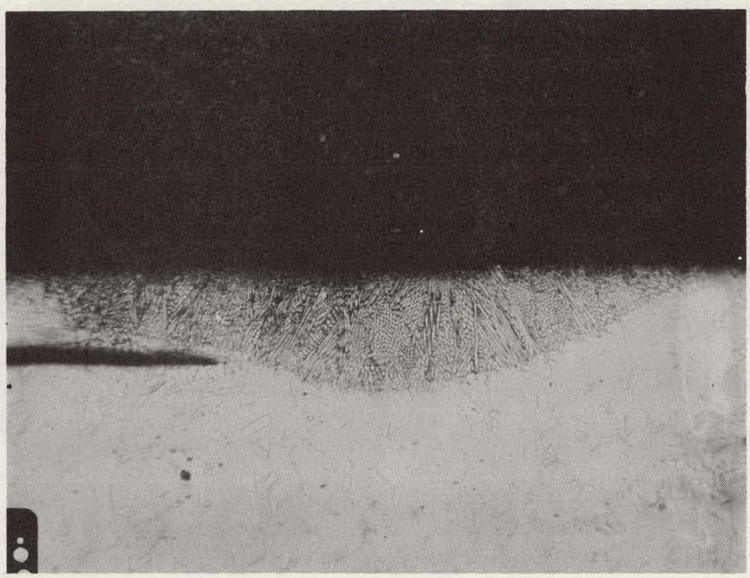


Fig. 6... Satisfactory External Appearance

TABLE I

SUMMARY OF WELDING VARIABLES
FOR PATHFINDER END CLOSURES

MAJOR VARIABLES	OPTIMUM LEVELS
Material	316 S.S. established by design
Weld Torch Angle	12 O'Clock
Weld Atmosphere	Argon
Power Supply	D-C straight Polarity
Welding Electrode	2 w/o Thoriated Tungsten 0.040 in.
Arc Gap	0.032 in.
Voltage	Function of Amperage
Arc Location Axial	Variable
Preheat & Decay	Variable
Weld Speed	Variable
Amperage	Variable
End Cap Design	Variable
Weld Travel	Variable

6.1 Factorial I- Amperage, Weld Travel, Preheat-Decay

Observations made during the exploratory phase of this program indicated that erratic weld quality could be corrected by a more prudent selection of weld parameters. Amperage to increase penetration, weld travel to assure complete perimeter fusion, and preheat-decay cycle to minimize thermal gradient, were selected for the initial study. A factorial type experiment was design to permit study of three levels of amperage, two levels of weld time and three levels of preheat-decay cycle. Details of the experimental design are shown in Table II.

TABLE II

EXPERIMENTAL DESIGN WITH FACTORIAL
STUDY OF AMPERAGE, WELD TIME, PREHEAT-DECAY

AMPERAGE (amp.)	WELD TRAVEL (rev.)	PREHEAT-DECAY CYCLE (rev.)
A_1 12	T_1 1.25	C_1 0.5
A_2 14	T_2 2.25	C_2 0.1
A_3 16		C_3 1.5

A complete run of this experiment required the welding of 18 samples. In order to provide a cross check between samples, a double run was performed (36 samples). The remaining major variables which were held constant, were as follows:

Arc location - 0.040 in. from joint

Weld Speed - 7 in/min.

End Cap Design - Straight plug

The samples were carefully cleaned using the Allis-Chalmers Nuclear Power Department cleaning procedure for stainless steel. Parts were handled with white gloves and assembled with a press fit to provide minimum parts clearance. Welds were made in the glass chamber using 10 CFH argon flow.

Evaluation consisted of visual examination for external appearance and destructive evaluation for weld penetration, weld microstructure, and weld integrity. The resulting data was analyzed statistically using the analysis of variance technique to determine which variable affected the weld most significantly. Results of the evaluation are summarized as follows:

1. Weld penetration was not significantly affected by the preheat and decay cycles in the range studied. Based on external appearance and performance during the weld cycle, a short preheat 0.5 rev. (4 sec) followed by a long decay 1.5 rev (12 sec) is the optimum for this geometry. A photo showing external appearances of a typical weld is shown in Figure 7.
2. Amperage, as expected, had a significant effect on penetration. The optimum current for this study was 14 amp (Figure 8).
3. Weld travel had a significant effect on penetration. The average depth of penetration was greater for the two-pass weld than for the one-pass weld under the same conditions. A significant increase in weld penetration variability was observed on the two-pass weld. This could prove to be a serious problem in control if multiple-pass welds were used.

From this experiment, it was possible to establish optimum parameters for several of the variables shown in Table I. Optimum preheat and decay cycles were set at 0.5 and 1.5 rev., respectively and weld travel was established at 1.25 rev. The arc location of 0.040 in. from the joint, which had been arbitrarily selected, was satisfactory for the plug-type cap. Amperage was related to variables that required further study.

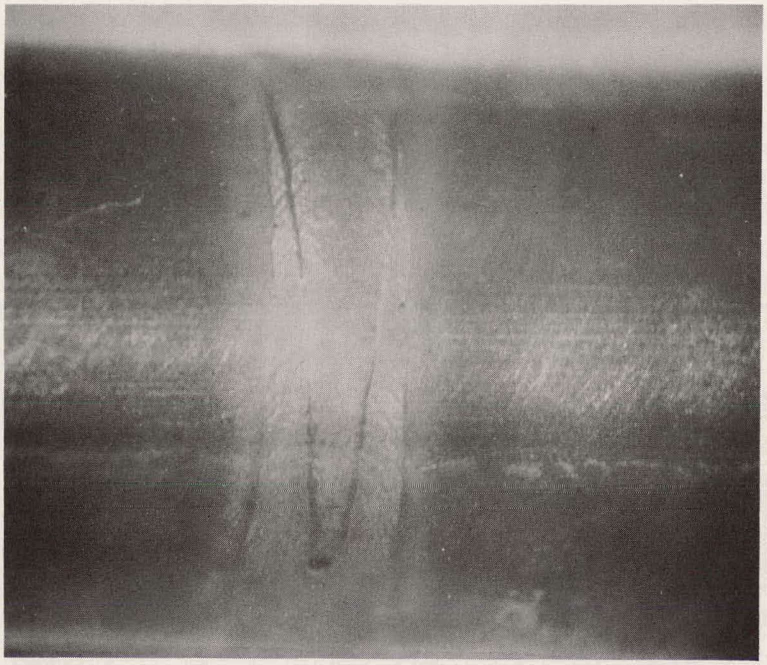


Fig. 7... External Appearance of Weld Made with Optimum Preheat-Decay. Note Smooth Runout.

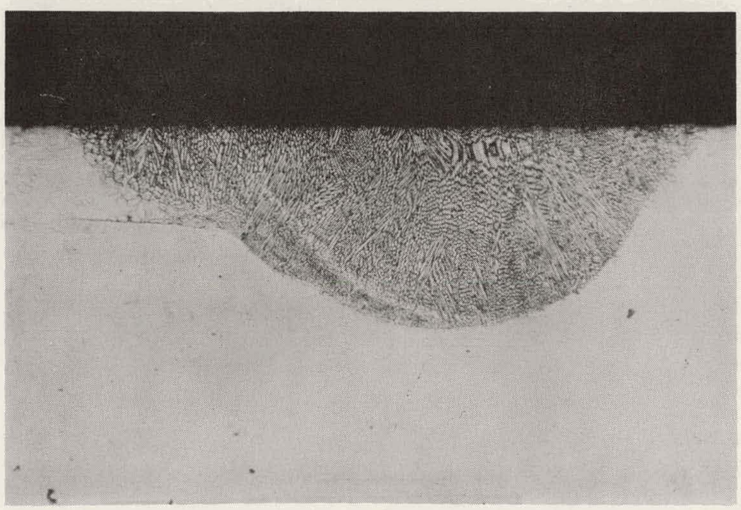


Fig. 8... Microstructure of Weld Made at 7 in/min, 14 amp.

6.2 Factorial 2 - Amperage and Weld Speed

During the previous study, a significant heat buildup occurred in the end plug during all welding operations. This was particularly true as the amperage was increased to improve penetration. Since end closure welding would eventually be performed on fuel rods in which expandable gas is trapped between the fuel and the end cap, heat buildup may cause excessive pressure during the weld cycle. To reduce heat buildup without reducing amperage, it is necessary to reduce weld time as much as possible, consistent with sound weld quality. A factorial experiment was performed to study the interaction of weld speed and amperage and their effect on weld quality. Hence, five levels of amperage and three speeds were studied. Details are given in Table III.

TABLE III

EXPERIMENTAL DESIGN WITH FACTORIAL STUDY OF AMPERAGE AND SPEED

AMPERAGE	SPEED (in/min)
A_1 14	S_1 10.5
A_2 16	S_2 14
A_3 18	S_3 17.5
A_4 23	
A_5 27	

Fifteen samples, including all combinations of the two variables, were prepared and welded. Other weld parameters were the same as the previous run. A summary of the parameters is as follows:

1. Arc gap - 0.040 in from joint
2. End cap design - straight plug type
3. Preheat cycle - 0.5 rev.
4. Decay cycle - 1.5 rev.
5. Weld time - 1.25 rev.

External weld quality was consistently sound. Destructive evaluation showed that weld penetration ranged from under-penetration, which occurred at 14 in/min and 18 amp (Fig. 9), to over-penetration, which occurred at 10.5 in/min and 27 amp (Fig. 10).

A complete evaluation of the data from this run showed that a straight line relationship existed between weld speed and amperage for a constant penetration. Since a weld penetration of 0.015 in. was optimum for the geometry under study, a curve was constructed to isolate the speed and amperage combinations which were best suited for the Pathfinder fuel rods (Figure 11). A study of the welds made, using the combinations established by the curve, showed that the most consistent welds were made at 14 in/min using 23 amp. Above and below this point the weld area overheated or tended to be dimensionally unstable.

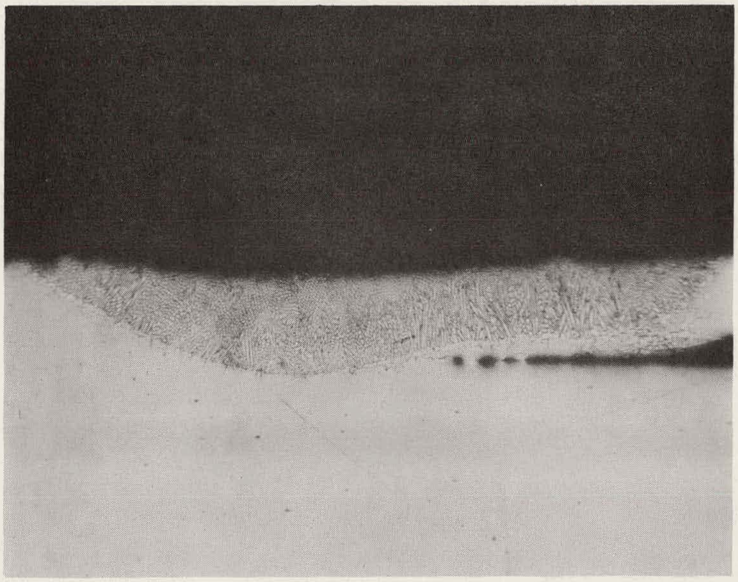


Fig. 9... Microstructure of Weld Made at 14 in/min, 18 amp.

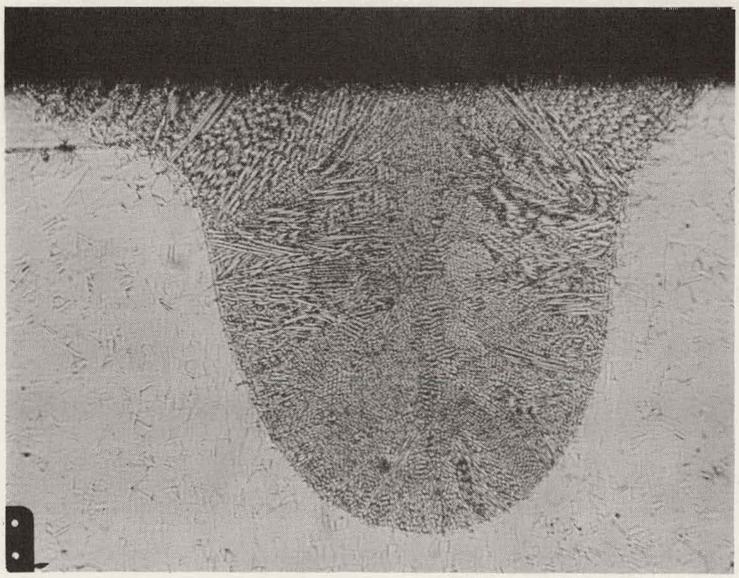


Fig. 10... Microstructure of Weld Made at 10.5 in/min, 27 amp.

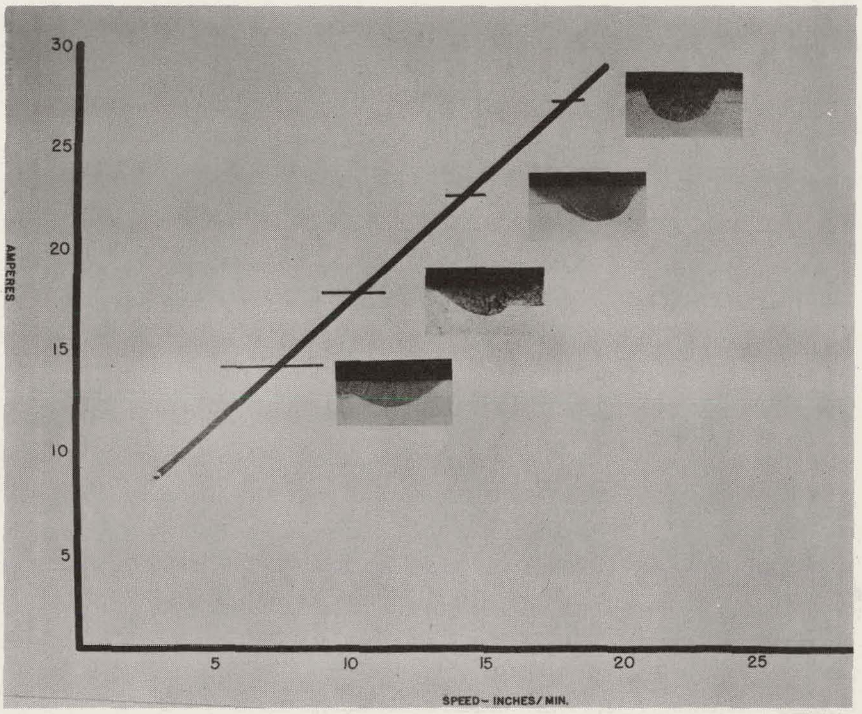


Fig. 11... Relationship of Speed and Amperage at .015 in. Approximate Penetration

Results of this experiment indicated the following:

1. A direct relationship exists between weld speed and amperage for a given penetration.
2. The optimum combination for Pathfinder geometry using straight plug caps is 14 in/min at 23 amp.
3. Improper selection of weld speed and amperage can result in under-penetrated welds, poor weld quality and erratic penetration.

4. Higher weld speeds are beneficial to a point. When speeds become too high, control or welding conditions with the end cap used became very erratic. This resulted in poor weld quality.

7.0 END CAP DESIGN

The previous experimentation produced a set of welding parameters which were suitable for welding straight plug-type end caps on thin walled tubing. When these parameters were carefully controlled, the welds were sound and met the general quality requirements for reactor service.

The program indicated, however, that weld quality was very sensitive to variations in welding parameters. The welds were especially sensitive to variation in arc location, arc gap, cleanliness, and end plug fit. This sensitivity was attributed to the large difference in the mass of the end plug and tube and the need for critical control of the heat distribution in the joint during welding. Use of an alternate end plug design, which would reduce the mass difference, appeared to be a feasible means of obtaining a less sensitive welding process.

Therefore, studies on two modified end cap designs were made. Both of the designs (Figure 12) effectively reduced the end cap mass in the weld joint area and improved heat balance.

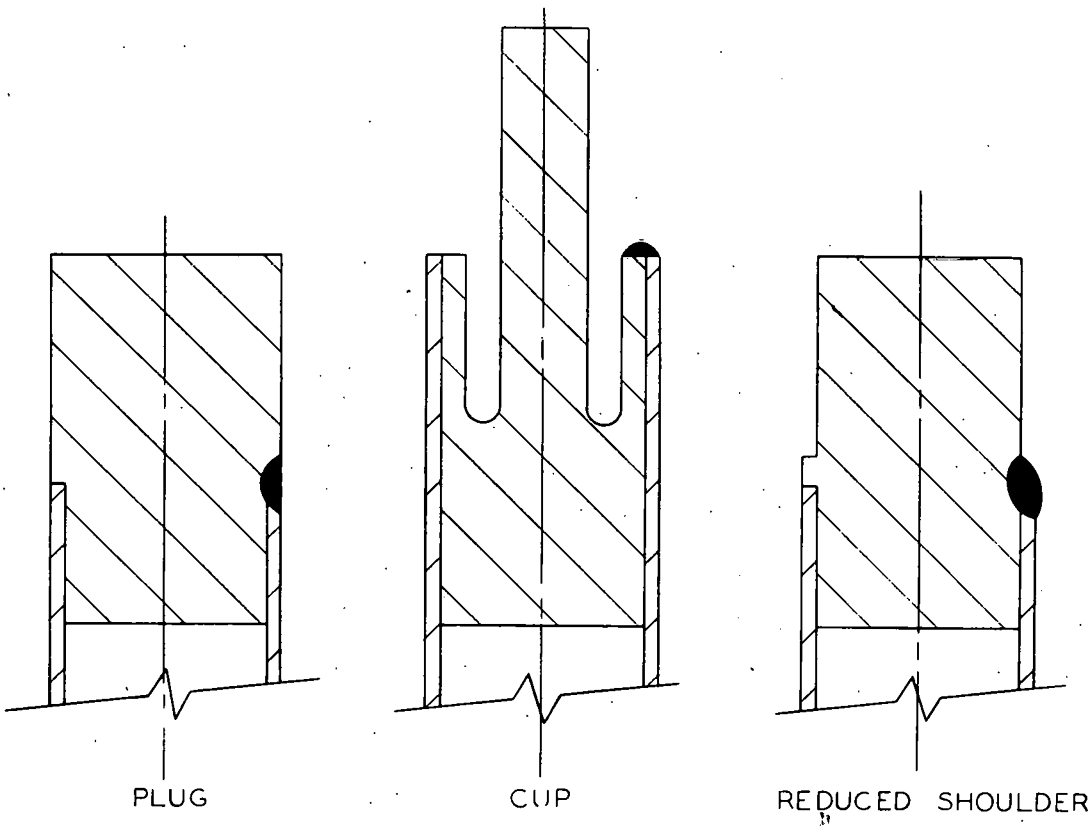


Fig. 12... Schematic of Modified End Caps with Improved Heat Balance

7.1 Cup Cap

The cup cap design is one which has been extensively used in industry. It can be designed so that the masses are relatively equal in the weld area. The design selected for this study utilized a wall thickness on the cap of approximately twice the tube-wall thickness. In addition, a central stub was provided to permit subsequent attachment of the fuel rod to a coolant flow director.

A series of welds was made using amperages ranging from 6 to 9 amp. All other parameters were the same as those used in previous studies. The samples were evaluated for welding characteristics, puddle geometry and weld penetration. In addition, burst tests were performed to determine relative weld strength. Results of this investigation are summarized as follows:

1. The improvement in heat balance significantly reduced sensitivity to weld variables. Arc gap, arc locations, and cleanliness could be varied within reasonable limits without affecting weld quality.
2. Optimum amperage was found to be 7 to 8 amp. Higher amperage resulted in beading and puddle distortion. Lower amperage produced insufficient or erratic penetration (Fig. 13).
3. Burst tests, even on low amperage welds, showed consistent failure in the tube wall, indicating that weld strength is adequate with the cup-type design (Fig. 14).

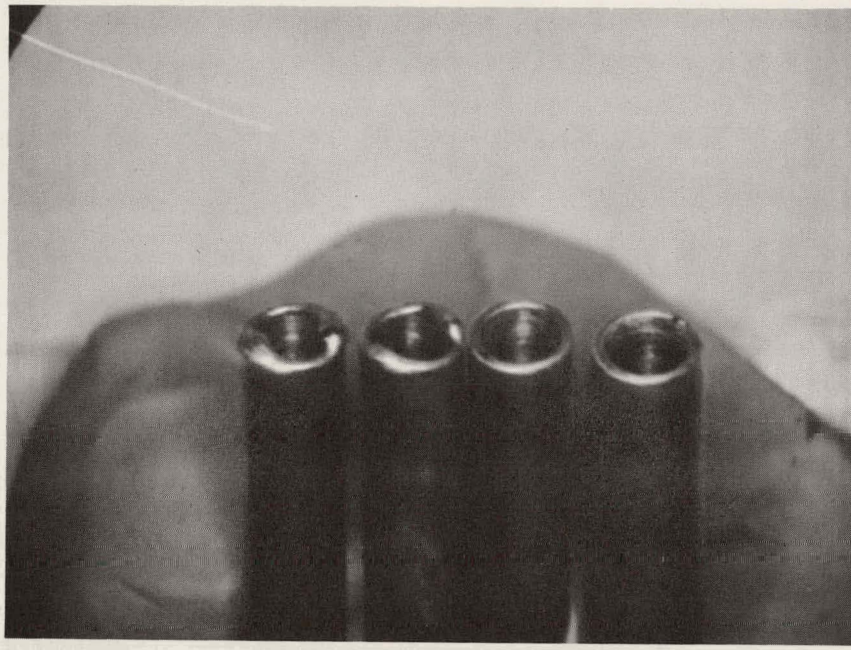


Fig. 13... Cup Type End Cap Welds... Left to Right:
9 amp, 8 amp, 7 amp, 6 amp. Stubs
Were Deleted to Simplify Machining

Fig. 14... Burst Test on 7 amp Welded Cup Cap

4. Weld penetration at 7 amp was at least the wall thickness of the tube. Microstructure was good but a slight unbalance of penetration was observed.

The preliminary welding experiments with the cup cap were performed using end caps without integral stubs. The success of the experiment prompted a weld series which utilized stubs on the end caps. Primary objectives of the work were to determine whether the stub would interfere with the welding electrode during welding and the optimum weld amperage for the increased cap mass.

A series of welds was made using the trepan cup cap with integral stub. The torch electrode was brought in at a 30 degree angle to clear the stub. Welding current ranged from 8 to 11 amp. The remaining parameters were held constant.

Results from this experiment showed the same insensitivity to weld parameters as previously noted. All welds were sound regardless of treatment; however, optimum weld penetration occurred at 9 amp. No interference with the welding electrode was encountered and the angled torch did not adversely affect the weld geometry. Typical welds are shown in Fig. 15 and 16.

7.2 Reduced Shoulder Cap

A reduced shoulder cap design which also limited the end cap mass at the joint, was studied. The design initially selected was a shoulder on the end cap, approximately 1/16 in. width. The remaining

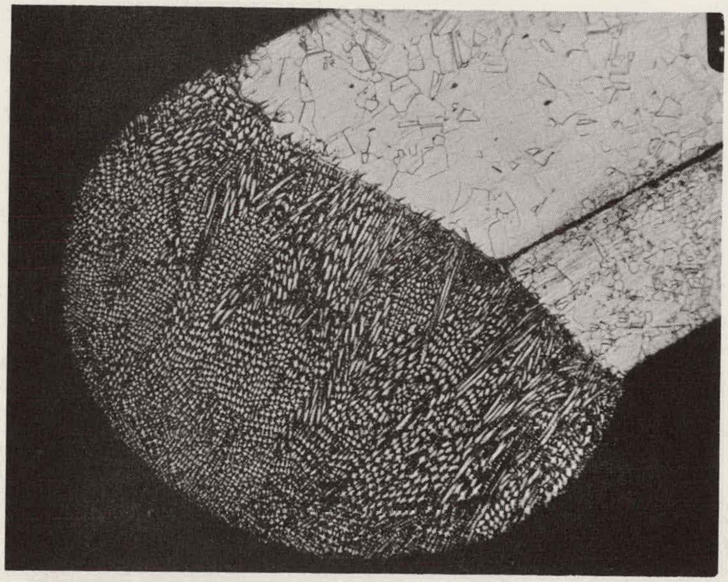


Fig. 15... Microstructure of Trepan Weld Cup Cap. Note Penetration Pattern.

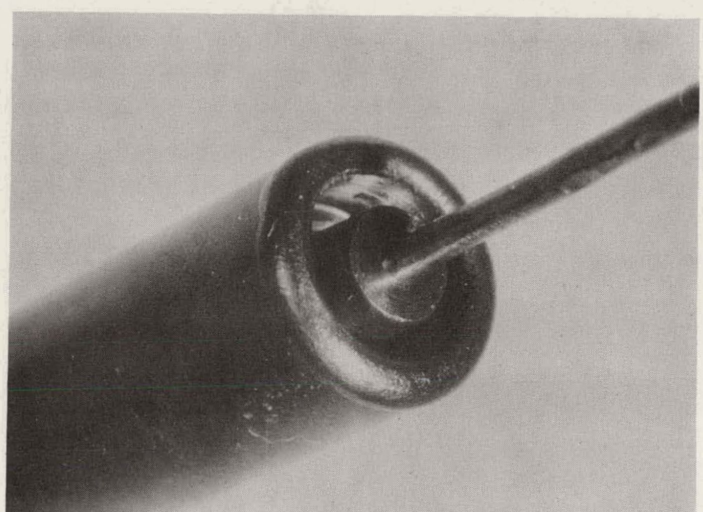


Fig. 16... Typical Trepan Cup Cap End Closure Weld

end cap material was reduced in cross section to a stub that could be used to attach the fuel rod to the coolant flow director.

Initial experiments consisted of welding a series of samples at various amperages ranging from 17 to 26 amp. Remaining parameters were held constant. These samples were then evaluated for welding characteristics, puddle geometry and weld penetration. Results are summarized as follows:

1. All samples welded satisfactorily, however, the 1/16 in. shoulder produced a heat balance problem. Some improvement over the straight plug was evident but sensitivity to weld parameter variation was sufficient to be undesirable.
2. Optimum amperage was found to be 25 amp.

A series of samples were prepared using end caps with 1/32 in. shoulder. Welds were made at amperages ranging from 17 to 27 amp.

The 1/32 in. shoulder proved far superior to the 1/16 in. shoulder previously used. No evidence of weld sensitivity was observed. All welds were consistently sound over the total amperage range studied. Optimum penetration and microstructure were attained at 19 amp. A typical shoulder cap weld is shown in Fig. 17.

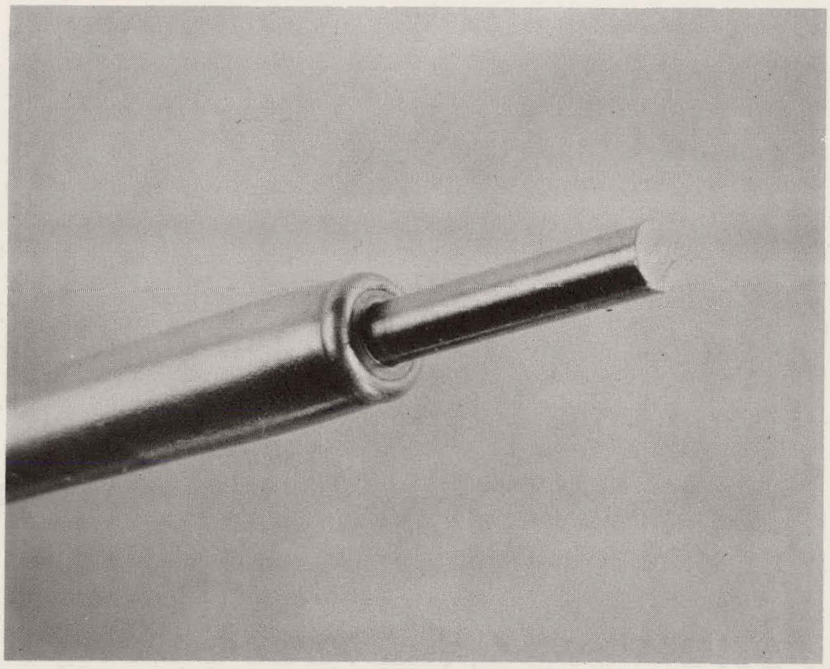


Fig. 17... Reduced Shoulder End Cap Weld

8.0 EFFECT OF CHILLS

Studies of these end cap designs has clearly shown that proper attention to component design could greatly reduce sensitivity to weld defects. It was evident however, that the design imposes a relatively large mass difference, therefore, optimum balance is not attainable merely through design.

Whereas the previous work had been performed using a fixed chill in which the fuel tube was rotated, a more effective chill appeared necessary. A collet-type chill, that was attached to the tube and rotated with it, was made for this purpose (Fig. 18). Experiments were performed with both cup and reduced shoulder caps. In both cases, through the use of a properly sized and properly located collet chill, the external weld bump (Fig. 19) was shifted to an internal position as shown in Fig. 20. The use of the chill reduced the size of the bump on the shoulder cap from 0.004" to 0.002" increase in diameter.

Destructive evaluation of welds made with proper chills showed significant improvement in puddle goemetry and uniformity of penetration. (Fig. 21 and 22).

It can be concluded that the heat balance and mass relationships are critical to the success of end closure welding. The work has clearly shown that satisfactory (but marginal) welds can be produced with poor heat balance, e.g. the plug cap, and that consistently sound welds with minimal attention to parameters can be made with a properly balanced system.

Fig. 18... Collet Type Chill Used to Improve Heat Balance

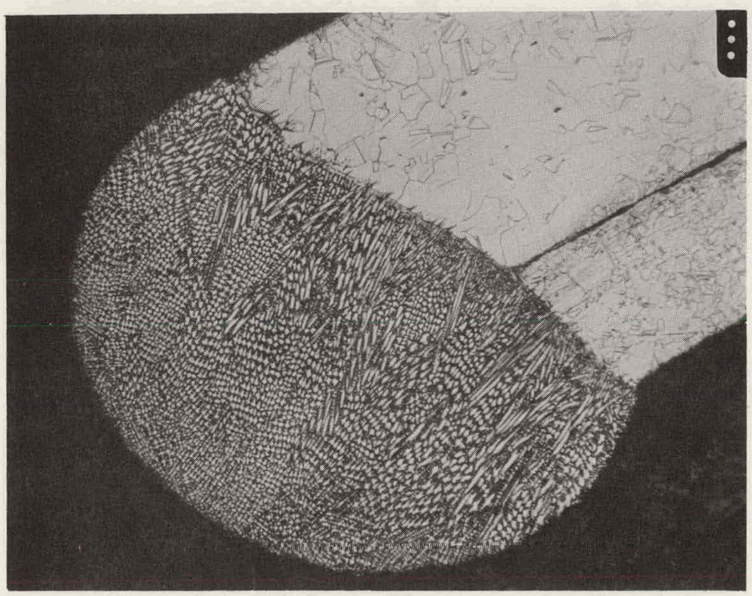


Fig. 19... Cup Type End Cap Weld without Chill. Note How Bump is on Outside of the Tube.

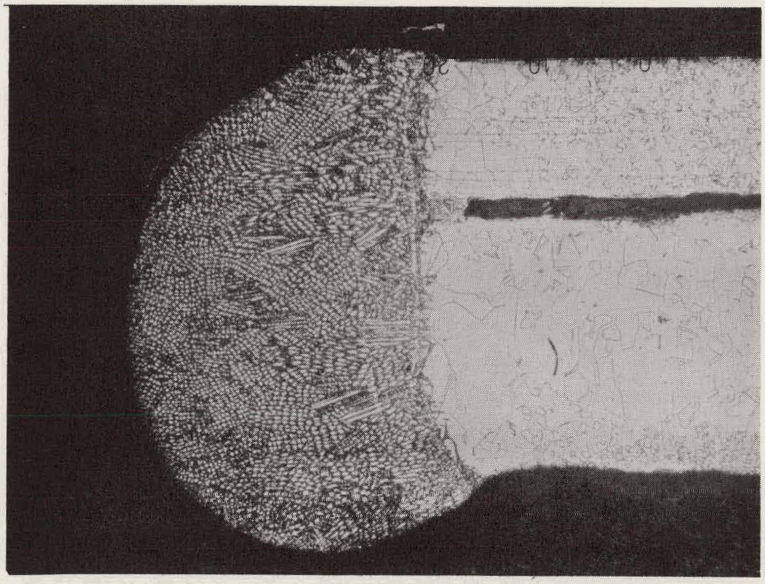


Fig. 20... Cup Type End Cap Weld with Chill.
Note Internal Position of Weld Bump

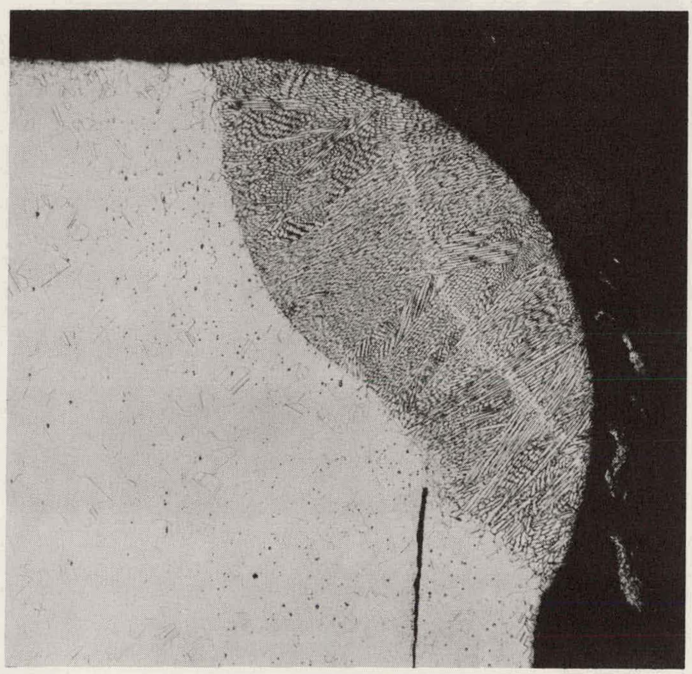


Fig. 21... Shoulder Type Cap Welded
without Proper Chill

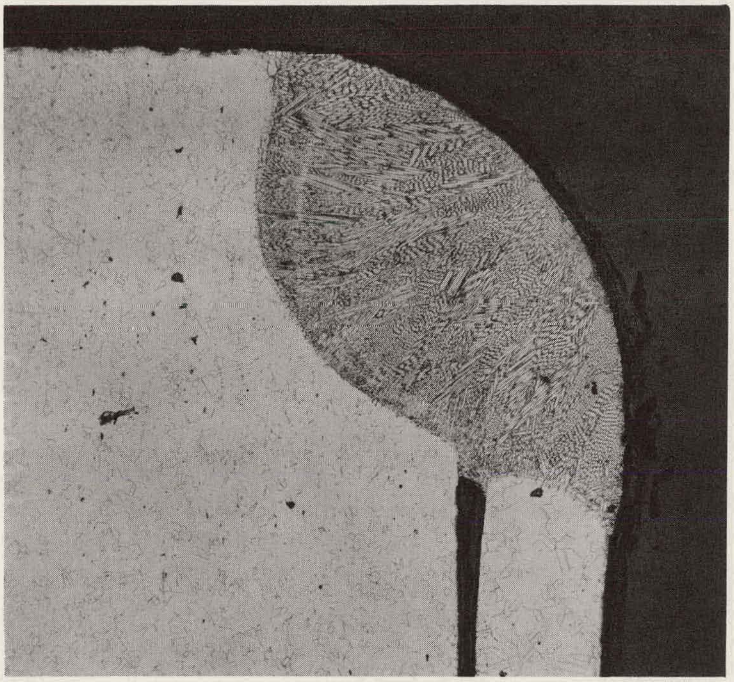


Fig. 22... Shoulder Type Cap Welded
with Proper Chill

9.0 END-CAP WELDING ON LOADED TUBES

Experiments were conducted to determine optimum weld parameters for rods containing UO_2 fuel. Parameters for this experiment were based on results of the previous studies with unfilled tubes. Table IV summarizes all the established constants. The only new technique required for this study involved removal of UO_2 ceramic fuel from the rod ends to provide a socket for the end plug. This was accomplished for the experiments by soaking the tube ends in hot HNO_3, rinsing, and oven-drying.

9.1 Plug Caps

The first attempt to weld plug caps on fueled rods was unsuccessful. As anticipated, trapped air (between the plug and the end cap) expanded during welding and caused sporadic blowout type defects. Although some welds appeared to be satisfactory, the results were erratic and unacceptable.

A second series of samples was prepared using end plug caps with small vent holes for outgassing (Fig. 23). A group of eight welds was successfully made with this cap. Although the process was still sensitive to minor variations in welding parameters, consistently sound welds could be obtained. Evaluation of these samples showed excellent external appearance (Fig. 24). Microstructure was free of porosity and contamination (Fig. 25). Weld puddle dimensions can be summarized as follows:

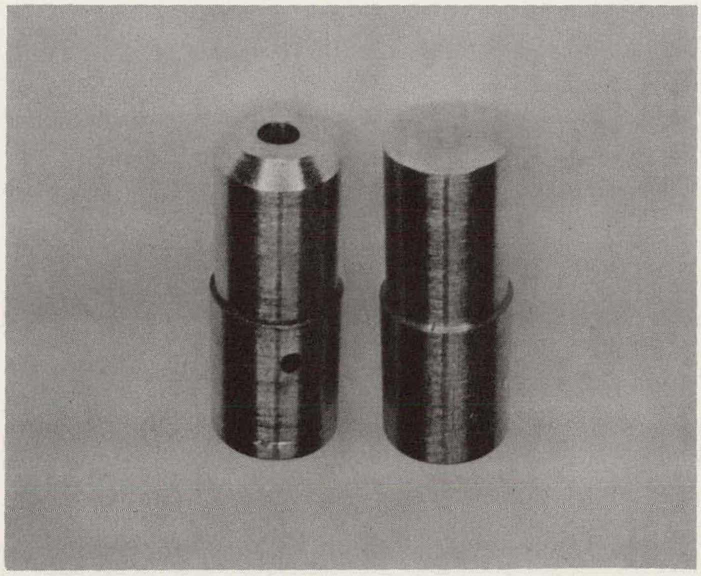


Fig. 23... Comparison of Two Types of Plug Cap Used for Pilot Run

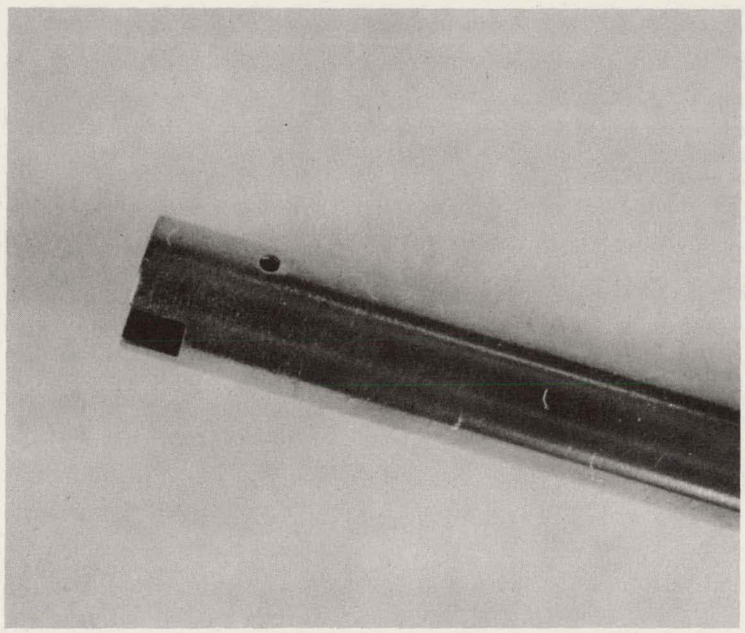


Fig. 24... Typical End Cap Weld on Fuel Rod Using Plug Cap with Vent Hole

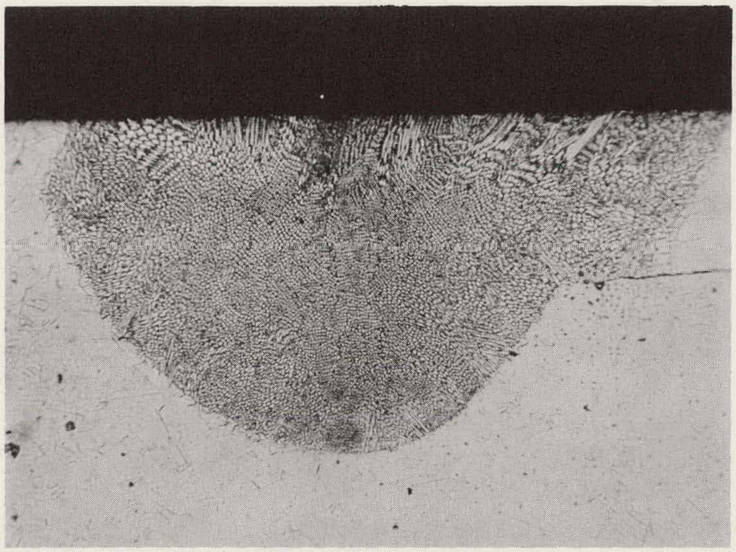


Fig. 25... Typical Microstructure of
Weld Made with Plug Cap.

Item	$\bar{X}$	Range
Puddle Width	0.025	0.022 to 0.035
Bump	0.222	0.220 to 0.226
Puddle Depth	0.015	0.012 to 0.017

9.2 Reduced Shoulder and Cup Caps

A series of fuel rods with both reduced shoulder and recessed cup caps were welded using previously established parameters. Results were completely satisfactory. Heat buildup was low enough so that no vent holes were required. All welds were sound both externally and internally. Typical welds are shown in Figs. 26, 27, 28, and 29. A summary of dimensions of the welds is given as follows:

	Shoulder Cap		Cup Cap	
Item	$\bar{X}$	Range	$\bar{X}$	Range
Puddle Width	0.042	0.038 to 0.046	0.033	0.030 to 0.036
Bump	0.224	0.222 to 0.228	0.222	0.220 to 0.224
Puddle Depth	0.016	0.013 to 0.020	0.014	0.011 to 0.018

Complete evaluation of the samples with both caps showed that the end closures would be satisfactory for reactor application.

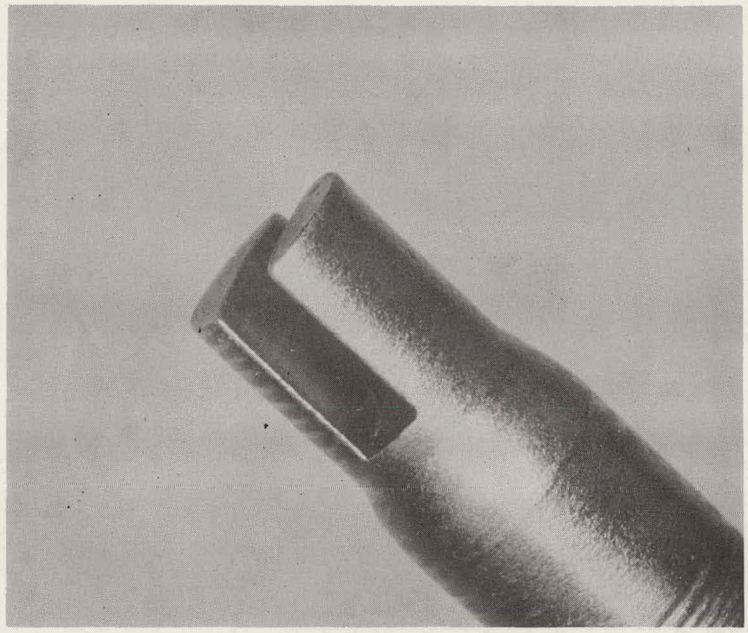


Fig. 26... Typical Appearance of a Reduced Shoulder Type End Cap Weld Made on Fuel Rod. Note notch used for assembly attachment.

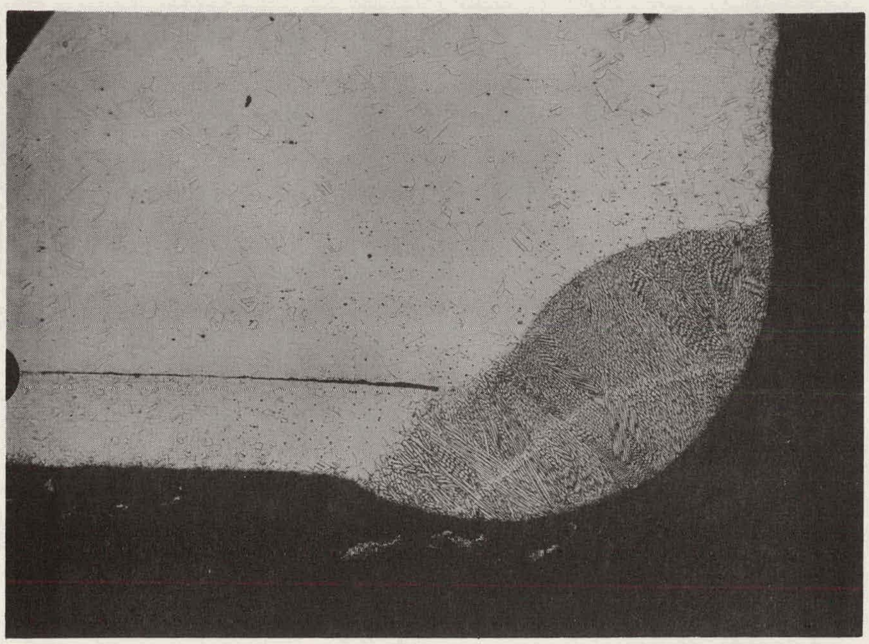


Fig. 27... Microstructure of Reduced Shoulder Type End Closure Weld.

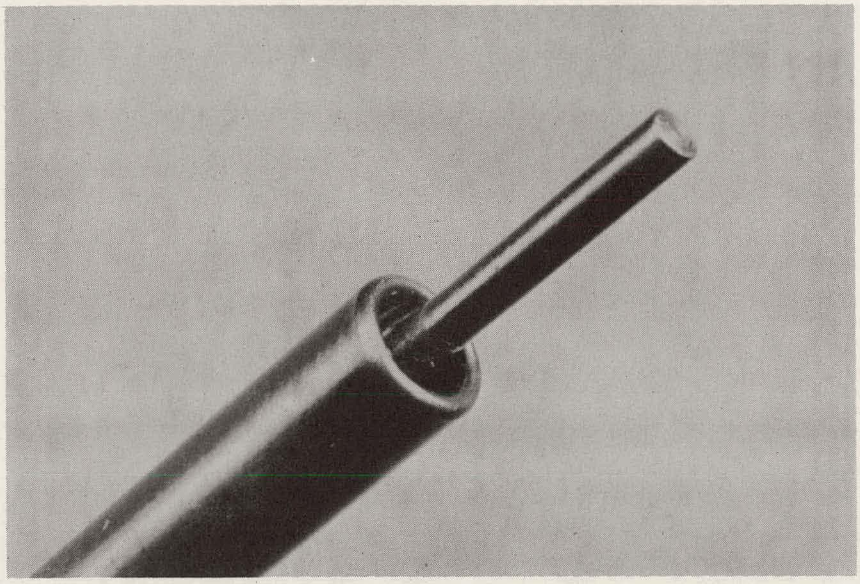


Fig. 28... Appearance of Cup Cap End
Plug Weld on Fuel Rod

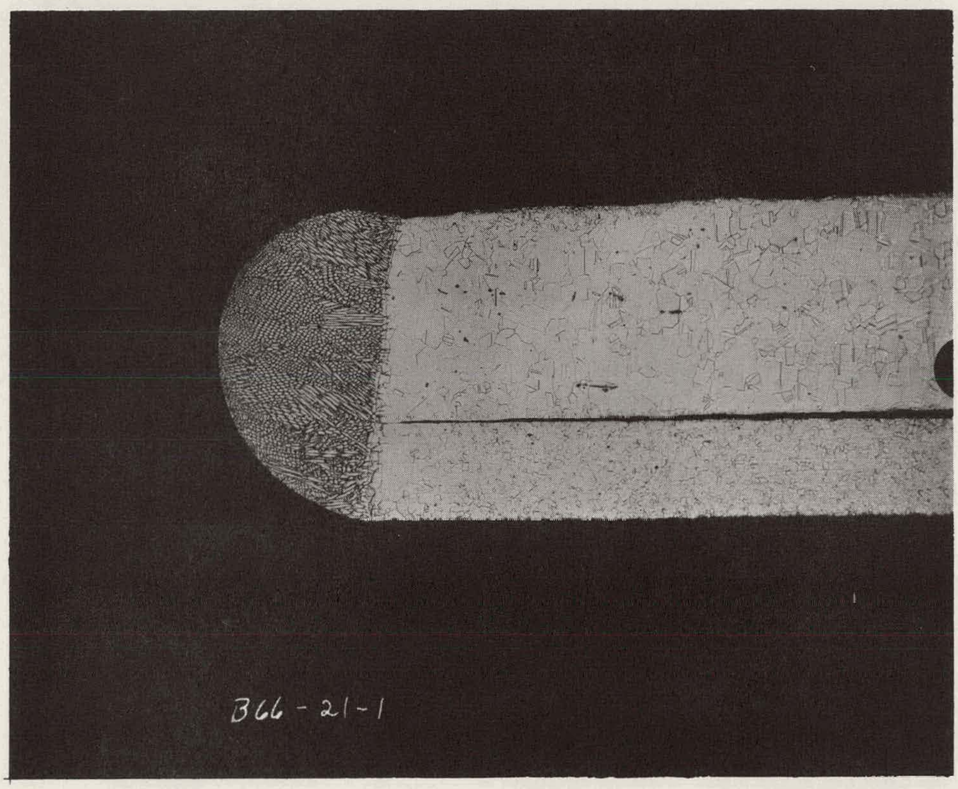


Fig. 29... Microstructure of Cup Cap End
Closure Weld on Fuel Rod.

TABLE IV

SUMMARY OF PARAMETERS USED ON FUEL ROD PILOT RUN

MAJOR VARIABLES	OPTIMUM LEVELS
Material	316 SS
Weld Torch Angle	12 O'Clock
Weld Atmosphere	Argon
Power Supply	D. C. Straight Polarity
Welding Electrode	1% Thoriated Tungsten 0.062 dia.
Arc Gap	0.032 in.
Voltage	Function of Amperage App. - 8 to 12 volts
Arc Location Axial	0.040 in. off joint
Preheat	4 sec.
Decay	8 sec.
Weld Speed	14 in/min
Amperage	
Cup	9 amps
Shoulder	19 amps
End Cap Design	Cup & Shoulder
Weld Time	1-1/4 rev.