JUN 10 1964

Report No. ACNP - 63031

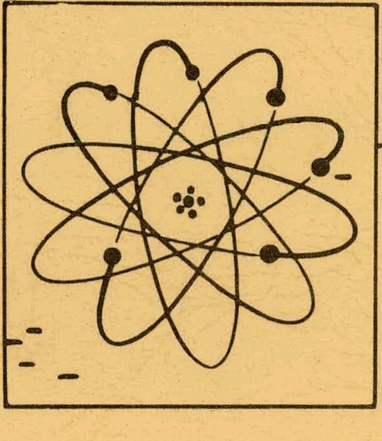
# PATHFINDER ATOMIC POWER PLANT

# FABRICATION DEVELOPMENT OF COLLAPSE CLAD

Submitted to
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**



Facsimile Price $ 2.60
Microfilm Price $ 1.10

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

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

# DISCLAIMER

## LEGAL NOTICE

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

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

B. Assumes any liabilities to others with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, 'person acting on behalf of the Commission or Allis-Chalmers Manufacturing Company' includes any employe or contractor of the Commission, or Allis-Chalmers Manufacturing Company or employe of such contractor, to the extent that such employe or contractor of the Commission, or Allis-Chalmers Manufacturing Company or employe of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission or Allis-Chalmers Manufacturing Company or his employment with such contractor.

ACNP-63031

# PATHFINDER ATOMIC POWER PLANT

## FABRICATION DEVELOPMENT OF COLLAPSE CLAD

By E. A. Wick, E. S. Boyko and R. A. Boschke

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**

May 15, 1964

Classification – UNCLASSIFIED

Approved: C. B. Graham
**C. B. Graham**
**General Manager's Staff**

Approved: Hibbert Hill
**Hibbert Hill**
**Vice President-**
**Engineering**

**ALLIS-CHALMERS MANUFACTURING COMPANY**
**ATOMIC ENERGY DIVISION**
**BETHESDA, MD. 20014**

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

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

# 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 fabrication development of collapse clad.

The Pathfinder plant will be located at a site near Sioux Falls, South Dakota, and is scheduled for operation in 1964. 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.

# TABLE OF CONTENTS

# LIST OF ILLUSTRATIONS

## 1.0 INTRODUCTION

The first superheat core of the Pathfinder reactor contains a highly enriched, annular fuel element. (Fig. 1) The fuel is a cermet composed of fully-enriched $UO_2$ particles and stainless steel powder which, in turn, is clad with stainless steel. The clad cermet is fabricated into plates which are subsequently formed into tubes of two diameters. The annular fuel element is assembled by inserting the small diameter fuel tube into the larger tube. A centrally located poison rod is in turn inserted into the smaller tube. The fully enriched fuel and the tedious fabrication process make this an expensive fuel element.

The incentive to reduce fuel cycle costs of future superheater cores resulted in the design of a low enriched fuel element. This element is a seven-rod cluster which contains partially enriched $UO_2$ fuel pellets. The rods are approximately 1/4 inch in diameter and six feet long. The diameter of the entire seven-rod cluster is slightly less than one inch.

Since the outside diameter of the fuel rod is fixed by flow considerations, the clad (or tube wall) thickness was minimized (0.010 to 0.012 in.) so that the fuel enrichment could be minimized. The thinner cladding resulted in a lower-capture cross section for thermal neutrons and a larger inside diameter, hence a larger pellet volume.

The thin clad requirement necessitated that the clad be in intimate contact with the fuel before insertion into the reactor. The intimate contact requirement is imposed to eliminate diametral clearance and also to

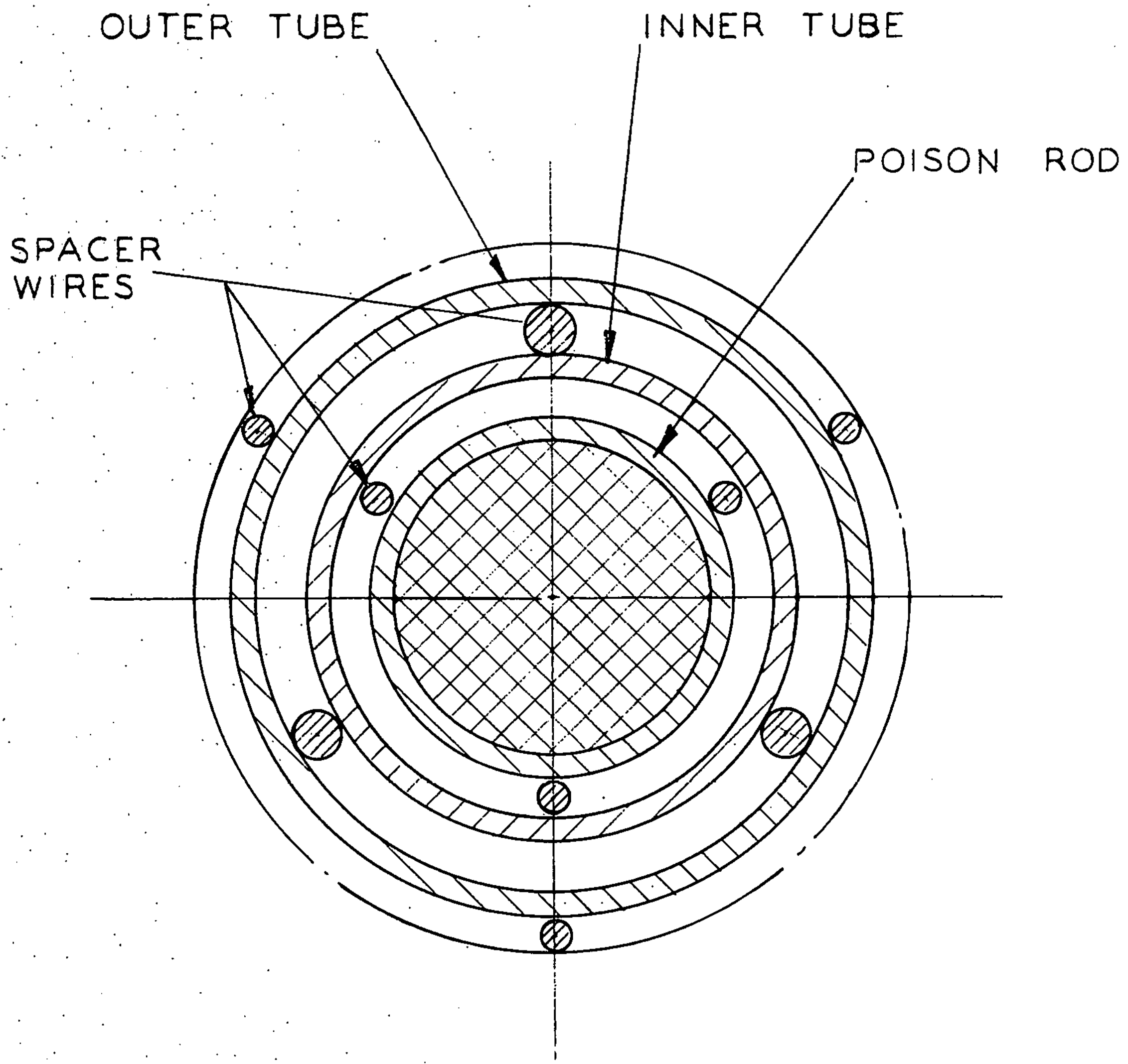


Fig. 1...Superheater Fuel Element Cross Section (43-025-844)

eliminate the possibility of a seam or wrinkle occurring in the clad while in service, as a result of creep or collapse in the 600 psi steam.

A literature search was conducted to select a fabrication process capable of achieving the desired mechanical contact between tubing and pellets. As a result, three processes were considered. They are stretch bonding, draw bonding, and push bonding. Draw bonding and stretch bonding studies were initiated on the basis of existing tools and equipment. Investigation of push bonding was deferred, pending the establishment of the feasibility of stretch and/or draw bonding. The term "bonding" in this case refers to the intimate mechanical contact between the tube wall and fuel pellets and does not mean bonding in either the chemical or metallurgical sense.

A research and development program was, therefore, 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 U-235 which is clad with thin-walled stainless steel tubes. The fuel assemblies consist of seven fuel rods with a 1/4 inch diameter and a length of 6 ft arranged in a circular bundle of approximately 1 inch diameter (Fig. 2). The development program covers three major areas:

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

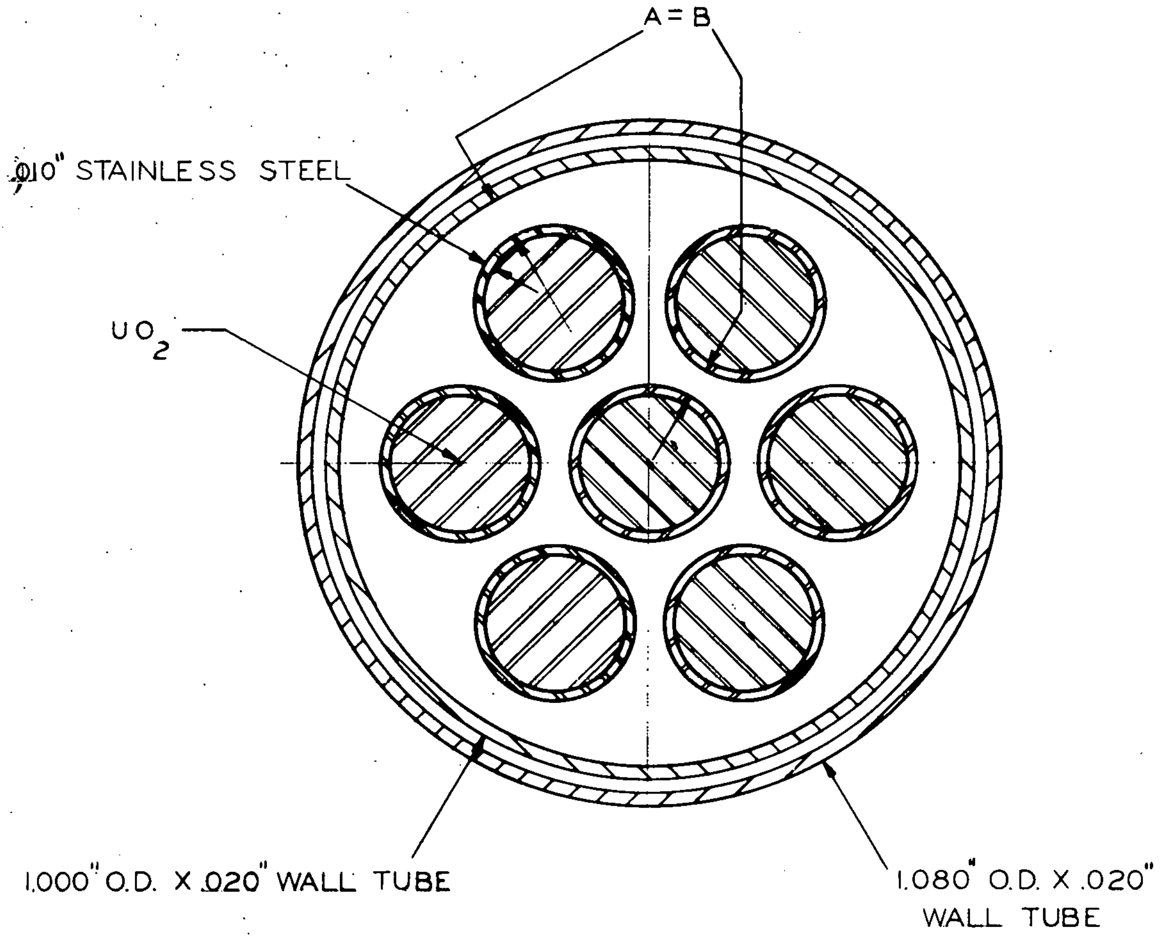


Fig. 2...Proposed Low Enrichment Superheater Fuel Rod Bundle (43-024-085)

## 2.0 OBJECTIVE

The object of this report is to describe the feasibility studies that were conducted on two methods for collapsing the cladding of tubular fuel elements onto low enriched uranium dioxide fuel pellets.

## 3.0 SUMMARY

The collapse clad development project can be summarized by the following statements:

### A. Draw Bonding

1. Extensive research into die design could improve this process.
2. Improved fixturing and auxiliary equipment, to maintain more rigid control of process.
3. Research cladding material and material condition for draw bonding process.
4. Elevated temperature process should be considered.

Of the above statements, it was felt that the most important factors were die design and fixtured tooling. This process has merit and should be developed to its fullest.

### B. Stretch Bonding

This process, of the two mentioned in this report, demands further investigation. From the data obtained, stretch bonding has shown definite promise as a method for intimate contact bonding. This could be achieved by development of techniques which would produce an acceptable product. The following statements will suggest ways in which future development might proceed.

1. High speed stretching technique,
2. Simultaneous stretching at each end,
3. Improve material conditions for stretching process,
4. Investigate various degrees of clearance between pellets and cladding.

5. Improve fixtures and tooling.

In conclusion, it can be said that both methods of contact bonding show promise for producing fuel pins. Further development should be considered to improve process and product.

## 4.0 DRAW BONDING

Draw bonding, to achieve intimate clad-to-pellet contact, is accomplished by passing the pellet-loaded clad tubing through fixed diameter draw dies. The final fuel pin diameter, and per cent of induced cold work can be controlled by the proper selection of die size, design, and clad-to-pellet clearance.

### 4.1 Equipment

Equipment on hand consisted of a 20,000 lb capacity hydraulic draw bench capable of handling tube lengths up to 12 feet.

The draw bench is equipped with a pressure-compensated speed control, which permitted investigation of a wide range of draw speeds. Draw dies and lubricants were purchased as standard items used in the tube fabrication industry.

### 4.2 Preliminary Studies

Preliminary studies were conducted to evaluate the equipment and to establish parameters.

Four 18-inch tubes were loaded with 1/2-inch long steel pellets and steel mandrel stock was then swaged to one end of each tube to provide a gripping surface for the draw head. At the other end, an end closure cap was welded on to contain the simulated fuel pellets. Prior to drawing, each tube received a coating of a commercial draw lubricant.

The four samples were inspected dimensionally to establish starting conditions. The outside diameter was measured at 2-inch intervals and recorded. The diametral clearance between tube and pellet was 0.003 ± .0005.

Each tube was drawn to a different reduction, using a draw speed of 18 inches/minute. Die diameters were selected to provide reductions in cross sectional area of the clad of 2.2, 3.5, 5 and 6.5 per cent, assuming that the clad thickness would remain constant.

### 4.3 Preliminary Study Results

The draw-bonded pins were evaluated visually, by measuring the outside diameter at regular intervals and by metallographic examination of cross sections taken at varying axial positions. The diameter of each of the drawn pieces was uniform; however, the diameters of the drawn pins were slightly larger (0.0004 in. to 0.0008 in.) than the die diameters in the case of the 3-1/2, 5 and 6-1/2 per cent reductions. Visual examination revealed circumferential grooves on the surface of the pins. The grooves appeared to be equally spaced and located at the joints of the steel pellets on the pins that received 5 and 6-1/2 per cent reductions. Metallographic examination showed mechanical contact between clad and steel pellets and showed that pellet separation had occurred, thus accounting for the circumferential grooves observed visually.

The preliminary study indicated that the process was sufficiently promising to warrant more detailed studies using depleted $UO_2$ pellets. These studies are included in the next section.

## 4.4 Fuel Bearing Feasibility Studies

Preliminary designs for the low enriched superheater fuel element established a pellet diameter of 0.199 inches. Type 316L stainless steel was selected for the clad material with a minimum wall thickness of 0.010 inches.

To verify the preliminary studies, four fuel pins containing depleted $UO_2$ pellets were "draw bonded". These four pins duplicated the reference design of the low enrichment superheat fuel element, i.e., Type 316L stainless steel tubing, 0.010 inch wall and a pellet diameter of 0.199 inches. Tubing with an outside diameter of 0.223 in. was used, which provided a diametral clearance of 0.003 in. between pellet and clad. Four pellets in each pin were notched to depths of 0.015 to 0.100 in. to observe the effect of the drawing operation upon defected pellets. The draw speed was 18 inches/minute and the rods were drawn to reductions of 2.2, 3.5, 6 and 6.5 per cent respectively.

During the draw process, pellet cracking was heard at reductions of 3.5, 5 and 6.5 per cent reduction. Visual inspection of the clad surface at the two lower reductions indicated slight grooves in the clad over the notched pellets. Dimensional inspection verified the existence of springback for each reduction, and other defects were noted. Sections of each pin were decanned to determine the extent of pellet cracking and clad damage. Fig. 3 illustrates the pellet conditions at the various reductions. At a reduction of 5 and 6.5 per cent extreme pellet fracturing and clad damage had occurred. (Figs. 4 and 5). Pellet damage was minimized at the two lower reductions and occurred in the form of longitudinal cracking. This condition was attributed to a misalignment of the pellets as they entered the draw die.

A metallographic cross section taken of the 3.5 per cent reduction indicated that intimate contact had been achieved, (Fig. 6) and springback was eliminated as a major variable.

Further examination of the drawn pins indicated that pellet separation was prevalent and would require additional investigation.

To study the effect of pellet alignment during the draw process, four pins 18 inches long were prepared using 0.220-inch OD tubing. The 0.010 cladding provided a maximum pellet-to-clad clearance of 0.001 in. The four pins were drawn to the same conditions established for the first series, to check reproducibility. Subsequent evaluation of the drawn pins did not indicate any significant change in pellet damage. However, pellet separation was still significant.

Additional studies were conducted to study the effects of draw speed and lubrication. Draw speeds of 18 to 72 inches/minute did not appear to have any significant effect on the process. Three draw lubricants were

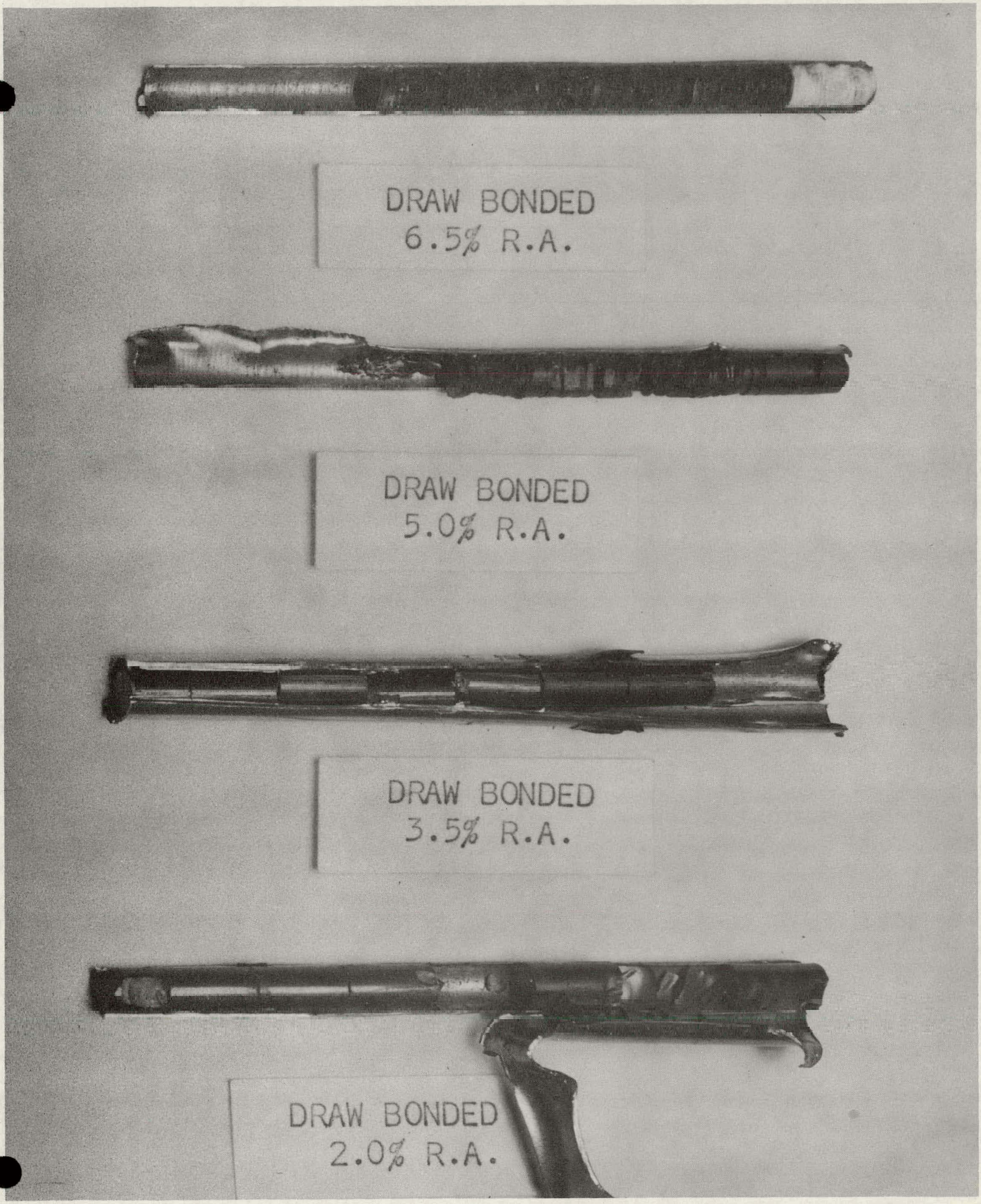


Fig. 3...Pellet Conditions at Different Reductions (40-B-0-1

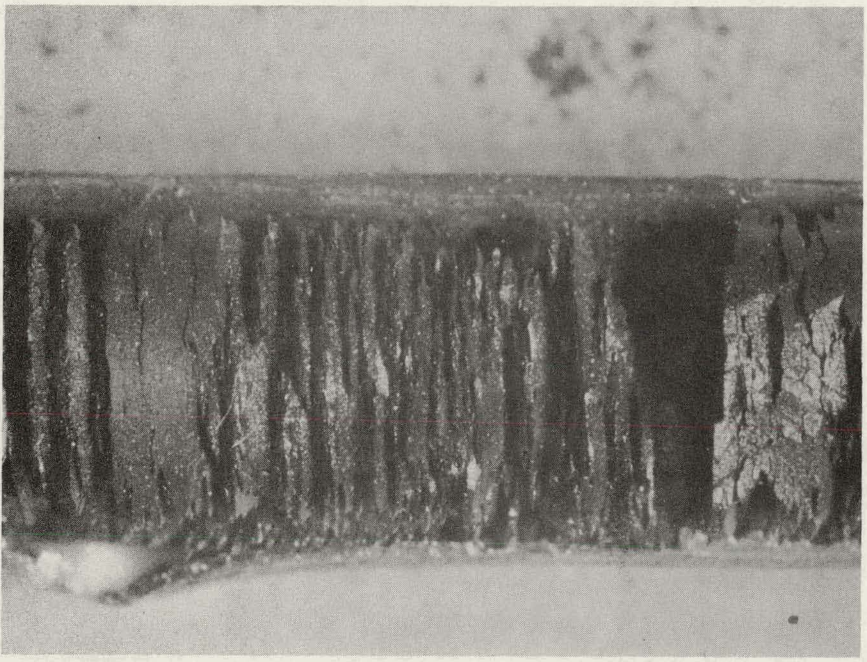


Fig. 4...Pellet Fracturing and Clad Damage at 5 Percent Reduction (40B-0-4...9.1x)

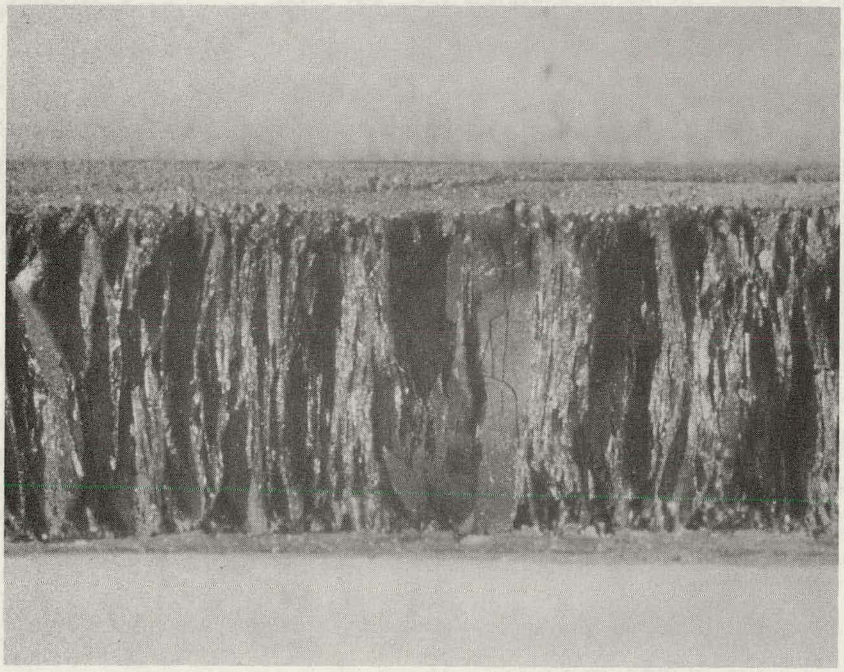


Fig. 5...Pellet Fracturing and Clad Damage at 6.5 Percent Reduction (40B-0-3...9.1x)

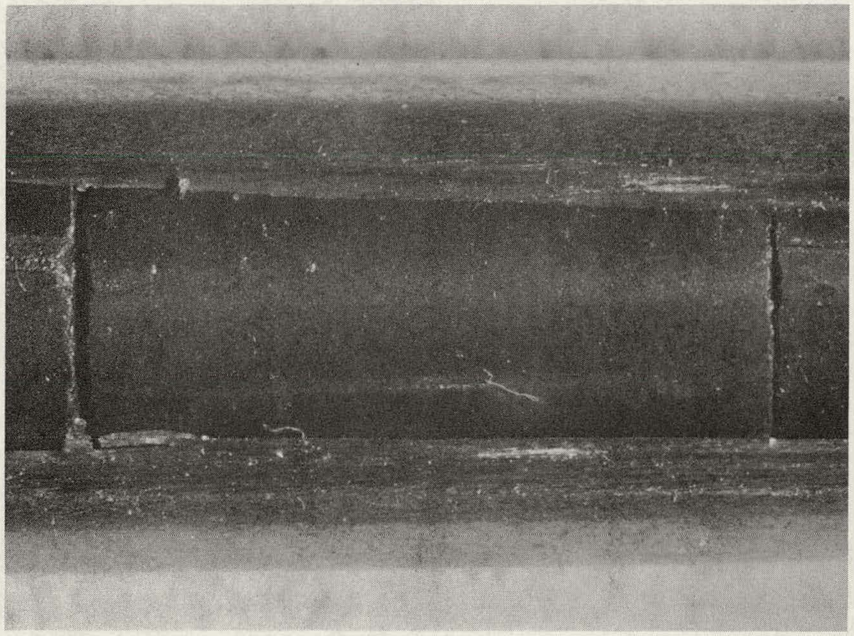


Fig. 6...Metallographic Cross Section Showing Intimate Contact of Clad and Pellets at 3.5 Percent Reduction. Note the Pellet Separation. (40B-0-5...9.1x)

investigated at a constant draw speed of 72 inches/minute, but did not have any apparent effect on the draw process.

Experiments designed to minimize pellet separation were unsuccessful. It was felt that extensive fixturing would be required to overcome this problem. Dimensional analysis of all the drawn tubes indicated that the straightness could not be controlled with any degree of reproducibility. It was felt that draw bonding could not be used as the reference process and all further work in this area was terminated.

## 5.0 STRETCH BONDING

Stretch bonding, to achieve intimate clad-to-pellet contact, is accomplished by elongating the clad under a tensile load to reduce the cross sectional area. Based on information derived from a literature survey, stretch bonding offered a potential fabrication process for producing the low enriched superheater fuel element.

### 5.1 Equipment

A stretch bonding fixture was designed and fabricated to permit utilization of a 20,000-lb capacity hydraulic draw bench. Pressure compensated speed control and a total draw stroke of 12 feet enabled process feasibility studies to be conducted over a wide range of pin lengths and stretch speeds.

The stretch bonding fixture, Fig. 7, was designed to accommodate fuel pin lengths up to 6 feet. Intermediate fixed end blocks support the fuel pins during the stretch process and permit stretching of shorter elements. A floating block at the front end of the fixture (Fig. 8) grips the fuel pin, and a yoke (Fig. 9) transmits the tensile load from the draw head to the floating block. An adjustable mandrel at each end of the fixture provides an axial load to maintain the pellet stock length. Prior to stretching, a stretch collar is brazed to the clad tube to transmit the load from the floating block to the fuel pin.

### 5.2 Preliminary Studies

Preliminary stretch bonding trials were performed to evaluate the fixturing and obtain data as to the behavior of the clad during and after stretching.

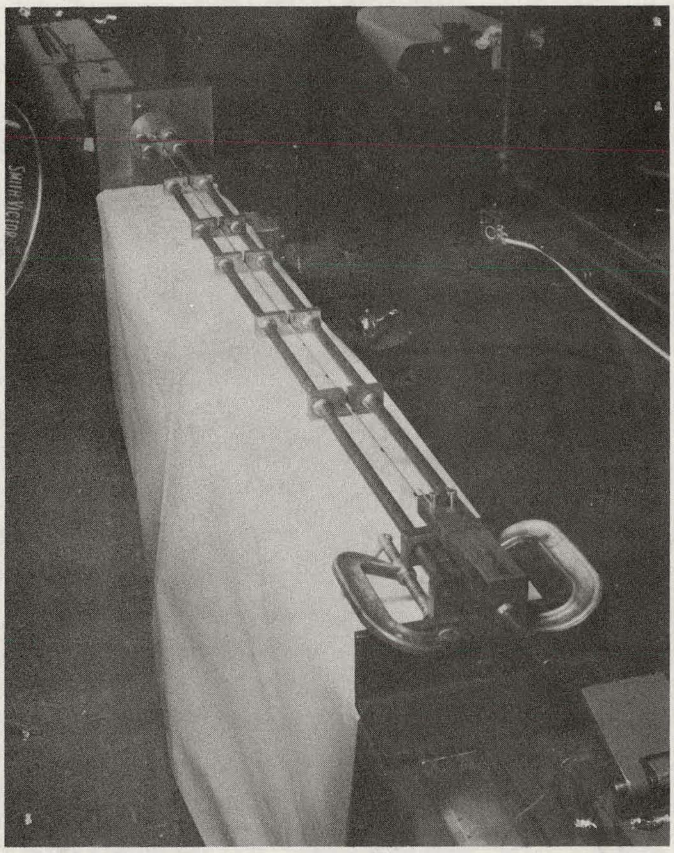


Fig. 7...Illustration of a Stretch Bonding Fixture

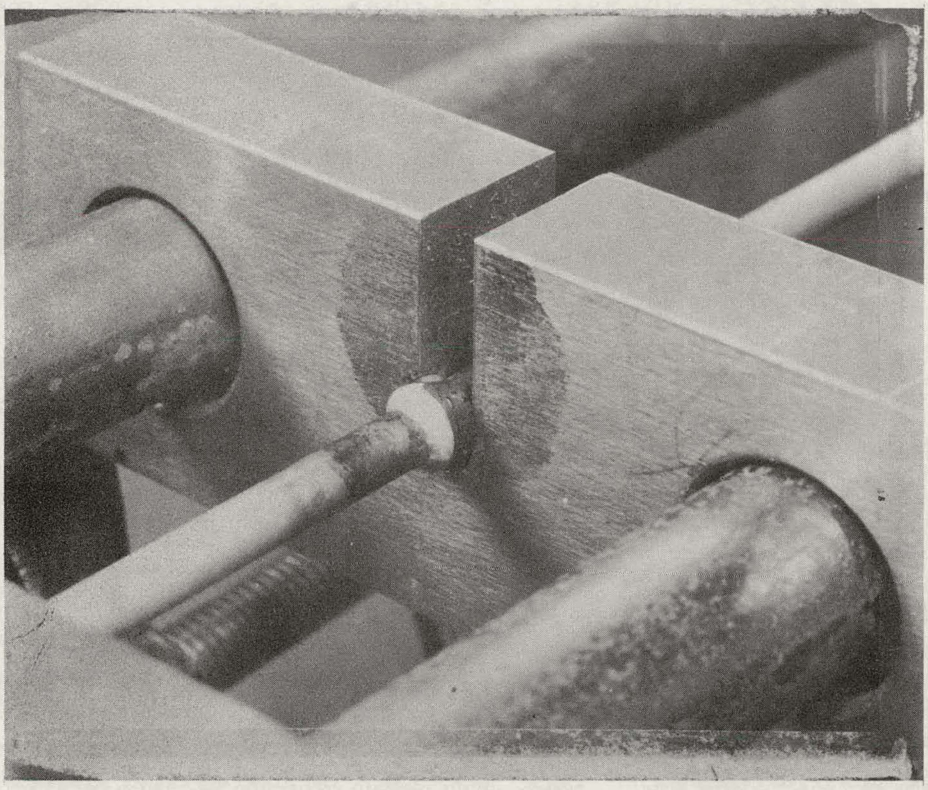


Fig. 8...Closeup of Draw Collar

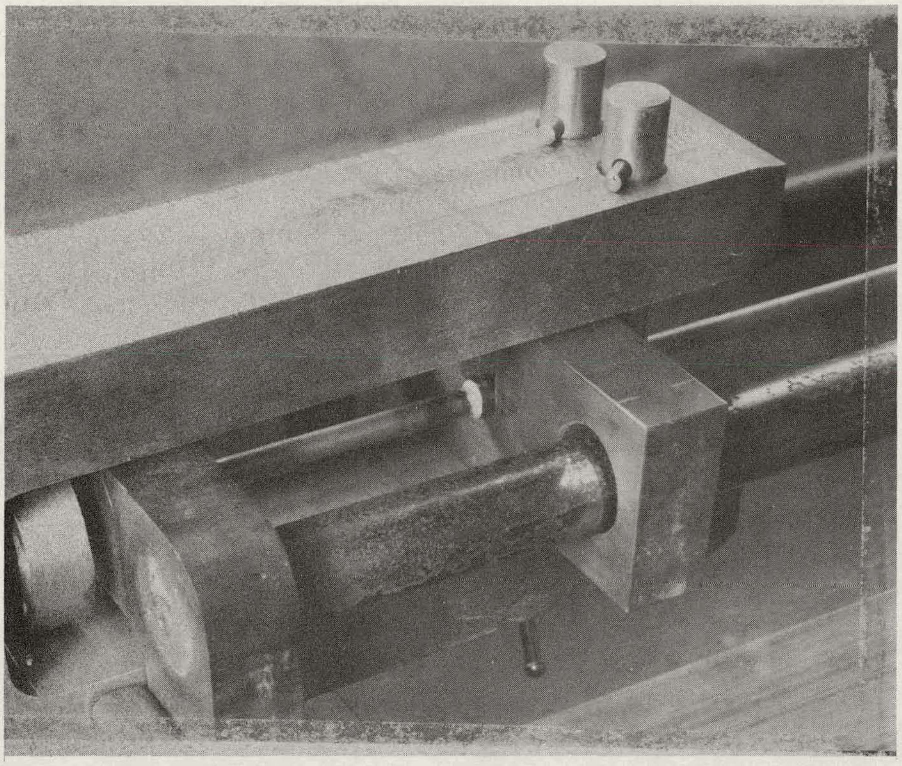


Fig. 9...Draw Collar Fixture

Three pins, 0.223 OD, 29 inches long, were loaded with 0.199 OD drill rod pellets. Gripping ferrules were brazed onto the clad approximately 1 inch in from each end. Gage marks were scribed on the clad, at five-inch intervals, and OD measurements were taken at each mark.

The pins were loaded into the stretch fixture and the end mandrels adjusted to support the pellet stack. Each pin was drawn in increments of 1/4-inch at which time gage length measurements and OD were taken and recorded. After a total elongation of 1-1/2 inches, the load was released and measurements were recorded to indicate springback. Further stretching terminated in clad failure at the gripping ferrule.

### 5.3 Preliminary Study Results

The results of the preliminary study indicated the following:

1. Clad reduction had been achieved, but was not uniform over the pin length.
2. Maximum reduction had occurred at the draw end of the pin.
3. Elongation between gage marks was not uniform and the maximum point occurred at the draw end of the pin.

It was felt at this point that the major cause of non-uniformity of the draw was the use of drill rod pellets which tended to gall the clad and increase friction. The increased frictional forces combined with a stress concentration at the gripping ferrule caused clad failure before intimate contact had been achieved over the entire pin length.

It was further theorized that friction forces would be reduced and a more uniform reduction achieved over the pin length by using depleted $UO_2$ pellets.

## 5.4 Fuel Bearing Feasibility Studies

A series of pins loaded with $UO_2$ pellets, 0.199 OD, was prepared and stretched to check the foregoing reasoning and establish the stretch characteristics of fuel loaded clad.

Dimensional analysis did not support the reduced friction theory. Elongations and reductions continued to be non-uniform, and in one case clad failure occurred at 3/4-inch total stretch. Prior to feasibility studies, investigations had been conducted to reduce stress concentrations and premature clad failure at the gripping ferrule.

Several ferrule designs were fabricated and applied to the stretch process. Ferrules which eliminated the draw end mandrel produced pellet separation which could not be controlled. In those cases where the double mandrels were utilized, premature clad failure occurred.

A re-evaluation of the data accumulated during the previous investigations brought out four important factors.

1. Pellet-to-clad contact had occurred in every case at the draw end of the pin.
2. Clad failure occurred after intimate contact had been achieved over approximately one-half of the pin length.
3. Uniform clad reduction had not progressed from the center of the pin outwards to the ends as previously reported.
4. Clad failure in each case was accompanied by neckdown between the gripping ferrule and the first pellet in the stack.

Based on these four factors, it was conjectured that a uniform reduction might be achieved if the pins were double stretched.

The double-stretch process was accomplished utilizing the following procedure. Fuel pins were prepared with the brazed gripping ferrules used for preliminary studies. Gage length and OD were recorded and the pins stretched until neckdown was observed at the draw end. The load was released and the pins were reversed in the stretch fixture. Gage length and OD were again recorded. The load was reapplied to the pin until clad failure occurred. Final dimensions were taken and evaluated. Figs. 10-A and 10-B summarize the result of this experiment. It can be seen from the curves that although the uniformity of clad reduction was greatly improved following the second draw, complete uniformity was not achieved. The results, however, did indicate that the process was feasible for low enriched fuel element studies.

Process qualification utilizing the double-stretch process was conducted on twelve 6-ft pins. Diametral clearance between clad and pellets was 0.003 inch. The purpose of this experiment was to determine reproducibility of the process. Outside diameter and gage length measurements were taken prior to the stretch, after the first stretch, and after the final stretching. After 7 pins were processed, it was observed that the pellets near the center of each pin were loose. It was then decided to terminate further experimentation along these lines until a satisfactory reason could be found for the non-reproducibility of the process.

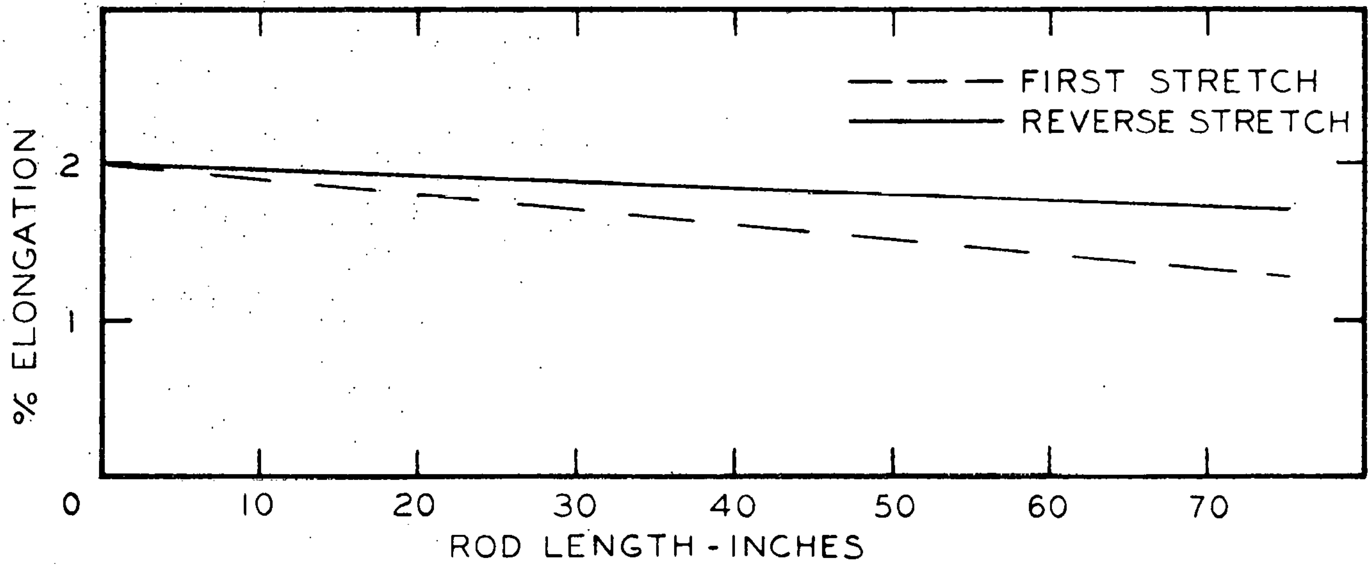


Fig. 10-A...Per Cent Elongation vs Rod Length (43-025-054)

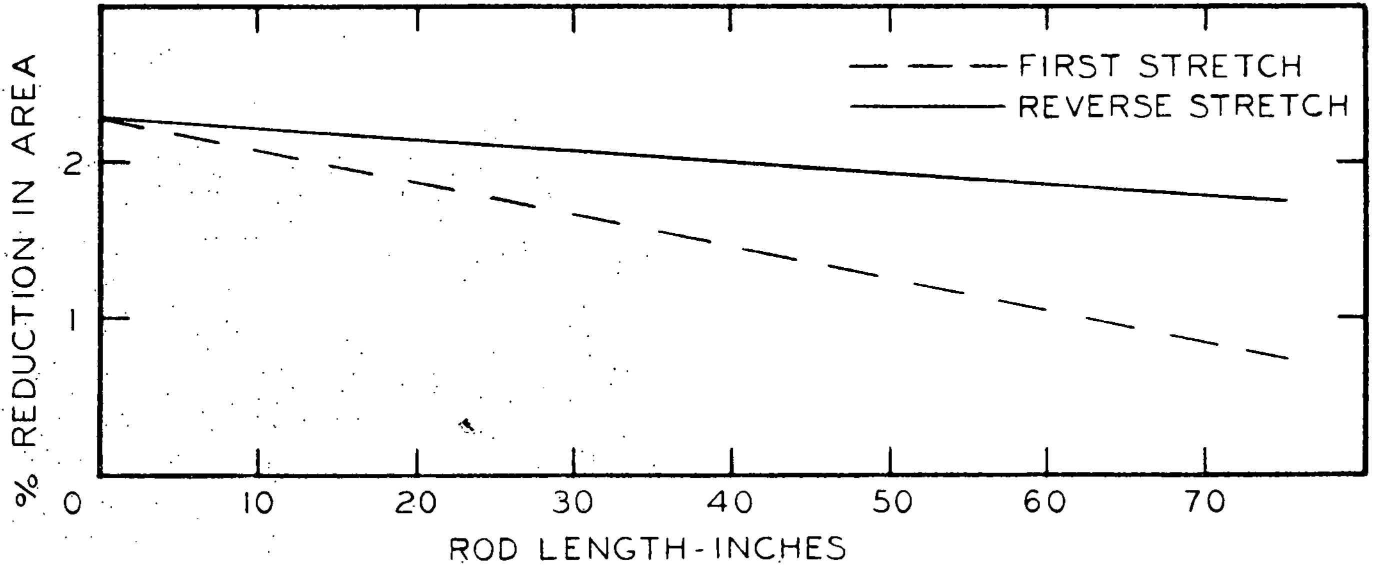


Fig. 10-B...Per Cent Reduction in Area vs Rod Length (43-025-054)

An extensive re-evaluation of the data indicated the following points.

1. Stretch bonding produced satisfactory pins with intimate clad-to-pellet contact in lengths up to 29 inches.
2. As the length of the stretched pin increased above 18 inches, reproducibility was unsatisfactory.
3. As clad-to-pellet clearance increased, reproducibility increased.
4. Fuel pins, double stretched, indicated intimate contact at the ends with slight or no contact at the center.
5. An empty clad tube was stretched to a diametral reduction of 27 mils without exhibiting clad failure.
6. Clad failure always occurred at the draw end of the pin.

The results of the re-evaluation have led to a conjecture as to the mechanism involved in premature clad failure and non-uniform reduction over the pin length. As described earlier in this report, the pellet-loaded clad tube was placed into the stretch fixture and an axial load was impounded upon the pellet stack to control separation. The two mandrels which supplied this load are fixed in position on the stretch fixture. As the load is applied to the clad material, localized yielding occurs in those grains which are properly orientated. The initially-stressed grains work-harden and further yielding progresses to those grains with least favorable orientations. This process continues until localized yielding reduces the cross sectional area at some point in the clad to the extent that the clad comes into contact with the pellets. At this point, a second force, friction, comes into play. With the pellet stack in the direction of the stretch, frictional forces increase. When the friction forces between pellets and clad exceed the yield strength of the clad, elongation can continue only from the contact area toward the end ferrule in the direction of stretch. This effect continues until contact has occurred over the first pellet. Further elongation and reduction can only progress in the area between the gripping ferrule and the first pellet, where ultimate failure occurs. (See Fig. 11).

Fig. 11...Neckdown Area on Stretch Tube (64B-0-54)