WANL-M-FR-72-004

NASA CR-120956
DECEMBER 1972

NASA

FINAL REPORT

FABRICATION OF FUEL PIN ASSEMBLIES - PHASE III

BY

A. R. KEETON AND L. G. STEMANN

PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA LEWIS RESEARCH CENTER
CLEVELAND, OHIO 44135

CONTRACT NAS 3-14415

(NASA-CR-120956) FABRICATION OF FUEL PIN ASSEMBLIES, PHASE 3 Final Report A.R. Keeton, et al (Westinghouse Electric Corp.) Dec. 1972 130 p CSCL 18J

N73-14710

Unclas
G3/22 51650

Astronuclear Laboratory
Westinghouse Electric Corporation

Westinghouse Electric Corporation - P.O. Box 10864 - Pittsburgh, Pa. 15236

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-120956		

4. Title and Subtitle	5. Report Date
Fabrication of Fuel Pin Assemblies - Phase III	December, 1972
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
A. R. Keeton and L. G. Stemann	WANL-M-FR-72-004
	10. Work Unit No.
9. Performing Organization Name and Address Westinghouse Astronuclear Laboratory P. O. Box 10864 Pittsburgh, Pa. 15236	11. Contract or Grant No. NAS 3-14415
	13. Type of Report and Period Covered Contractor
12. Sponsoring Agency Name and Address NASA Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 44135	14. Sponsoring Agency Code

15. Supplementary Notes

Project Manager, Byron L. Siegel, Nuclear Systems Division, NASA Lewis Research Center, Cleveland, Ohio

16. Abstract

Five full size and eight reduced length fuel pins were fabricated for irradiation testing to evaluate design concepts for a fast spectrum lithium cooled compact space power reactor. These assemblies consisted of uranium mononitride fuel pellets encased in a T-111 (Ta-8W-2Hf) clad with a tungsten barrier separating fuel and clad. Fabrication procedures were fully qualified by process development and assembly qualification tests. Detailed specifications and procedures were written for the fabrication and assembly of prototype fuel pins.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Fuel Pin Space Power Reactor Uranium Mononitride Tantalum Alloy Clad	Limited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	128	

* For sale by the National Technical Information Service, Springfield, Virginia 22151

Astronuclear Laboratory

FOREWORD

The work described herein was done at the Astronuclear Laboratory, Westinghouse Electric Corporation, under NASA Contract NAS 3-14415, with Mr. Byron L. Siegel, NASA-Lewis Research Center, as Project Manager. Mr. A. R. Keeton was Project Manager for Westinghouse Electric Corporation, while Mr. L. G. Stemann was responsible for overall supervision and for weld development as required.

ACKNOWLEDGEMENT

The authors wish to express their appreciation for the guidance and close cooperation of NASA Lewis Research Center Project Management, Messrs. Byron L. Siegel and Jack Slaby.

Special recognition is given to Mr. William F. Mattson of NASA for his work in the bonding of tungsten liners to the I. D. of the fuel pin tubes and for developing the detailed procedure included in Supplement 1 of this report and to Mr. Gordon F. Watson for the original bonding concept.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 SUMMARY

Fuel pin assemblies fabricated in this program were designed by the Nuclear System Division of Lewis Research Center for evaluation of fuel pin design concepts for a fast spectrum lithium cooled compact space power reactor. These assemblies, designated by NASA as Phase III Fuel Pins, will be encapsulated and instrumented under Contract NAS 3-15332 for irradiation testing at the NASA Plum Brook Facility.

These fuel pins consist of uranium mononitride fuel pellets encased in T-111 alloy. A tungsten liner bonded to the ID of the T-111 cladding serves as a diffusion barrier.

Assembly procedures and construction techniques were fully qualified,and complete documentation was maintained for each assembly. Fuel pins were completely assembled and welded in the same vacuum purged inert atmosphere chamber to prevent exposure of fuel to air and provide the stringent cleanliness standards required in the program. Thorough inspection and quality assurance techniques were utilized to assure assemblies of the highest quality.

The procedures employed have been developed into a group of specifications designed to control the fabrication of actual reactor fuel pins. Inspection, machining, cleaning and handling, welding, and assembly are individually defined.

2.0 INTRODUCTION

A technology program for a fast spectrum Advanced Power Reactor is being carried out by the Nuclear Systems Division at Lewis Research Center. This program involves design of the reactor structure, control devices, neutronics, materials compatibility studies, fuel elements, and in-pile testing. The general reactor concept involves use of a lithium coolant, a refractory alloy fuel clad and structural material, and a fully enriched uranium nitride ceramic fuel.

The in-pile testing program for this reactor concept involves compatibility studies between different combinations of fuel, clad and liners, investigation of the effects of fission gas release, and fuel swelling. Fuel pin design and the effects of variable power density, burnup, and irradiation time will be evaluated. Irradiation tests to obtain this data are being conducted in the Oak Ridge Research Reactor and the NASA Plum Brook Reactor Facility.

In this program, full size prototype and reduced length fuel pins were fabricated for testing and evaluation of the fuel elements for this Advanced Power Reactor. For the "L" or prototype pins the fuel length is 38.1 cm (15.0 in.) while the reduced length "L/3" pins have a fuel zone 9.22 cm (3-3/4 in.) long. All the fuel pins will be used for true time tests. Experience obtained in the fabrication of fuel pins under NASA Contract NAS 3-12978 and reported in NASA Contract Report CR-72905 was utilized where applicable.

This report summarizes the details of hardware fabricated in this program with cross references to drawings and assembly procedures. Fuel pin descriptions and drawings are presented along with the salient features of assembly and procedural information. Detailed assembly sequences, cleaning, handling, and welding procedures are appended.

A number of separate tasks were performed as a service to NASA Lewis Research Center under this contract. These activities were distinct in purpose from the main object of the program. Brief discussions of these separate tasks have been appended to this report.

3.0 FUEL PIN ASSEMBLY FABRICATION

Fuel pins were constructed to NASA drawings CD-352472, CD-352471, and CD-352466, Figures 1, 2, and 3. The drawing nomenclature will be used in the discussions throughout this report. A summary of the hardware produced in this program is presented in Table 1. Assembly and fabrication procedures are described in general in this section of the report while detailed step by step assembly and inspection procedures are included in the Appendices.

In addition, detailed specifications have been prepared and assembled for use in fabrication and inspection of prototype reactor fuel pins (see Figure 1, Drawing CD-352472). These specs are designed for general contractural control of manufacturing procedures. These documents have been included as Supplement 1 to this report.

3.1 FUEL PIN DESCRIPTION

Fuel pins are composed of ceramic uranium mononitride pellets sealed inside a T-111 alloy (Ta-8W-2Hf) container. A thin barrier of tungsten prevents contact of the uranium nitride fuel pellets with the T-111 cladding as these materials are not compatible at elevated temperature. Spacers are located at each end of the fuel stack to absorb differential expansion and fuel swelling.

Three types of fuel pins were fabricated in this program and are described as follows:

"L" Prototype - Figure 1, Dwg. CD352472, duplicates the fuel element design for the Advanced Power Reactor as close as possible. Fuel pin outside diameter is 1.91 cm (.75 in.), fuel stack length 38.1 cm (15.0 in.), and clad thickness .147 cm (.058 in.).

"L" Instrumented - Figure 2, Dwg. CD352471, specifically designed for inpile testing and contained thermocouple wells in end caps that extended into the end fuel pellets for direct measurment of the fuel temperature. The dimensions of the "L" prototype above are applicable to the "L" instrumented. The only differences are in the end cap and spacer design.

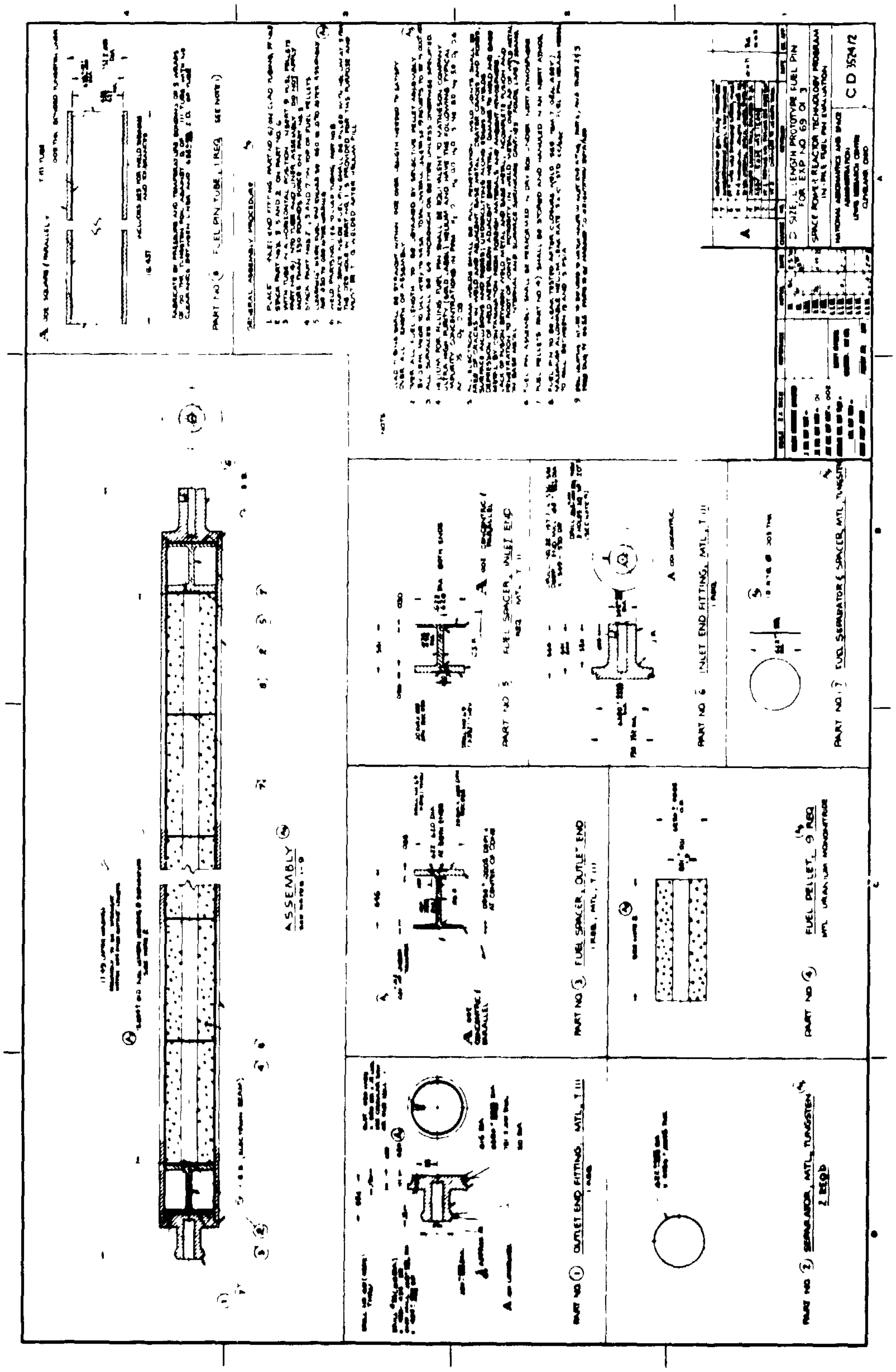


Figure 1. NASA Drawing CD-352472

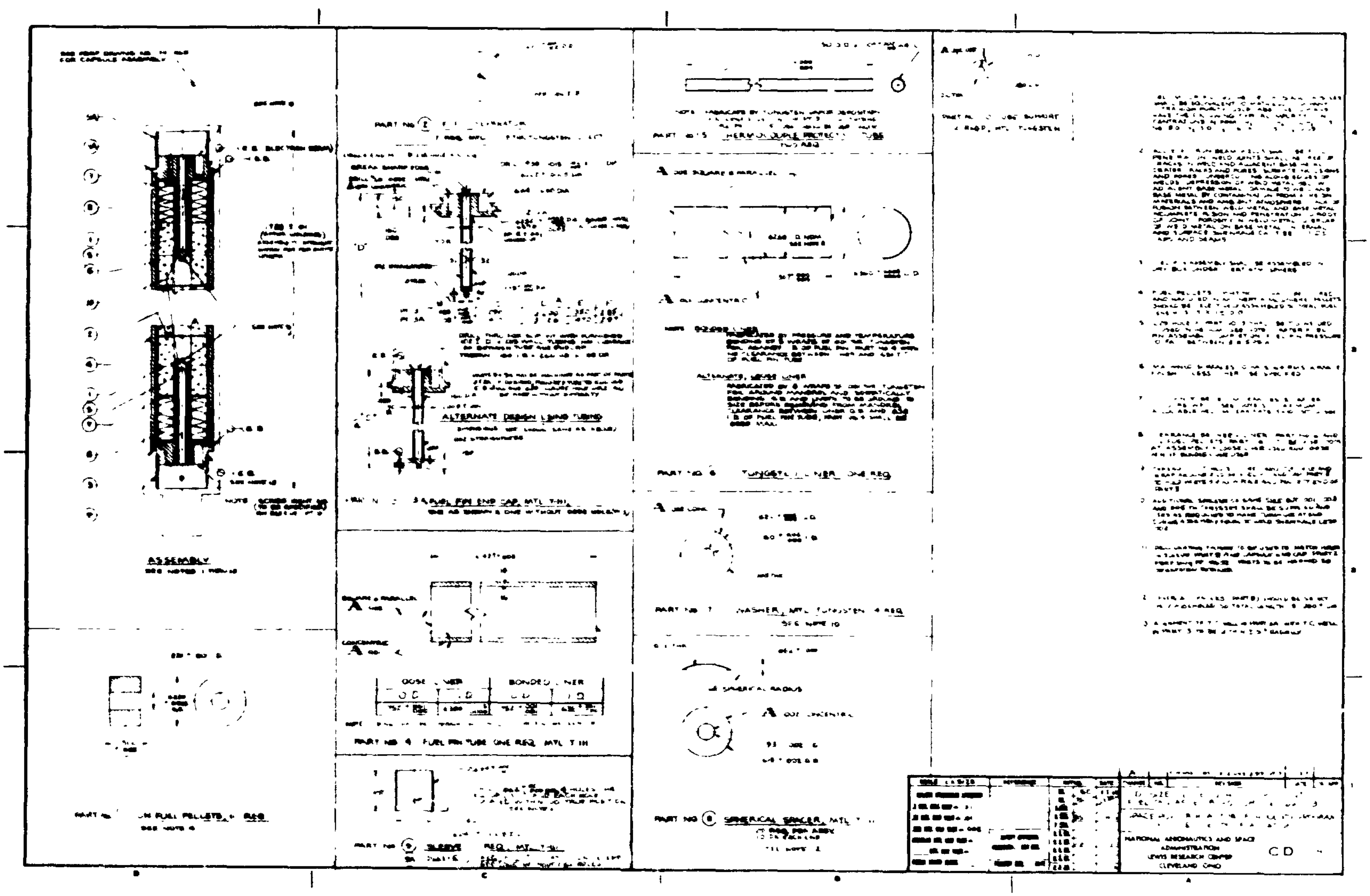


Figure 2. NASA Drawing CD-352471

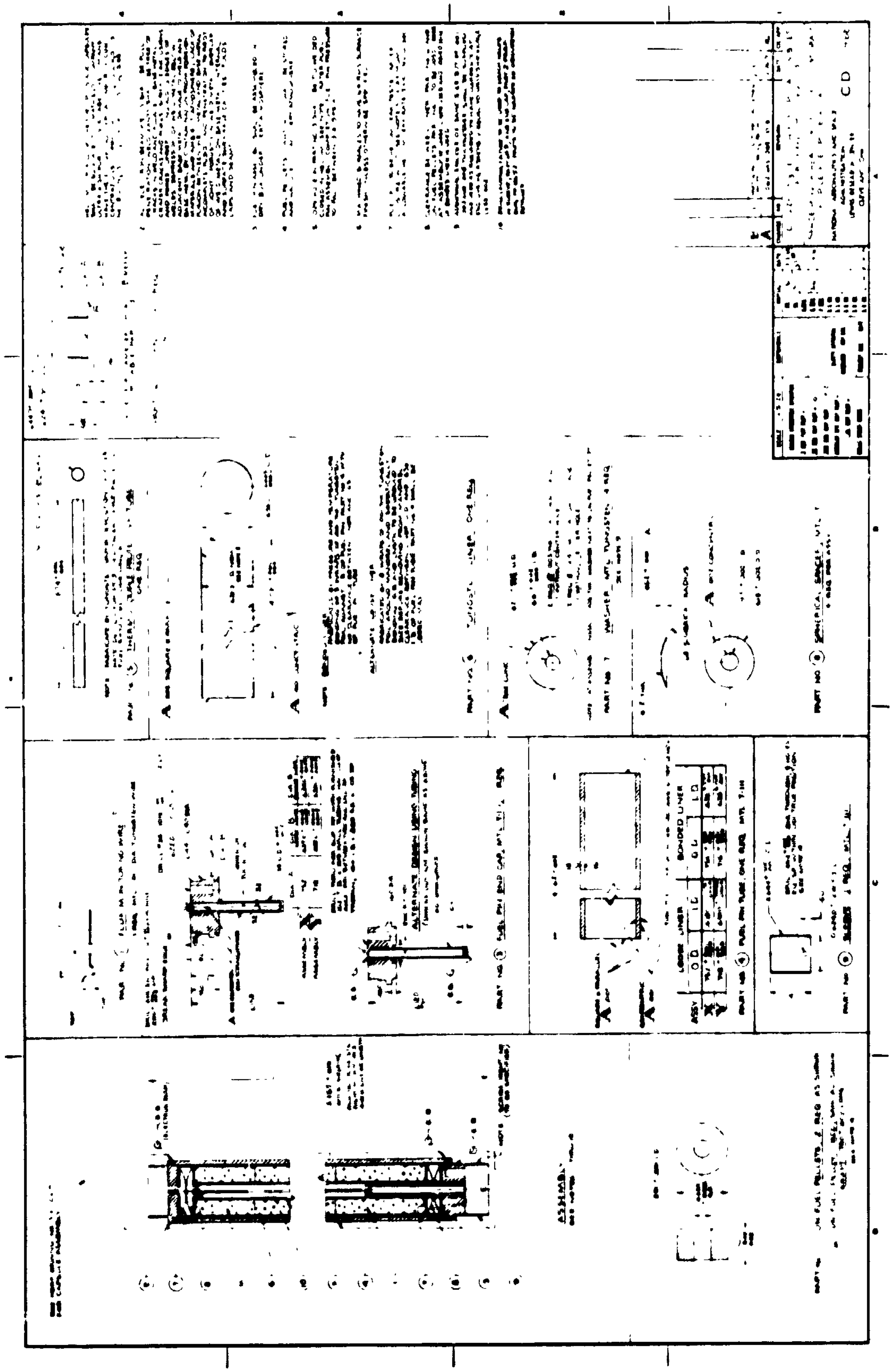


Figure 3. NASA Drawing CD-352466

Table 1. Hardware Summary

Fuel Pin No.	Drawing No.	Fuel Pin Type	Fuel Pin Tube Wall Thickness (nom.)	Designated Purpose	Remarks	Disposition
603	CD-352471 Rev. A	"L" Instrumented	1.47 mm (.058 in.)	Dummy for practice capsule	Fuel pellets consisted of (3) enriched UN and (7) machined molybdenum	Encapsulated under Contract NAS 3-15332 Capsule 901-603
510A	CD-352471 Rev. A	"L" Instrumented	1.47 mm (.058 in.)	For reactor testing		Encapsulated under Contract NAS 3-15332 Capsule 901-510A
510B	CD-352471 Rev. A	"L" Instrumented	1.47 mm (.058 in.)	Spare		Encapsulated under Contract NAS 3-15332 Capsule 901-510B
512A	CD-352472 Rev. A	"L" Prototype	1.47 mm (.058 in.)	For reactor testing		Encapsulated under Contract NAS 3-15332 Capsule 901-512A
512B	CD-352472 Rev. A	"L" Prototype	1.47 mm (.058 in.)	For reactor testing		Encapsulated under Contract NAS 3-15332 Capsule 901-512B
512C	CD-352472 Rev. A	"L" Prototype	1.47 mm (.058 in.)	Spare		Encapsulated under Contract NAS 3-15332 Capsule 901-512C
514A	CD-352466 Rev. A	L/3 "X" Assembly	1.47 mm (.058 in.	For reactor testing		Encapsulated under Contract NAS 3-15332 Capsule 901-514A
514B	CD-352466 Rev. A	L/3 "X" Assembly	1.47 mm (.058 in.)	For reactor testing		Encapsulated under Contract NAS 3-15332 Capsule 901-514B
514C	CD-352466 Rev. A	L/3 "X" Assembly	1.47 mm (.058 in.)	Spare		Encapsulated under Contract NAS 3-15332 Capsule 901-514C
604	CD-352466 Rev. A	L/3 "X" Assembly	1.47 mm (.058 in.)	Out of pile tests	Fuel stack length 7.62 mm (.30 in.) short fuel exposed to air	Delivered to NASA
605	CD-352466 Rev. A	L/3 "X" Assembly	1.47 mm (.058 in.)	Out of pile tests	Fuel stack length 7.62 mm (.30 in.) short fuel exposed to air	Delivered to NASA
516A	CD-352466 Rev. A	L/3 "Y" Assembly	1.01 mm (.040 in.)	Spare	Fuel pin inlet sleeve damaged while handling; repair was made	Encapsulated under Contract NAS 3-15332 Capsule 901-516A

Table 1 (Continued)

Fuel Pin No.	Drawing No.	Fuel Pin Type	Fuel Pin Tube Wall Thickness (nom.)	Designated Purpose	Remarks	Disposition
516B	CD-352466 Rev. A	L/3 "Y" Assembly	1.01 mm (.040 in.)	For reactor testing		Encapsulated under Contract NAS 3-15332 Capsule 901-516B
516C	CD-352466 Rev. A	L/3 "Y" Assembly	1.01 mm (.040 in.)	For reactor testing		Encapsulated under Contract NAS 3-15332 Capsule 901-516C
518A	CD-352466 Rev. A	L/3 "Y" Assembly	1.01 mm (.040 in.)	For reactor testing		Encapsulated under Contract NAS 3-15332 Capsule 901-518A
518B	CD-352466 Rev. A	L/3 "Y" Assembly	1.01 mm (.040 in.)	Spare		Encapsulated under Contract NAS 3-15332 Capsule 901-518B

B

"L/3" Fuel Pins - Figure 3, Dwg. CD352466, constructed similar to "L" instrumented except have provision for instrumentation from only one end. Fuel stack length is 9.22 cm (3.75 in.). "L/3" pins have two different clad thicknesses, .147 cm (.058 in.) designated as "X" assemblies and .102 cm (.040 in.) designated as "Y" assemblies.

All fuel pins have the same inside diameter, 1.61 cm (.636 in.), a .0127 cm (.005 in.) thick tungsten liner bonded to the clad I. D. giving a liner I. D. of 1.59 cm (.626 in.), the same diametrically sized fuel pellets 1.58 cm (.622 in.) O. D. x .51 cm (.201 in.) I. D., and fuel pellets with an average U-235 enrichment of 5.03%.

3.1.1 Piece Part Fabrication

Fuel pin piece parts were fabricated by various methods depending on the material and configuration of the part. Uranium nitride fuel was fabricated by cold isostatic pressing, sintering, and machining at the Oak Ridge National Laboratory under NASA contract C-60080-B. Tungsten washers and T-111 spacers were furnished by NASA as completed parts. Thermocouple protective tubes were fabricated by chemical vapor deposition utilizing the hydrogen reduction of gaseous WF_6. Deposition was performed on molybdenum mandrels heated to 600°C and was timed to yield a coating of the desired thickness. Mandrel and coating were cut to length and the mandrel removed by chemical etching leaving a tube of tungsten. The etching solution was composed of 50% nitric acid and 50% water by volume then adding 3.5% sulfuric acid as necessary to keep the reaction going. Tungsten liners were formed by wrapping foil on a mandrel and bonding the foil to the ID of the T-111 fuel pin tubes by a differential thermal expansion process. This procedure, performed by NASA-LeRC, is described in detail in Supplement 1. All other parts were constructed by conventional machining methods. Each finished piece part was 100% inspected to assure conformance with drawing requirements. In addition, the following inspection was performed on each fuel pin tube:

- Ultrasonic inspection for defects as described in Appendix G, Inspection Procedures.
- Ultrasonic inspection for wall thickness as described in Appendix G, Inspection Procedures.
- O. D. measurements recorded for every axial position at 0° and 90°. Axial positions were at each 1/2 inch increment along the entire tube length.
- Dye penetrant inspection as described in Appendix G, Inspection Procedures.
- Straightness measurements as described in Appendix G, Inspection Procedures.

Fuel pin tubes that were accepted after the above inspection and all other T-111 detailed parts were cleaned in accordance with Appendix E, Cleaning Procedures and vacuum annealed at $1589^{\circ}K$ ($2400^{\circ}F$) for one hour at a pressure less than 1.33×10^{-3} N/m^2 (10^{-5} torr). It was necessary for tungsten liners to be bonded to the ID of the fuel pin tubes after vacuum annealing to preclude the possibility of entrapment of cleaning solution between the liner and tube.

A cross reference of each piece part fabricated in this program, the raw material from which it was made, the fabrication process, and the inspection procedures are presented in Appendix G.

3.1.2 Assembly

Fuel pins were completely assembled, welded, and sealed in the chamber of an electron beam welder modified for inert gas glove box operation, Figure 4. This permitted vacuum degassing of components and fuel at a pressure less than 1.33×10^{-3} N/m^2 (10^{-5} torr) prior to assembly and also provided an inert gas cover for fuel handling. Hence, the fuel, which was received in a sealed canister containing an inert cover gas, was never compromised by exposure to air. This approach had numerous advantages:

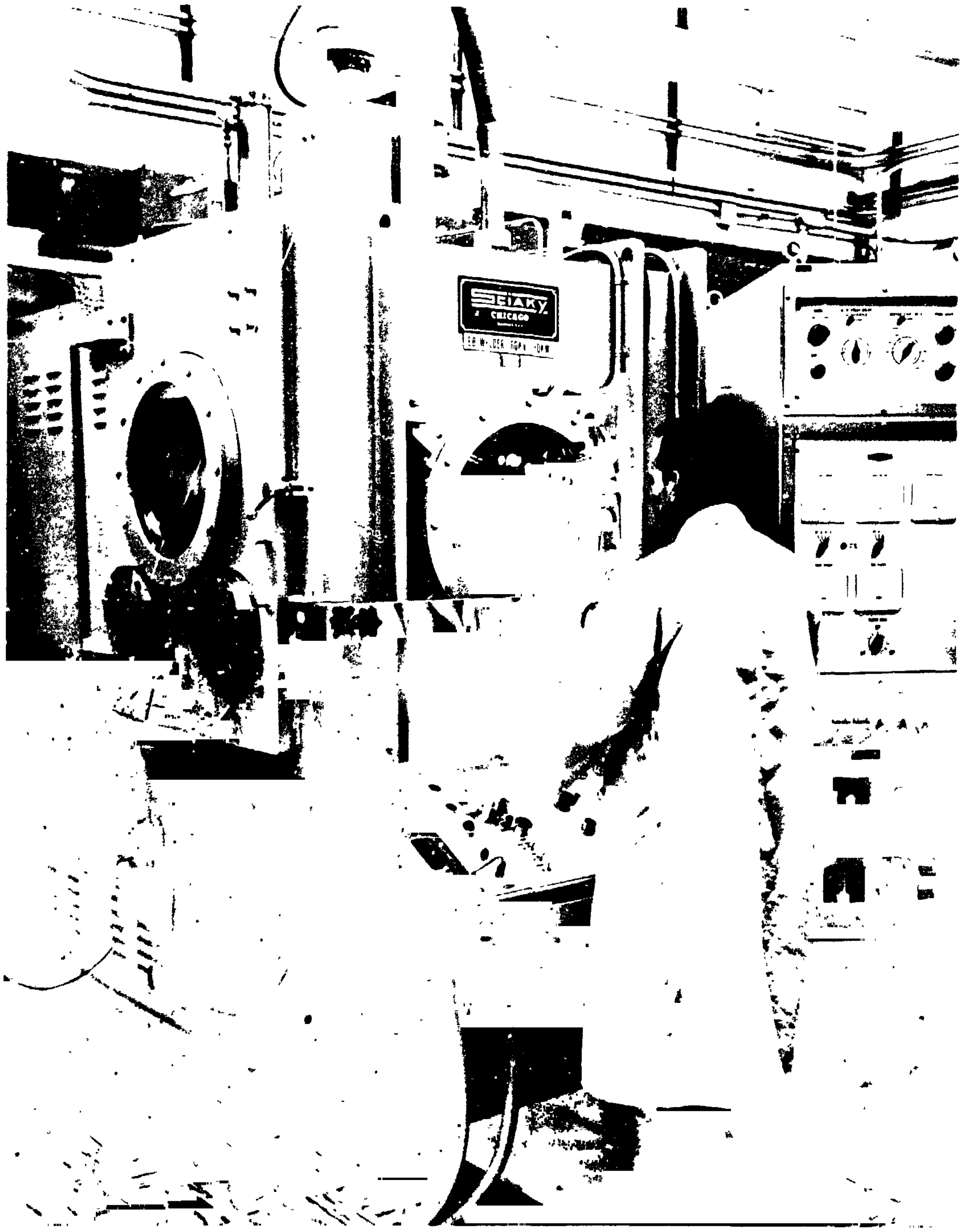


Figure 4. Sciaky Welding and Assembly Chamber

- It provided the cleanest possible environment for handling components.
- Contamination of fuel pellets was avoided in the event that difficulty was encountered since they could be stored indefinitely in sealed holding containers located within the weld chamber if opening the chamber became necessary.
- The weld assembly chamber was equipped with an inert gas monitoring system to assure compliance with high standards required for refractory metals. Ultra-high purity helium was used throughout for fuel pin assembly.
- Only one lot of helium was used for this project. Hence, all handling and backfilling of fuel pins and capsules could be accomplished with the fully qualified high purity helium under ideal monitored conditions.
- In all cases an overnight pumpdown 1.33×10^{-4} N/m ^{2} (10^{-6} torr range) was employed with heat lamp bakeout ($\sim 366^{o}$K, 200^{o}F) to assure degassing of adsorbed gases by both pin components and fuel. The overnight pumpdown was preceded by a short pumpdown and backfill of inert gas. During this backfill the fuel is removed from its shipping container to permit overnight degassing.

In all cases after final cleaning, extreme care was exercised to prevent fuel pin parts from contacting any metallic surface except refractory metals. This precaution is necessary to prevent possible metallic contamination of the T-111 alloy. Work surfaces, tools, and containers used in the assembly and welding of fuel pins are made from, covered, or coated with refractory metals.

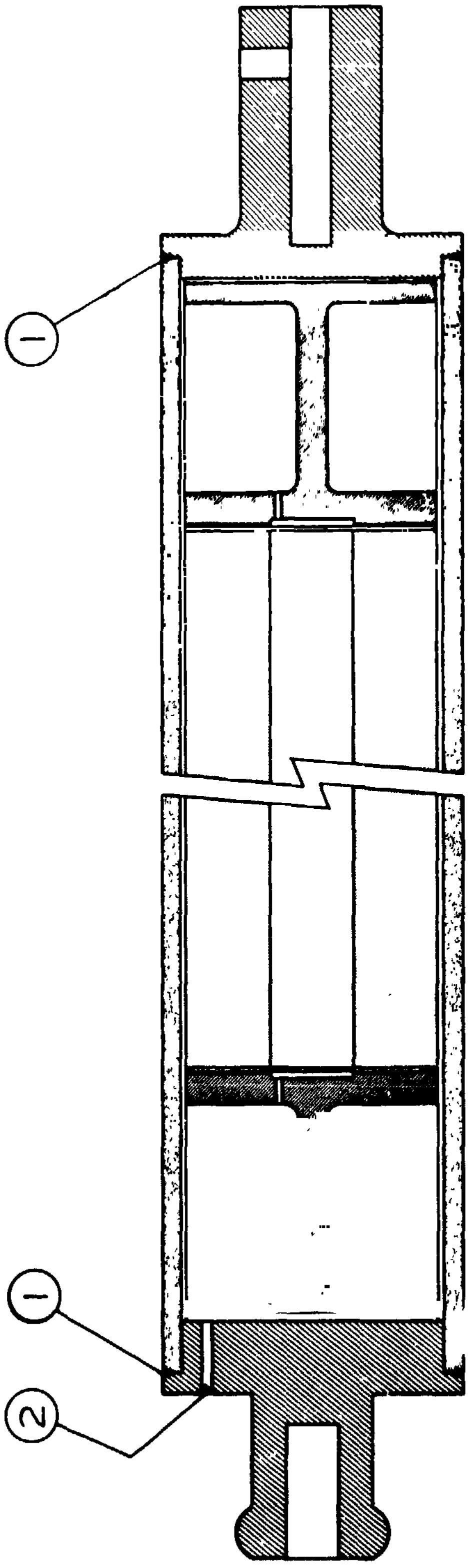
Final assembly consisted of inserting fuel, washers, spacers, and end caps in the proper order into the fuel pin tubes. Specific details and sequence of assembly are included in Appendices B, C, and D. A pre-irradiation data record was compiled for each fuel pin constructed. This serves as a permanent record of pertinent information unique to that particular fuel pin. A pre-irradiation fuel pin data record is included in Appendix A.

3.1.3 Welding

Following final assembly, end caps are electron beam welded to fuel pin tubes. Appendix F describes the general welding procedure applied to all welding in this program and also includes the welding procedure parameters for each different weld joint. Figures 5, 6, and 7 indicate the location of each weld for each different type fuel pin and identifies them to the individual weld procedure documentation. The final gas tungsten arc seal weld is the only weld not performed with the electron beam process.

Electron beam welded construction proved to be advantageous throughout the assembly of the fuel pins. The narrowness of EB welds coupled with deep penetration permits use of minimum thickness end caps. This characteristic minimizes total weld heat input thereby minimizing weld distortion allowing weld joints to be designed for self alignment. This feature was essential in achieving overall straightness so that fuel pins could maintain concentricity with the capsule.

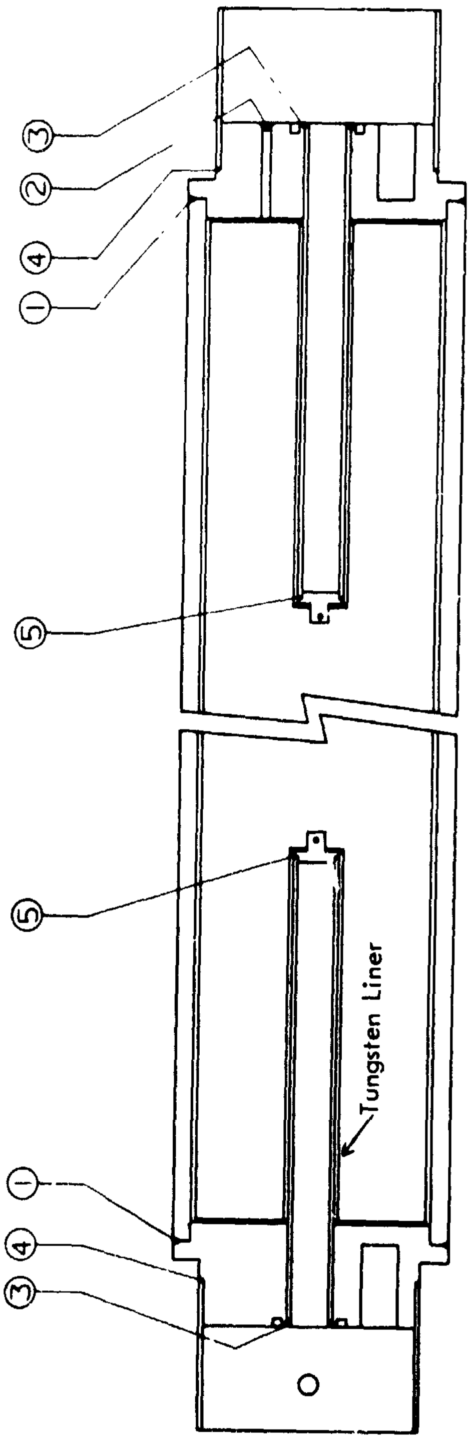
Quality requirements for these welds as defined by the drawings are restrictive and including among others: full penetration; freedom from cracks in welds or adjacent base metal; and freedom from porosity, lack of fusion and overlap. To achieve these requirements, qualified procedures and careful in-process control was employed in addition to post-weld nondestructive testing including visual, dyepenetrant, helium leak testing, and radiographic inspection. Process control welds were produced immediately prior to the production weld lot for each different weld joint. These were sectioned and examined for anomalies. A process control weld was made before and after welding end caps to each "L" fuel pin and each lot of "L/3" fuel pins. These welds were sectioned so that both the longitudinal and circumferential view of the weld could be examined. Figures 8 and 9 are a typical process control weld sectioned in this manner.



1 - Fuel Pin End Cap to Fuel Pin Tube - EB Weld Procedure No. 70821-1

2 - Fuel Pin Final Closure - GTA Weld Procedure No. 70821-2

Figure 5. Weld Location Schematic L-Prototype Fuel Pin



1 - Fuel Pin End Cap to Fuel Pin Tube - EB Weld - Procedure No. 70821-1

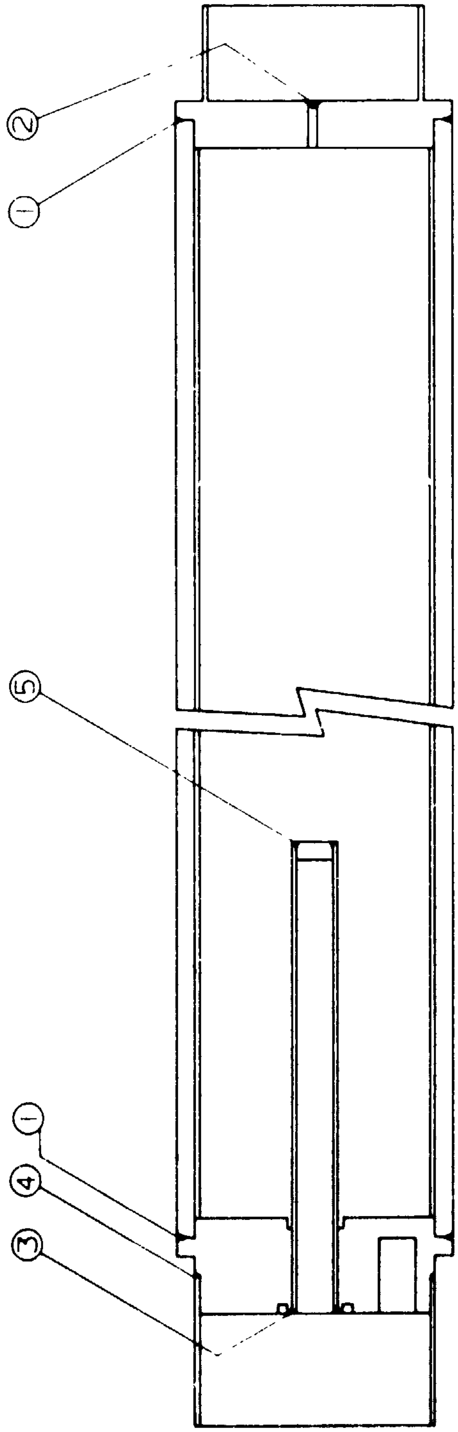
2 - Fuel Pin Final Closure - GTA Weld - Procedure No. 70821-2

3 - Thermocouple Well to End Cap - EB Weld - Procedure No. 70821-3

4 - Sleeve to End Cap Weld - .020 wall - EB Weld - Procedure No. 70821-4

5 - Thermocouple Well Plug to Tube (L-I Configuration) - Procedure No. 70821-5

Figure 6. Weld Location Schematic L-Instrumented Fuel Pin



1 - Fuel Pin End Cap to Fuel Pin Tube (X & Y) - EB Weld - Procedure No. 70821-1

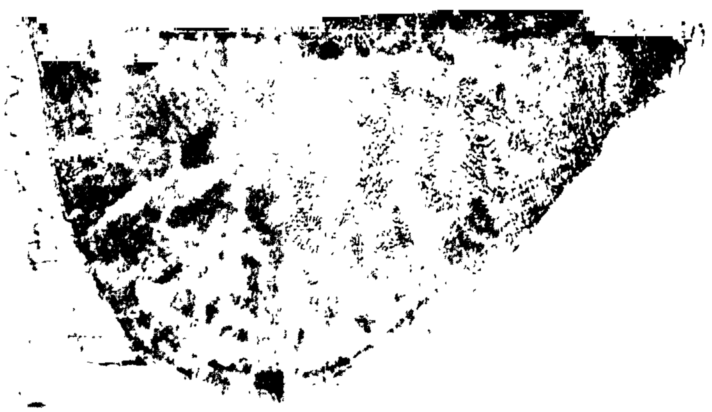
2 - Fuel Pin Closure - GTA Weld - Procedure No. 70821-2

3 - Thermocouple Well to End Cap - EB Weld - Procedure No. 70821-3

4 - Sleeve to End Cap Weld - .010 Wall - EB Weld - Procedure No. 70821-4A

5 - Thermocouple Well Plug to Tube (L/3 Configuration) - Procedure No. 70821-5A

Figure 7. Weld Location Schematic L/3 Fuel Pin



30X

Figure 8. Typical Process Control Weld, Longitudinal View

5X

Figure 9. Typical Process Control Weld, Circumferential Cross Section View

As an added precaution, a bead on tube weld was also made before welding end caps to fuel pins. This allowed a quick, visual check on penetration depth just before end cap welds were made.

In every case on this program, process control welds and production welds met all applicable quality requirements.

3.1.4 Inspection

Completed fuel pins as well as sub-components, finished parts, and raw materials were thoroughly inspected and documented throughout construction. Details of inspection methods and procedures are presented in Appendix G. The assembly checkoff procedures and the pre-irradiation fuel pin data in Appendices A, B, C, and D provide a record of the inspection methods used and the sequence in which it was performed.

A complete quality analysis was performed for each fuel pin constructed. This analysis included a review of all fuel pin construction and inspection records and a comparison with drawing requirements as well as applicable specifications. Deviations were recorded for disposition and remain a part of the permanent fuel pin record.

APPENDIX A

PRE-IRRADIATION FUEL PIN DATA

PRE-IRRADIATION FUEL PIN DATA

A. Fuel Pin Data — Date Completed ____________

1. Fuel Pin Ident. No. ______________
2. Size Designation ______________
3. Assembly Designation ____________
4. Drawing No. ______________ Rev. __________

B. Fuel Pellet Data

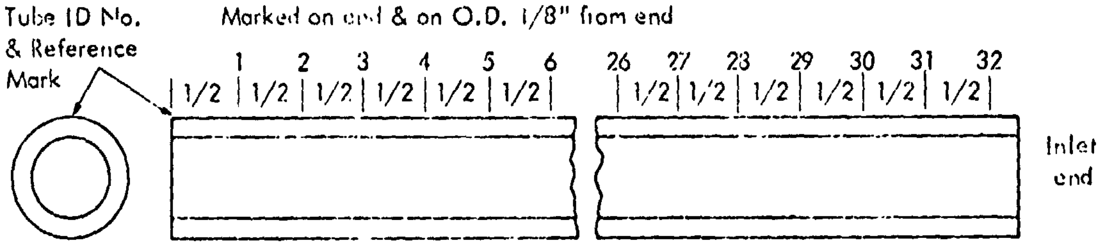
Pellet No.	ORNL No.	Fuel Type	I.D. (in.)	O.D. (in.)	Wt. GMS	Length (in.)	Avg. U-235 Enrichment
(Inlet) 1							
2							
3							
4							
5							
6							
7							
8							
9							
(outlet) 10							
				TOTAL			

Measured Stack Length ________________

C. Fuel Pin Tube

1. Material ______________
2. Ident. No. ____________
3. Heat No. ____________
4. Length ______________

5. Fuel Pin Tube Measurements



ID Dia. Test	Axial Position	After Machining O.D. 0°	After Machining O.D. 90°	After Machining Wall Thickness max.	After Machining Wall Thickness min.	After Machining T.I.R.	Completed Fuel Pin T.I.R.	Completed Fuel Pin O.D. 0°	Completed Fuel Pin O.D. 90°
	1					—	—		
	2								
	3					—	—		
	4					—	—		
	5					—	—		
	6					—	—		
	7								
	8					—	—		
	9					—	—		
	10					—	—		
	11					—	—		
	12					—	—		
	13								
	14					—	—		
	15					—	—		
	16					—	—		
	17					—	—		
	18					—	—		
	19								
	20					—	—		
	21					—	—		
	22					—	—		
	23					—	—		
	24					—	—		
	25								
	26					—	—		
	27					—	—		
	28					—	—		
	29					—	—		
	30					—	—		
	31								
	32					—	—		

Straightness (Appendix G, Section 7C)

	Radial Position	(Axial traverse by dial indicator from a flat parallel surface) (outlet) end	2"	4"	6"	8"	10"	12"	14"	16"	(inlet) end
Before Ass'y	0°										
	90°										
After Ass'y	0°										
	90°										

D. Fuel Pin Tube Liner (Between Fuel & Tube)

1. Material ______________
2. Bonded or loose ______________
3. Distance from outlet end of tube to liner (see figure Section I) ______________
4. Distance from inlet end of tube to liner (see figure Section I) ______________

E. End Caps

1. (Inlet) end cap Material ________ Ident. No. ________
2. (Outlet) end cap Material ________ Ident. No. ________

F. Thermocouple Protective Tube(s)

	Inlet	Outlet
1. Material	________	________
2. Ident. No.	________	________
3. O.D.	________	________
4. I.D.	________	________
5. Length	________	________

G. Spacers

Material ________

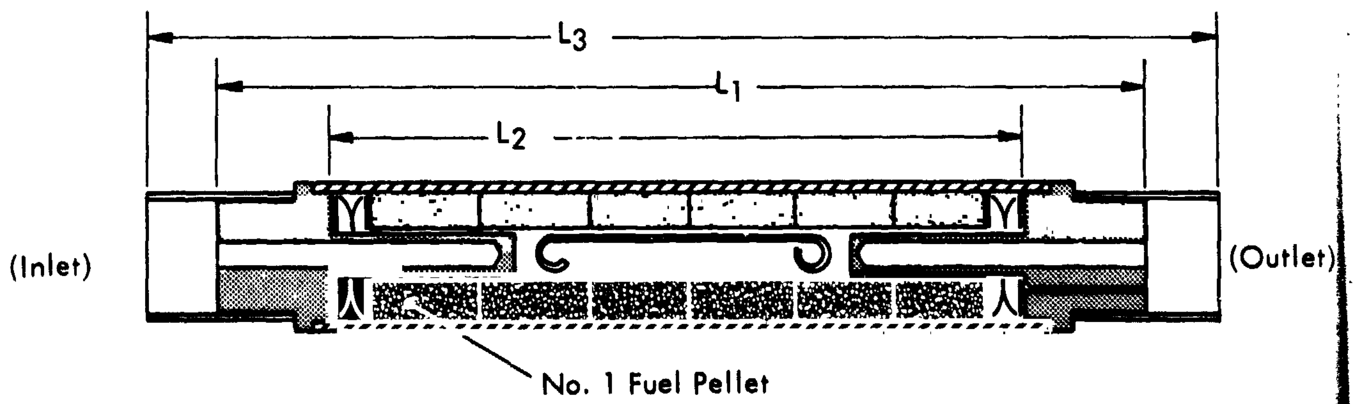
Location	No. Spacers	Thickness	Total Height
Inlet			
Outlet			

H. Washers & Separators

Material ____________

Location	No. Washers	Total Thickness	Center Hole Dia.
Inlet next to end cap			
Inlet next to fuel			
Between pellet 1 & 2			
Between pellet 2 & 3			
Between pellet 3 & 4			
Between pellet 4 & 5			
Between pellet 5 & 6			
Between pellet 6 & 7			
Between pellet 7 & 8			
Between pellet 8 & 9			
Between pellet 9 & 10			
Outlet next to fuel			
Outlet next to end cap			

I. Fuel Pin Measurements



1. L_1 Between end cap flats (outside, before welding) ____________
2. L_2 Between end cap flats (inside, before welding) ____________
3. Total internal stack length:
   (a) Fuel ________
   (b) Spacers ________
   (c) Washers ________
   (d) Weld Shrinkage Allowance ________

4. L_1 Between end cap flats (outside, after welding) ________
5. L_3 Overall length (after welding) ________
6. Weight of Assembly ________
7. O.D. measurements (See C-5)
8. Fuel Pin overall straightness ________

J. Fuel Pin Closure

1. Helium Pressure (psia) ________ Temperature (°F) ________
2. Helium Purity (ppm) (From supplier certification)
   (a) H ____
   (b) Ne ____
   (c) N ____
   (d) O_2 ____
   (e) A ____
   (f) CO_2 ____
   (g)
   (h)
3. Helium Purity (ppm) Ⓦ Spot Check
   H_2O ______
   O_2 ______

K. Inspection

1. Visual ______________ Date ______________ Initial ______________
2. Ident. No. ______________ Date ______________ Initial ______________
3. Helium Leak Check ________ Date ______________ Initial ______________
   Standard Leak Rating ________ Leak Detector Scale Reading ________
   Test Chamber Empty Scale Reading ________ With Fuel Pin ________
4. Dye Penetrant ______________ Date ______________ Initial ______________
5. X-ray ______________ Date ______________ Initial ______________

APPENDIX B

FUEL PIN ASSEMBLY CHECKOFF - "D" SIZE, L/3 LENGTH

FUEL PIN ASSEMBLY CHECKOFF
"D" SIZE L/3 LENGTH
DWG CD-352466 REV. _____

I. PREPARATION

Initial

_________ 1. Fuel Pin I.D. No. ____________________ Assembly ________________

_________ 2. Select the following parts and verify complete material certification and identification as designated in the "Pre-Irradiation Fuel Pin Data" section.

_____a. One fuel pellet group (Part No. 1).
_____b. One outlet end cap (Part No. 2)
_____c. One inlet end cap (Part No. 3)
_____d. One fuel pin tube (Part No. 4). (Tube was cleaned before bonding liner.)
_____e. One thermocouple protective tube (Part No. 5).
_____f. One set of washers as required (Nom. 4) (Part No. 7).
_____g. Four spherical spacers (Part No. 8)
_____h. One flux monitoring wire (Part No. 10).

_________ 3. Complete necessary sections of Pre-Irradiation Fuel Pin Data sheets.

_________ 4. Clean parts b. thru h. above (except for "d" which was cleaned before bonding liner, handle accordingly) as specified in cleaning procedure section of this checkoff. Note: all cleaning is to be accomplished as near to time of use as practical. Handle refractory metal parts only with refractory metal tools.

_________ 5. Clean equipment, tools and storage containers as specified under cleaning procedure section of this checkoff.

_________ 5. a. Weld together inlet end cap parts using alternate design Part 3, dwg. 352466.

_________ 5. b. Leak check end cap.

_________ 6. Stack (1) .003 thick "W" washer next to end cap then (2) spherical spacers (small end back to back) and (1) .005 thick "W" washer on inlet end cap Part No. 3.

_________ 7. Load parts for one fuel pin into glove box.

_________ 8. Load clean fuel pin assembly plug and measuring instruments into glove box.

_________ 9. Load clean handling tools and welding fixtures into glove box.

NOTE: All surfaces that will contact fuel pin parts during assembly and welding must be constructed from or coated with refractory metal.

_________ 10. Load sample weld pieces into weld box with one sample ready to weld.

II. PUMPDOWN

Initial

__________ 1. Evacuate Glove box to at least 5×10^{-5} torr. Press _______________

__________ 2. Backfill glove box with UHP helium to 1 atmosphere.

__________ 3. Open fuel container and make visual check of fuel. Set fuel out of container so that it will degass properly.

__________ 4. Evacuate glove box to the 10^{-6} range while heating fuel and fuel pin parts to 200°F with heating lamps. PRESSURE __________ (Normally an overnight pumpdown is desirable).

_____ a. Weld sample piece immediately before backfill.

__________ 5. Backfill with UHP helium to atmospheric pressure.

__________ 6. Monitor and record O_2 and H_2O level in glove box. O_2 _______________ H_2O __________

III. FUEL PIN ASSEMBLY

__________ 1. Insert stepped plug into outlet end of fuel pin tube liner subassembly and hold in the horizontal position.

__________ 2. Load fuel pellets (Part No. 1) into fuel pin tube in the order specified in Pre-Irradiation Fuel Pin data sheet.

__________ 3. Insert thermocouple protective tube (Part No. 5).

__________ 4. Insert inlet end cap and washers into fuel pin tube.

__________ 5. Rotate fuel pin to the vertical position resting on inlet end cap and remove plug.

__________ 6. Insert flux monitoring wire (Part No 10) into fuel pin with closed end toward outlet.

__________ 7. Stack (1) .005 "W" washer without center hole next to fuel then (2) spherical spacers (small end back to back) and finally as many .003 and .005 washers as indicated for correct clearance in fuel pin Pre-Irradiation section.

__________ 8. Insert outlet end cap into fuel pin tube.

III. FUEL PIN ASSEMBLY (Continued)

Initial

_________ 9. Measure length of fuel pin before welding _____________ (outside end cap flats).

_________ 10. Load fuel pin assembly into EB weld fixture and weld both end caps to fuel pin tube.

_________ 11. Backfill chamber with ultra pure helium.

_________ 12. Visually inspect welds.

_________ 13. Load and weld sample weld piece.

IV. FUEL PIN FINAL SEAL

_________ 1. Position fuel pin and welding electrode for final seal.
a. Make a sample seal weld on a practice piece.

_________ 2. Record chamber O_2 _______ and H_2O _______ (must each be 5.0 PPM or less before proceeding).

_________ 3. Record chamber temperature ________ and pressure _________.

_________ 4. Make seal weld.

_________ 5. Visually inspect seal weld.

V. INSPECTION, HANDLING AND SLEEVE INSTALLATION

NOTE: Handle fuel pin carefully and avoid any contamination of end caps or thermowells as these will not be recleaned.

_________ 1. Remove sealed fuel pin from weld chamber and immediately helium leak check.

a. Leak detector calibration - minimum detectable leak ___________ std. cc/sec.

b. Fuel pin leak rate ___________ std. cc/sec.

_________ 2. Store fuel pin in a clean receptacle until ready to install sleeve.

_________ 3. Drill (4) .062 dia. holes in .450 lg sleeve using matched drilling fixture.

V. INSPECTION, HANDLING AND SLEEVE INSTALLATION (Continued)

_________ 4. Deburr and clean sleeve per cleaning procedure.

_________ 5. EB weld sleeve to inlet end cap using alignment fixture.

_________ 6. Insert rubber plug into each end cap sleeve and tighten.

_________ 7. Visually inspect fuel pin welds. Result ______________________________

_________ 8. Check NASA identification number on inlet end plug.

_________ 9. Dye penetrant inspect fuel pin welds. Outlet end cap _____ Inlet end cap_____ Seal _____

a. Section all sample welds and inspect.

_________ 10. Measure length of fuel pin.

_________ 11. X-ray fuel pin. 0° and 90°

_________ 12. Measure straightness & OD of fuel pin. (See Appendix A, Section C-5 of Pre-irradiation Fuel Pin Requirements and Appendix G, Section 7 of Inspection Procedures)

_________ 13. Clean fuel pin as per attached cleaning procedure Appendix E, Section A, Steps 1 thru 5. NOTE: Keep rubber plugs inserted while cleaning.

_________ 14. Remove end plugs and degass 1 hour at 2000°F wrapped in Ta foil in vacuum of 5×10^{-5} torr or better. Furnace cool to room temperature before removing.

_________ 15. Pressurize to 50 psig helium for 1/2 hour then leak check.

a. Leak detector calib. ____________ std. cc/sec.
b. Fuel pin leak rate ____________ std. cc/sec.

_________ 16. Weigh fuel pin ____________

DATE ________________________

SIGNED ______________________

REMARKS: ____

____

____

____

APPENDIX C

FUEL PIN ASSEMBLY CHECKOFF - "D" SIZE "L" LENGTH, INSTRUMENTED

FUEL PIN ASSEMBLY CHECKOFF
"D" SIZE "L" LENGTH INSTRUMENTED
Dwg. 352471 Rev. ___________

I. Preparation

Initial

__________ 1. Fuel Pin I.D. No. _______________

__________ 2. Select the following parts and verify complete material certification and identification as designated in the "Pre-Irradiation Fuel Pin Data" section. (Note: Complete necessary sections of "Pre-Irradiation Fuel Pin Data")

_______ a. One fuel pellet group (Part No. 1)
_______ b. One outlet end cap (Part No. 3A)
_______ c. One inlet end cap (Part No. 3)
_______ d. One fuel pin tube (Part No. 4) (Tube was cleaned before bonding liner.)
_______ e. Two thermocouple protective tubes (Part No. 5)
_______ f. One set of washers as required (Nom. 4) (Part No. 7)
_______ g. Twenty spherical spacers (Part No. 8)
_______ h. Seven fuel separators (Part No. 2)
_______ i. Two tube supports (Part No. 10)
_______ j. ~6.0" of .010 tungsten wire

__________ 3. Scribe a line 1/32" long x .003" wide x .003" deep in a straight line at each end of the fuel pin tube. Scribe a line .003" wide by .003" deep axially across largest OD of end caps directly adjacent to TC well.

__________ 4. Clean parts b thru j above (except for (d) which was cleaned before bonding liner, handle accordingly) as specified in cleaning procedure section of this checkoff. Note All cleaning is to be accomplished as near to time of use as practical. Handle refractory metal parts only with refractory metal tools.

__________ 5. Clean equipment, tools and storage containers as specified in cleaning section of this checkoff.

__________ a. Weld together end cap parts using alternate design Part No. 3 & 3A dwg. 352471.

__________ b. Leak check end caps

__________ 6. Stack washers and spherical spacers on inlet and outlet end caps in the arrangement specified in Section G and H of Pre-Irradiation Fuel Pin Data.

__________ 7. Install thermocouple protective tube over thermocouple well of inlet and outlet end caps.

__________ 8. Install tube support washer and tungsten wire on each end cap.

__________ 9. Load parts for one fuel pin into glove box.

Initial

__________ 10. Load clean fuel pin assembly plug and measuring instruments into glove box.

__________ 11. Load clean handling tools and welding fixtures into glove box.

NOTE: All surfaces that will contact fuel pin parts during assembly and welding must be constructed from or coated with refractory metal.

__________ 12. Load sample weld pieces into weld box and set up one for welding.

II. Pumpdown

__________ 1. Evacuate glove box to at least 5×10^{-5} torr. Press. __________

__________ 2. Backfill glove box with UHP helium to 1 atmosphere.

__________ 3. Open fuel container and make visual check of fuel. Set fuel out of container so that it will degass properly.

__________ 4. Evacuate glove box to the 10^{-6} torr range while heating fuel and fuel pin parts to ~200°F with heating lamps. Pressure __________. (Normally an overnight pumpdown is desirable.)

__________ 5. Make sample end cap to fuel pin tube weld immediately before backfill.

__________ 6. Backfill with UHP helium to atmosphere pressure.

__________ 7. Monitor and record O_2 and H_2O level in glove box.

O_2 __________ PPM H_2O __________ PPM

III. Fuel Pin Assembly

__________ 1. Insert stepped plug into outlet end of fuel pin tube liner sub-assembly and hold in the horizontal position.

__________ 2. Insert outlet fuel pellet (see Pre-Irradiation Fuel Pin Data for order) and push all the way through fuel pin tube until firmly against outlet mandrel.

__________ 3. Insert next fuel pellet & a separator and push all the way against outlet pellet.

__________ 4. Load a fuel pellet and fuel separator and push to last fuel pellet.

NOTE: A fuel separator is to be placed between each fuel pellet except between the outlet two pellets and inlet two pellets.

Initial

__________ 5. Continue loading in this manner until all pellets are in place.

__________ 6. Measure distance from end of fuel pin tube to first fuel pellet and check against end cap washer stack.

__________ 7. Insert inlet end cap with washers into fuel pin tube.
NOTE: Align mark on end cap with mark on fuel pin tube.

__________ 8. Remove plug and insert outlet end cap with washers into fuel pin tube.
NOTE: Align mark on end cap with mark on fuel pin tube.

__________ 9. Load fuel pin assembly into EB weld fixture and weld both end caps to fuel pin tube.

__________ 10. Backfill chamber with ultra pure helium.

__________ 11. Visually inspect welds.

__________ 12. Load and weld sample weld piece.

IV. Fuel Pin Final Seal

__________ 1. Position fuel pin and welding electrode for final seal.
a. Make a sample seal weld on a practice piece.

__________ 2. Record chamber O_2 ________ and H_2O _______ (must each be 5.0 ppm or less before proceeding).

__________ 3. Record chamber temperature _________ and pressure _________.

__________ 4. Make seal weld.

__________ 5. Visually inspect seal weld.

V. Inspection, Handling and Sleeve Installation

NOTE: Handle fuel pin carefully and avoid any contamination of end caps or thermowells as these will not be recleaned.

__________ 1. Remove sealed fuel pin from weld chamber and immediately helium leak check.
a. Leak detector calibration. Minimum detectable leak __________ std. cc/sec.
b. Fuel pin leak rate __________ std. cc/sec.

______ 2. Store fuel pin in a clean receptacle until ready to install sleeves.

______ 3. Drill (4) .062 dia. holes in .450 lg. sleeve using matched drilling fixture.

______ 4. Deburr and clean sleeve per cleaning procedure.

______ 5. EB weld sleeve with .062 holes to inlet end c p using alignment fixture.

______ 6. EB weld sleeve without holes to outlet end cap.

______ 7. Insert rubber plug into each sleeve and tighten.

______ 8 Visually inspect fuel pin welds. Result ______________

______ 9. Check NASA identification number on (inlet) end plug.

______ 10. Dye penetrant inspect fuel pin welds. Outlet end cap ________
Inlet end cap __________ Seal __________

a. Section all sample welds and inspect.

______ 11. Measure length of fuel pin.

______ 12. X-ray fuel pin. 0° and 90°

______ 13. Measure straightness & OD of fuel pin. (See Appendix A, Section C 5 of Pre-irradiation Fuel Pin Data and Appendix G, Section 7 of Inspection Procedures)

______ 14. Clean fuel pin as per attached cleaning procedure Appendix E, Section A, Steps 1 thru 5. Note: Keep rubber plugs inserted while cleaning.

______ 15. Remove end plugs and degass 1 hour at $2000^{\circ}F$ wrapped in Ta foil in vacuum of 5×10^{-5} torr or better. Furnace cool to room temperature before removing.

______ 16. Pressurize to 50 psig helium for 1/2 hour then leak check:

a. Leak detector calib. __________ std. cc/sec.
b. Fuel pin leak rate __________ std. cc/sec.

______ 17. Weigh fuel pin __________

DATE ______________________

SIGNED ______________________

REMARKS: ____

____

____

APPENDIX D

FUEL PIN ASSEMBLY CHECKOFF - "D" SIZE "L" LENGTH, PROTOTYPE

FUEL PIN ASSEMBLY CHECKOFF
"D" SIZE "L" LENGTH PROTOTYPE
Dwg. 352472 Rev. __________

I. PREPARATION

Initial

__________ 1. Fuel pin I.D. No. ____________________.

__________ 2. Select the following parts and verify complete material certification and identification as designated in the "Pre-Irradiation Fuel Pin Data" section. (Note: Complete necessary sections of "Pre-Irradiation Fuel Pin Data".)

a. One outlet end fitting (Part No. 1).
b. Two separators (Part No. 2).
c. Eleven separators (Part No. 2A).
d. One fuel spacer, outlet end (Part No. 3).
e. One fuel pellet group (Part No. 4).
f. One fuel spacer, inlet end (Part No. 5).
g. One inlet end fitting (Part No. 6).
h. Weld shrinkage spacers as required (Part No. 7).
i. One fuel pin tube (Part No. 8). (Tube was cleaned before bonding liner.)

__________ 3. Clean parts (a) thru (h)above (except Item (e)) as specified in cleaning procedure section of this checkoff. (Note: All cleaning is to be accomplished as near to time of use as practical.) Handle refractory metal parts only with refractory metal tools.

__________ 4. Clean equipment, tools and storage containers as specified in cleaning section of this checkoff.

__________ 5. Load parts for one fuel pin into glove box.

__________ 6. Load clean fuel pin assembly plug and measuring instruments into glove box.

__________ 7. Load clean handling tools and welding fixtures into glove box.

NOTE: All surfaces that will contact fuel pin parts during assembly and welding must be constructed from or coated with refractory metal.

__________ 8. Load sample weld pieces into weld box and set up for welding.

II. PUMPDOWN

Initial

_________ 1. Evacuate glove box to at least 5×10^{-5} torr. Press _________.

_________ 2. Backfill glove box with UHP helium to 1 atmosphere.

_________ 3. Open fuel container and make visual check of fuel. Set fuel out of container so that it will degass properly.

_________ 4. Evacuate glove box to the 10^{-6} torr range while heating fuel and fuel pin parts to $200^{\circ}F$ with heating lamps. Pressure _________. (Normally an overnight pumpdown is desirable.)

_________ 5. Make sample end cap to fuel pin tube weld immediately before backfill.

_________ 6. Backfill with UHP helium to atmospheric pressure.

_________ 7. Monitor and record O_2 and H_2O level in glove box.

O_2 _________ PPM H_2O _________ PPM

III. FUEL PIN ASSEMBLY

_________ 1. Insert stepped plug into outlet end of fuel pin tube liner subassembly and hold in the horizontal position.

_________ 2. Insert outlet fuel pellet and separator (see Pre-Irradiation Fuel Pin Data for order) and push all the way through fuel pin tube until firmly against mandrel.

_________ 3. Insert next fuel pellet and a separator and push all the way until it is firmly against outlet pellet.

_________ 4. Continue loading in this manner until all pellets are in place and a separator is between each 2 pellets.

_________ 5. Measure distance from end of fuel pin tube to 1st fuel pellet and check against spacer and washer length.

_________ 6. Insert a separator (Part No. 2A), fuel pin spacer - inlet end, a separator (Part No. 2), necessary number of weld shrinkage spacers (Part No. 7) and inlet end fitting into fuel pin tube.

III. FUEL PIN ASSEMBLY (Continued)

Initial

_________ 7. Remove plug and insert a separator (Part No. 2A), fuel spacer - outlet end, a separator (Part No. 2) and outlet end fitting into fuel pin tube.

_________ 8. Load fuel pin assembly into EB weld fixture and weld both end caps to fuel pin tube.

_________ 9. Backfill chamber with ultra pure helium.

_________ 10. Visually inspect welds.

_________ 11. Load and weld sample weld piece.

IV. FUEL PIN FINAL SEAL

_________ 1. Position fuel pin and welding electrode for final seal.
a. Make a sample seal weld on a practice piece.

_________ 2. Record chamber O_2 _______ and H_2O _______ (must each be 5.0 PPM or less before proceeding).

_________ 3. Record chamber temperature _________ and pressure _________.

_________ 4. Make seal weld.

_________ 5. Visually inspect seal weld.

V. INSPECTION

_________ 1. Remove sealed fuel pin from weld chamber and immediately helium leak check fuel pin.

_____ a. Leak detector calibration - minimum detectable leak ____________ Std. cc/sec.

_____ b. Fuel pin leak rate _________ Std. cc/sec.

_________ 2. Visually inspect fuel pin welds. Result ____________________________

_________ 3. Check NASA identification number on inlet end plug.

_________ 4. Dye penetrant inspect fuel pin welds. Outlet end cap ________ Inlet end cap _________ Seal _________

a. Section all sample welds and inspect.

V. INSPECTION (Continued)

Initial

__________ 5. Measure length of fuel pin.

__________ 6. Weigh fuel pin ________________

__________ 7. X-ray fuel pin. 0° and 90°

__________ 8. Measure straightness and OD of fuel pin. (See Appendix A, Section C-5 of Pre-irradiation Fuel Pin Data Sheets and Appendix G, Section 7 of Inspection Procedures.

__________ 9. Clean fuel pin as per attached cleaning procedure Appendix E, Section A, Steps 1 thru 5.

__________ 10. Degass 1 hour at 2000°F wrapped in ta foil in vacuum of 5×10^{-5} torr or better. Furnace cool to room temperature before removing.

__________ 11. Pressurize to 50 psig helium for 1/2 hour then leak check.

a. Leak detector calib. __________ Std. cc/sec.

b. Fuel pin leak rate __________ Std. cc/sec.

DATE ________________

SIGNED ______________

REMARKS: ____

APPENDIX E

CLEANING PROCEDURES

T-111, Ta, W, and Stainless Steel Cleaning Procedures

A. Refractory Metals Cleaning (Note: Handle parts while cleaning only with refractory metal or teflon coated tongs. Also to assure optimum cleanliness, perform cleaning operation as near to time of use as practical.)

1. Degrease parts by M-6 (oxylene) solvent rinse or ultrasonic cleaning.

2. Pickle with nitric-hydrofluoric-sulfuric acid solution nominally 20-15-10% balance water by volume. Time one to two minutes.

3. Rinse as follows (this is the most important step since pickling residues can cause surface contamination or degas severely on heating).

   a. Fast transfer from pickle bath to rinse without any surface drying of pickle solution.
   b. 30 seconds boiling distilled water.
   c. 1 minute flowing cold water.
   d. 5 minutes boiling distilled water (not the same water as in "b" above).
   e. Fast rinse in ethyl alcohol.
   f. Hot air flash dry.

4. Store in clean glass containers and/or in clean dry kim wipes. Polyethelene bags or other plastic containers not acceptable.

5. Handle only with clean tools or lint free gloves over pylox or quixams gloves.

6. Degas for 1 hour at 2400°F wrapped in tantalum foil in vacuum 5×10^{-5} torr or better. Furnace cool to room temperature before removing.

B. Stainless Steel Cleaning (Note: To assure optimum cleanliness, perform cleaning operation as near to time of use as practical.)

1. Scrub with "Comet" cleanser.

2. Rinse in flowing hot tap water.

3. Rinse in boiling distilled water.

4. Wash with ethyl alcohol.

Note: Very small parts and parts with small holes and crevices cannot be effectively cleaned by this method. Clean these parts in a clean ultrasonic tank using clean M-6 (oxylene) solvent for 15 minutes minimum then proceed to Step 4.

5. Air dry (hot air flash drying with heat gun acceptable)

6. Handle only with clean tools or lint free gloves over pylox or quixams gloves.

7. Store in clean glass containers and/or in clean dry kim wipes. Polyethelene bags or other plastic containers not acceptable.

Tools, Equipment and Containers Cleaning Procedure

A. Tools and Fixtures for Handling Refractory Metals

1. All tools and fixtures that contact refractory metal parts for welding or final assembly must be constructed of refractory metal or coated with refractory metal.

2. Tools and equipment are to be cleaned prior to use by the methods described below.

B. Small Tools and Equipment Cleaning

1. Degrease all small tools and equipment by ultrasonic cleaning or M-6 rinse.

2. Rinse with ethyl alcohol.

3. Air dry (hot air flash drying with heat gun acceptable).

C. Large Tools, Equipment and Containers

1. Degrease by wiping with rag or kim wipe saturated with M-6 or other suitable solvent.

2. Wipe dry with clean rag or kim wipe.

3. Wipe with rag or kim wipe dampened with ethyl alcohol.

4. Air dry.

APPENDIX F

WELDING PROCEDURES

WELDING

A. Fusion Welding

The principal document applied in the control of all fusion welding, either electron beam or tungsten arc, is WANL process specification PS 294614-1 (attached). This specification defines general weld quality requirements as revealed by visual, dye penetrant, and radiographic (where applicable) inspection.

Helium leak testing is also performed at various assembly stages as noted in the Fuel Pin Assembly Checkoff Procedures Appendices B, C, and D.

The welding specification defines the requirements for procedure qualification prior to production welding. Two sample parts must be produced with the final parameters to demonstrate capability. A "Welding Procedure Sheet" is prepared for each weld joint, defining the techniques employed. The seven procedures required for this program are attached.

Procedure No.: 70821-1

Date: 3-24-71

WELDING PROCEDURE

Name of Part: Fuel Pin End Cap to Fuel Pin Tube   Drawing No.: CD-352466, 71, 72

Welding Spec. No.: --

Material: T-111 Alloy   Material Spec. No.: --

Description of Welds Covered by this Procedure (type, size, location): Shoulder Joint - .058 in. wall tube to cap - Pass A approx. 3/4 in. dia.; .040 in. wall tube to cap - Pass B

Welding Process: Electron Beam

Welding Machine: Sciaky 30KW   Type Current: --

Electrode - Type: --   Size: --   Spec.: --

Filler Material - Comp.: --   Spec.: --

Shielding Gas: --   Backup Gas: --

Cleaning Prior to Welding: --

Detailed Procedure:

	Pass	A Pass	B Pass
Current		90 milliamps	60 milliamps
Voltage		20 KV	25 KV
Filler Wire Size			
Filler Feed Rate			
Travel Speed		15 RPM	15 RPM
Interpass Temp.			
Weld Position		Fuel Pin Horizontal	Fuel Pin Horizontal

Remarks (include details of fixturing, tacking where required, chills, etc.)

Weld Program: Initial and final current, 5 ma., initial slope rate - 300, final slope rate - 900, initial and final voltage - 14 KV, high voltage slope - 2.0, high voltage start delay .3 sec., run time 7.0 sec., decay time 2.0 sec.

Work Distance: 2 in. to bottom of scanner coil.

W59160

Procedure No.: 70821-2

Date: 6-16-71

WELDING PROCEDURE

Name of Part: Fuel Pin Final Closure   Drawing No. NASA-CD-352466, 71, 7:

Welding Spec. No. --

Material: T-111 Alloy   Material Spec. No. --

Description of Welds Covered by this Procedure: Arc spot seal of .029 in. dia. hole
(type, size, location)

Welding Process: Tungsten Arc

Welding Machine: Merrick 300 Amp Welder--Amp Trak   Type Current: DCSP

Electrode - Type: w (2% Thoria)   Size: 3/32 in.   Spec. --

Filler Material - Comp. --   Spec. --

Shielding Gas: UHP Helium   Backup Gas: --

Cleaning Prior to Welding: Pre-cleaned and handled in assembly chamber as defined in checkoff procedure.

Detailed Procedure:

	Pass	Pass	Pass
Current	140 amps.		
Voltage			
Filler Wire Size			
Filler Feed Rate			
Travel Speed			
Interpass Temp.			
Weld Position	Horizontal or Perpendicular		

Remarks (include details of fixturing, tacking where required, chills, etc.)

Weld current, 140 amps for 0.5 seconds then tapers to 50 amps during 0.75 seconds.

Amp-Trak settings: PFT = 0, IC = 140 amps, IT = 1 second, WT = 0.5 seconds.

WC (Pendant) 140 amps, taper = off, FST = 0.75 seconds, PHC = 50 amps, PHT = 0, PFT = 0.

Arc start settings: One shot (reset after each), intensity 60%.

W59160

Procedure No.: 70821-3

Date: 6-14-71

WELDING PROCEDURE

Name of Part: Thermocouple Well to End Cap   Drawing No. CD-352466 and 71

Welding Spec. No. --

Material: T-111   Material Spec. No. --

Description of Welds Covered by this Procedure (type, size, location): Edge Weld - .102 in. ID x .015 in. wall tube to .015 in. lip on the end cap

Welding Process: Electron Beam

Welding Machine: Hamilton-Zeiss   Type Current: --

Electrode - Type: --   Size: --   Spec. --

Filler Material - Comp. --   Spec. --

Shielding Gas: Vac. - 1 x 10^{-4} mm Hg (max.)   Backup Gas: --

Cleaning Prior to Welding: Precleaned to assembly checkoff procedure. Handle with clean lint free gloves. Contact only with refractory metal tools and handling devices.

Detailed Procedure:

	Pass	Pass	Pass
Current	2.5 MA		
Voltage	100 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	36 RPM		
Interpass Temp.			
Weld Position	Beam ∥ to tube axis		

Remarks (include details of fixturing, tacking where required, chills, etc.)

Weld Time - 1-1/2 revolutions

Work Distance - 1-1/2 in.

Deflection - zero

Pressure ≈5 x 10^{-4}

W59160

Procedure No.: 70821-4

Date: 3/24/71

WELDING PROCEDURE

Name of Part: Sleeve to End Cap Weld (.020 wall) Drawing No. CD-352471

Welding Spec. No. --

Material: T-111 Material Spec. No. --

Description of Welds Covered by this Procedure: Butt Weld Between Sleeve and End Cap
(type, size, location)

Welding Process: Electron Beam

Welding Machine: Sciaky Type Current --

Electrode - Type -- Size -- Spec. --

Filler Material - Comp. -- Spec. --

Shielding Gas: Vac 1 x 10^{-4} mm (maximum) Backup Gas --

Cleaning Prior to Welding: Precleaned to assembly checkoff procedure handle with clean, lint free gloves. Contact only with refractory metal tools and handling devices.

Detailed Procedure:

	Pass	Pass	Pass
Current	50 MA		
Voltage	20 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	15 RPM		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Weld Program: Initial and final current - 5 MA, initial slope rate - 300, final slope rate - 900, initial and final voltage - 14 KV, high voltage slope - 2, high voltage start delay - .3 sec., run time - 5.0 sec., decay time 2.0 sec.
2. Work distance - 2 in. to bottom of scanner coil.

W59160

Procedure No.: 70821-4A

Date: 3/24/71

WELDING PROCEDURE

Name of Part: Sleeve to End Cap Weld (.010 wall) Drawing No. CD-352466

Welding Spec. No. --

Material: T-111 Material Spec. No. --

Description of Welds Covered by this Procedure: Butt Weld Between Sleeve and End Cap
(type, size, location)

Welding Process: Electron Beam

Welding Machine: Sciaky Type Current: --

Electrode - Type: -- Size: -- Spec.: --

Filler Material - Comp.: -- Spec.: --

Shielding Gas: Vac 1×10^{-4} mm (maximum) Backup Gas: --

Cleaning Prior to Welding: Precleaned to assembly checkoff procedure handle with clean, lint free gloves. Contact only with refractory metal tools and handling devices.

Detailed Procedure:

	Pass	Pass	Pass
Current	30 MA		
Voltage	20 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	15 RPM		
Interpass Temp.			
Weld Position			

Remarks (include details of fixturing, tacking where required, chills, etc.)

1. Weld Program: Initial and final current - 5 MA, initial slope rate - 300, final slope rate - 900, initial and final voltage - 14 KV, high voltage slope - 2, high voltage start delay - .3 sec., run time - 5.0 sec., decay time - 2.0 sec.
2. Work distance - 2 in. to bottom of scanner coil.

W59160

E

Procedure No.: 70821-5

Date: 3-24-71

WELDING PROCEDURE

Name of Part: Thermocouple Well Plug to Tube (L-I)   Drawing No. CD-352471

Welding Spec. No. ____

Material: T-111 Alloy   Material Spec. No. ____

Description of Welds Covered by this Procedure (type, size, location): Electron beam weld of bottom plug to the tubular end cap extension. Butt weld - .015 penetration

Welding Process: Electron Beam

Welding Machine: Hamilton-Zeiss   Type Current: --

Electrode - Type: --   Size: --   Spec. --

Filler Material - Comp. --   Spec. --

Shielding Gas: Vac 1×10^{-4} mm Hg (max.)   Backup Gas: --

Cleaning Prior to Welding: Precleaned to assembly checkoff procedure. Handle with clean lint free gloves. Contact only with refractory metal tools and handling devices.

Detailed Procedure:

	Pass	Pass	Pass
Current	2.8 MA		
Voltage	100 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	36 RPM		
Interpass Temp.			
Weld Position	Tube axis ⊥ to beam		

Remarks (include details of fixturing, tacking where required, chills, etc.)

Manual start and taper

Work Distance - 1-1/2 in.

Deflection - zero

Pressure $\approx 5 \times 10^{-4}$

W59160

Procedure No.: 70821-5A

Date: 3/24/71

WELDING PROCEDURE

Name of Part: Thermocouple Well Plug to Tube (L/3) Drawing No. CD-352466

Welding Spec. No.

Material: T-111 alloy Material Spec. No.

Description of Welds Covered by this Procedure: Edge weld - .102 ID x .015 wall tube to plug inserted flush
(type, size, location)

Welding Process: Electron Beam

Welding Machine: Hamilton-Zeiss Type Current: --

Electrode - Type: -- Size: -- Spec.: --

Filler Material - Comp.: -- Spec.: --

Shielding Gas: Vac 1×10^{-4} mm Hg (max.) Backup Gas: --

Cleaning Prior to Welding: Precleaned to assembly checkoff procedure. Handle with clean lint free gloves. Contact only with refractory metal tools and handling devices.

Detailed Procedure:

	Pass	Pass	Pass
Current	2.8 MA		
Voltage	100 KV		
Filler Wire Size			
Filler Feed Rate			
Travel Speed	36 RPM		
Interpass Temp.			
Weld Position	Beam ‖ to tube axis		

Remarks (include details of fixturing, tacking where required, chills, etc.)

Manual start and taper

Work Distance - 1-1/2 in.

Deflection - zero

Pressure $\approx 5 \times 10^{-4}$

W59160

INFORMATION CATEGORY

UNCLASSIFIED

Authorized Classifier Date 9/10/64

Westinghouse Electric Corporation

Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pa. 15236
(Fed. Ident. Code No. 14683)

*PROCESS SPECIFICATION 294614, Revision No. 1
(Not for Publication)

November 21, 1968

WELDING, FUSION - AUSTENITIC STAINLESS STEELS FOR POWER GENERATING SYSTEMS

1. SCOPE

This specification covers requirements for fusion welding of austenitic stainless steels by the inert-gas tungsten arc, inert-gas metal arc, or electron beam process, intended for liquid metal or radioisotope heat source power generating systems, designated as follows:

Designation	Description
294614-1	Fusion welding of AISI 300 series stainless steels for systems requiring sound welds with no surface defects as indicated by liquid penetrant inspection.
294614-2	Fusion welding of AISI 300 series stainless steels for systems requiring sound welds with less restrictive surface quality requirements than 294614-1.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect, shall form a part of this specification to the extent specified herein.

MIL-T-5021 MIL-E-19933 MIL-STD-271 PS 294564 PDS 52118AE

2.2 Copies of MIL Specifications and Standards required by contractors in connection with specific procurement functions should be obtained as indicated in the Department of Defense Index of Specifications and Standards.

3. REQUIREMENTS

3.1 SAFETY: Some of the materials and/or operations required by this specification may be hazardous. The vendor is requested to consult a qualified Safety or Industrial Hygiene Engineer for necessary precautions. If processed by a Westinghouse plant, the instructions in Safe Practice Data Sheet, for example, Sheet W-1, shall be consulted to obtain information regarding the nature and properties of any material or processing requirement to avoid accident to employees or damage to equipment.

3.2 MATERIAL AND EQUIPMENT

3.2.1 Maintain all equipment including accessories, holders, leads, ground connections and any other equipment necessary to fulfill requirements of this specification at a level such that welds meeting the quality standards of this specification may be consistently produced. Maintenance within minimum accepted safety requirements is also required.

3.2.2 The welding area shall be protected from air movement due to fans, welding generators, open windows, exhaust hoods, etc.

3.2.3 The materials shall be as specified on the applicable drawing.

3.3 SURFACE PREPARATION: All foreign material shall be removed from both sides of the area that is to be welded or that will be heated by the welding.

3.3.1 All parts shall be free of grease and oil and other possible contaminates such as marking crayons, layout dyes, inks and similar materials prior to welding.

3.3.2 All oxides shall be removed from the immediate vicinity of the area to be welded. Extreme care shall be exercised in the cleaning procedures applied to each restrike area and to each completed weld prior to application of the next bead. All grit residue shall be removed with a clean, stainless steel wire brush prior to further welding. Pits or laps shall be blended mechanically before welding over them.

3.4 PROCESS

3.4.1 Manual or automatic inert-gas shielded tungsten arc or inert-gas metal arc processes, or the electron beam process shall be used.

3.4.2 Wherever feasible, grooved back-up bars or inert-gas backing shall be employed.

3.4.3 For tungsten arc welding, the electrode shall be the thoriated type and dressed to a point the diameter of which is one half that of the base.

3.4.4 Unless otherwise specified, the filler wire shall be as follows:

Base Material	Filler Wire
AISI 304	MIL-E-19933, Type 308
AISI 304L	MIL-E-19933, Type 308L
AISI 310	MIL-E-19933, Type 310
AISI 316	MIL-E-19933, Type 316
AISI 316L	MIL-E-19933, Type 316L
AISI 321	MIL-E-19933, Type 308L or 347
AISI 347 or 348	MIL-E-19933, Type 308L or 347

3.4.5 Shielding and backup gas shall be welding grade argon as specified by PDS 52118 AE.

3.4.6 Each weld pass shall be visually inspected and any porosity, surface cracks or oxide removed prior to additional welding (See Section 3.3).

3.5 PROCEDURE QUALIFICATION

3.5.1 The detailed welding procedure shall be qualified for production welding of parts covered by this specification by producing a minimum of two acceptable welds simulating actual production welding position and conditions. The qualification welds shall be made on parts which simulate the heat sink and joint configuration of the actual parts.

3.5.2 The qualification welds shall conform to the applicable quality requirements of Section 4.4.

3.5.3 At least one cross section through each of the qualification welds shall be polished and etched. These sections shall reveal no cracks, excessive oxide, lack of penetration or incomplete fusion.

3.5.4 The detailed welding procedure used in producing the qualification welds shall be documented and include all appropriate weld parameters, joint configuration, and all pertinent information of welding power source, torch, and accessory equipment and be submitted to the purchaser for approval prior to production welding. The results of the required quality control inspection shall also be included.

3.6 PERSONNEL QUALIFICATION:

3.6.1 (294614-1) Manual welding shall require qualification according to the detailed procedure defined in Section 3.5, and shall require qualification according to MIL-T-5021 for the applicable material.

3.6.2 (294614-2) For manual welding, the operator performing a procedure qualification as defined in Section 3.5 shall be considered qualified. Once the procedure has been approved, any operator certified to MIL-T-5021 for the applicable material may perform production welds using the approved procedure for a given joint configuration.

4. QUALITY ASSURANCE

4.1 SURVEILLANCE: Adherence to the provisions of this specification shall be under the surveillance of a Westinghouse Quality Control representative.

4.2 COMPLIANCE: No change shall be made from this specification, or an approved procedure, without first obtaining written approval of the purchaser.

4.3 PRODUCTION WELDING: Production welding shall be performed using only an approved procedure and a qualified operator for manual welding.

4.4 INSPECTION

4.4.1 Liquid Penetrant

4.4.1.1 (294614-1): Both sides of the root pass (if accessible) and the surface of the final weld pass, shall be penetrant inspected in accordance with 294564-1 and shall conform to class 0 acceptance standard.

4.4.1.2 (294614-2): Both sides of the root pass (if accessible) and the surface of the final weld pass shall be liquid penetrant inspected in accordance with 294564-1 and shall conform to the following:

4.4.1.2.1 No cracks or crack type indications shall be permitted.

4.4.1.2.2 The weld shall conform to 294564-1, class 3-2A requirements.

4.4.2 Visual: The weld surface shall be smooth, free of cracks, laps, and unfused areas. No undercut or depressions below the level of the base metal shall be permitted on the face or root of the weld. For butt welds a maximum of 0.050 inch root reinforcement and a minimum total weld thickness of 125% of the base metal thickness is required unless otherwise specified by the drawing. A visible smooth 100% penetration shall be required at the root of all welds exposed to liquid metals.

4.4.3 Radiography: When specified by an applicable drawing, radiographic inspection shall be conducted on all qualification and production welds. The inspection shall be in accordance with MIL-STD-271. Acceptance criteria are as follows:

4.4.3.1 (294614-1) Indications of defects or discontinuities on a radiograph shall be referred to the responsible engineer for his review and disposition.

4.4.3.2 (294614-2) The following shall be cause for rejection:

4.4.3.2.1 Cracks.

4.4.3.2.2 Lack of fusion or root penetration.

4.4.3.2.3 Porosity or inclusions with sharp tails.

4.4.3.2.4 Linear porosity or inclusions. Linear porosity is defined as the condition in which three (3) or more indications having a diameter 1/32 inch or over intersect a straight line parallel to the longitudinal axis of weld and their distance of closest approach is less than 1/8 inch.

4.4.3.2.5 The scattered porosity and inclusion standard shall be as follows:

Minimum Thickness of Materials Being Joined	Maximum Allowable Void Diameter	Minimum Allowable Spacing	Maximum Frequency (indications of any size per inch of weld)
0 - 1/4"	1/3 T or 3/64" (whichever is less)	3 times the diameter of the largest of any two adjacent defects.	4
1/4 - 3/8"	1/4 T	"	6

4.5 REPAIR

4.5.1 Weld defects in excess of the requirements of Section 4.4 shall be removed using a small carbide burr, grinding wheel, or file.

4.5.2 The weld shall be liquid penetrant inspected in accordance with 294564-1 to insure complete removal of the defect. If this inspection reveals the continued presence of the defect, Section 4.5.1 shall be repeated.

4.5.3 All penetrant and developer shall be removed prior to rewelding by wiping with a clean, lint-free cloth saturated with methanol or other equivalent solvent.

4.5.4 Where complete removal of surface defects can be accomplished by the removal of metal such that the weld still meets all size and quality requirements, no further repair work shall be required.

4.5.5 All weld repairs shall meet the quality requirements of Section 4.4 of this specification.

4.6 REPORTS: A report shall be prepared covering the welding of each assembly or subassembly and submitted to the responsible engineer. The minimum content shall be the date, equipment identification, details of welding procedure, identification of parts by name and number, operator qualification details and date qualified, and a statement that the welds conformed to the requirements of Section 4.4.

APPENDIX G
INSPECTION PROCEDURES

1. Helium Leak Test

A. Helium leak testing was performed to MIL-STD-271D (Ships) paragraph 6 and WANL Process Specification 294502 Rev. 1 (see Supplement 1). Maximum allowable leak rate was 5×10^{-7} std cc/sec of helium.

B. Each fuel pin was required to be helium leak tested twice: 1st within 4 hours after removal from glove box where fuel pin was sealed in helium, and 2nd after the post weld anneal.

C. The 1st helium leak check was performed in accordance with WANL Process Specification 294502 Rev. 1 except that Section 5.1, "Pressurizing Operation" was omitted.

D. The 2nd helium leak check was performed in accordance with WANL Process Specification 294502 Rev. 1. Extreme care was exercised during this test to prevent contamination of fuel pin.

2. Ultrasonic Test (for Defects)

A. Ultrasonic inspection of materials for hidden flaws or defects was performed in accordance with MIL-STD-271D (Ships) paragraph 7. Any indication greater than 5% of the wall thickness was cause for rejection of the finished part or that section of pipe.

3. Dye Penetrant Test (Liquid Penetrant Inspection)

A. Liquid penetrant inspection was performed in accordance to WANL Process Specification 294564 Rev. 4 (see Supplement 1) to the general acceptance level of Class 00.

4. Radiography

A. Radiographic inspection of fuel pins is primarily for the examination of the arrangement and condition of internal parts after construction. However, any flaw or defect indicated in weldments, fuel pin tube, or end caps was fully investigated.

B. Radiography was performed to MIL-STD-271D (Ships) paragraph 3.

5. Dimensional Inspection

A. Dimensional inspection was performed with precision instruments that could be read accurately to the degree required on the drawing for the part being inspected. All instruments were periodically calibrated to maintain accuracy.

B. Measurements were made in such a manner as not to scratch, mar, bend, distort, or damage parts being inspected.

C. Dimensional inspection (unless otherwise specified) was performed at an ambient temperature of 75 $\pm$ 3°F.

6. Visual Inspection

A. Visual inspection was interpreted as the careful, minute examination by the unaided eye or up to 10X magnification of all of the visible areas of a component or part. Examination was made in a well lighted area.

B. Visual inspection included the comparison of the part with the drawing or other description and noting any anomaly.

7. Straightness Measurements

A. Straightness of fuel pins or tubes was determined by two methods. Method (1) was by axial traverse with dial indicator from a flat parallel surface, and (2) by T. I. R. (Total Indicated Runout).

B. Method (1) - Place fuel pin or tube on Vee blocks of uniform height at intervals no more than 12 inches apart. (Vee blocks should not be located at a weld or any other local distortion.) Record dial indicator readings made from a flat parallel surface to the highest point on tube within 1/2 inch from each end and at every 2 inch interval along entire length. Rotate tube 90° and repeat above measurements. Overall straightness is the albegraic difference between the two points with the greatest difference in any one plane.

C. Method (2) - Place fuel pin or tube on Vee blocks as indicated in Method (1). Measure T.I.R. (Total Indicated Runout) with a dial indicator at points within 1/4 inch from each end and at every 2 inch interval along entire length by rotating fuel pin or tube 360° and recording high and low points. Overall straightness is 1/2 the T.I.R. at the point with the largest T.I.R.

D. Overall straightness of the entire fuel pin or tube is construed to be the larger straightness measurement of the two methods.

8. Wall Thickness Measurements

Wall thickness variation measurements of fuel pin machined T-111 tubes were mapped and evaluated utilizing Ultrasonic Immersion Inspection Equipment, methods and techniques compatible with the requirements of MIL-STD-271D. Wall sections having thickness variations > 4% from nominal were considered unacceptable for pin assembly fabrication. Equipment required to perform this inspection was as specified below or the direct equivalent:

A. Sperry Reflectoscope Model 721.

B. 15 MHZ Transducers with 187 mil dia. window, Type SIL.

C. Water immersion

D. Water path .4 inches

E. Sperry Pulser Receiver, Model 50W.

F. Thickness Readout Unit, Automation Ind., Type UM

G. Brush Recorder, Mark II

H. Rotating Apparatus and Speed Control System to facilitate 360° inspection capability thru generation of transversing helixing rate of approximately 10 rev./inch.

I. Calibration Standard of T-111 tube material.

9. Raw Material Inspection

Raw materials including government furnished raw materials were characrerized by specification, heat number, destructive and nondestructive testing. T-111 tubing was purchased to NASA Specification C-393643 (Specifications for Seamless Tubing, T-111) and T-111 rod to NASA Specification C-393644 (Specification for Rod, T-111).

The helium gas used for backfilling capsules was "Airco Ultra High Purity Grade 5 Helium" purchased from the Air Reduction Company, Inc., Riverton, New Jersey. Impurity level was guaranteed not to exceed the following:

		ppm
H_2	-	1.0
H_2O	-	1.5
O_2	-	1.0
N_2	-	5.0
Ne	-	2.0
$CO + CO_2$	-	0.5
Total Hydrocarbons		0.5

Impurity level as analyzed by Westinghouse:

		ppm
H_2	-	0.09
H_2O	-	<2.0 (monitored at < 0.5)
O_2	-	.44

		ppm
N_2	-	2.20
Ne	-	1.29
Ar	.29	
CO_2	.05	

Listed in Table G-1 is a cross reference of each part, the raw material from which it was made, inspection of the raw material, heat number, fabrication process, finished part inspection, and fuel pin in which part was used. Table G-2 is a summary of certified test reports for the T-111 alloy.

Table G-1. Piece Part and Raw Material Cross Reference

Drawing No. CD-	Part No.	Part Name	Description of Raw Mat'l.	Raw Material Inspection	Heat No.	Fabrication Process	Finished Part Inspection	Fuel Pin No.
352466 Rev. A	1 & 1A	UN Fuel Pellets	Fabricated by ORNL under NASA Contract C-60080-B	Supplied by NASA		Cold isostatic pressing, sintering, and machining	Visual	514A, B, & C 516A, B, & C 518A & B 604 & 605
352466 Rev. A	2 Assy. "X"	End Cap Outlet	Rod, T-111 3/4" dia.	Visual, dimensional, dye penetrant, Hardness, metallography, chemistry, ultrasonic	9597	Machining	Visual, dimensional	514A, B, C, 604 and 605
352466 Rev. A	2 Assy. "Y"	End Cap Outlet	"	"	"	"	"	516A, B, C 518A, B
352466 Rev. A	3 Assy. "X"	End Cap Inlet (Alternate Design)	Rod, T-111 3/4" dia. Tubing, T-111 .102"ID x .015 wall Rod, T-111 .250 dia.	" Same except no ultrasonic Same except no ultrasonic	9597 8435 65059	" " "	Visual, dimensional, helium leak test	514A, B, C, 604 & 605
352466 Rev. A	3 Assy. "Y"	End Cap Inlet Alternate Design)	Rod, T-111 3/4" dia. Tubing, T-111 .102"ID x .015 wall Rod, T-111 .250 dia.	Same with ultrasonic Same except no ultrasonic Same except no ultrasonic	9597 8435 65059	" " "	Visual, dimensional, helium leak test	516A, B, C 518A & B
352466 Rev. A	4 Assy. "X"	Fuel Pin Tube	Tube, T-111 .755"OD x .067 wall	Visual, dimensional, dye penetrant, hardness, chemistry, metallography, ultrasonic	8480	Machining and honing	Visual, dimensional, ultrasonic, dye penetrant	514A, B, C 604 & 605
352466 Rev. A	4 Assy. "Y"	Fuel Pin Tube	"	"	8480	"	"	516A, B, C 508A & B
352466 Rev. A	5	Thermocouple Protective Tube	Gaseous WF_6	--	--	Chemical vapor deposition of "W" on Mo mandrel then etching away mandrel	Visual, dimensional,	514A, B, C 516A, B, C 518A & B 604 & 605
352466 Rev. A	6	Tungsten Liner	Tungsten Foil .001 tk.	--	--	Differential Thermal expansion bonding	Visual, chemistry, metallography, dimensional	514A, B, C 516A, B, C 518 A, B 604 & 605

F

Table G-1 (Cont'd.)

Drawing No. CD-	Part No.	Name	Description of Raw Mat'l.	Raw Material Inspection	Heat No.	Fabrication Process	Finished Part Inspection	Fuel Pin No.
352466 Rev. A	7	Washer, Tungsten	Tungsten sheet .003 and .005 thick	Supplied by NASA	--	EDM	Visual, dimensional	(same as part no. 6)
352466 Rev. A	8	Spherical Spacer	[illegible] sheet .012 thick	Supplied by NASA	--	Formed	Visual, dimensional	(same as part no. 6)
352466 Rev. A	9	Sleeve	Rod, T-111 3/4" dia.	Visual, dimensional, dye penetrant, hardness, chemistry, metallography, ultrasonic	9597	Machining	Visual, dimensional	(same as part no. 6)
352466 Rev. A	10	Flux Monitoring Wire	Wire, Tungsten .016 dia.	Visual, dimensional	--	Formed	Visual, dimensional	(same as part no. 6)
352471 Rev. A	1	UN Fuel Pellets	Fab. by ORNL under NASA Contract C-60080-B	Supplied by NASA		Cold isostatic pressing, sintering & machining	Visual	510A & B, 603
352471 Rev. A	2	Fuel Separator	Tungsten Sheet .005 Tk.	Supplied by NASA		EDM	Visual, dimensional	"
352471 Rev. A	3 & 3A	Fuel Pin End Cap (Alternate Design)	Rod, T-111 3/4" dia. Tubing, T-111 .102"ID x .015 wall Rod, T-111 .250 dia.	Visual, dimensional, dye penetrant, hardness, chemistry, metallography " (also ultrasonically 3/4 dia.)	9597 8435 65059	Machining	Visual, dimensional, helium leak test	"
352471 Rev. A	4	Fuel Pin Tube	Tube, T-111 .755"OD x .067 wall	Visual, dimensional, dye penetrant, hardness, chemistry, metallography, ultrasonic	8480	Machining and honing	Visual, dimensional dye penetrant, ultrasonic	510A & B 603
352471 Rev. A	5	Thermocouple Protective Tube	Gaseous WF$_6$	--	--	Chemical vapor deposition of "W" on Mo. mandrel then etching away mandrel	Visual, dimensional, dye penetrant	"
352471 Rev. A	6	Tungsten Liner	Tungsten Foil .001 tk.	--	--	Differential Thermal expansion bonding	Visual, chemistry, metallography, dimensional	"
352471 Rev. A	7	Washer, Tungsten	Tungsten sheet .005 thick	Supplied by NASA		EDM	Visual, dimensional	"
352471 Rev. A	8	Spherical Spacer	T-111 sheet .012 thick	Supplied by NASA		Formed	Visual, dimensional	"
352471 Rev. A	9 & 9A	Sleeve	Rod, T-111 3/4" dia.	Visual, dimensional, dye penetrant, hardness, chemistry, metallography, ultrasonic	9597	Machining	Visual, dimensional	"

Table G-1 (Cont'd.)

Drawing No. CD-	Part No.	Part Name	Description of Raw Mat'l.	Raw Material Inspection	Heat No.	Fabrication Process	Finished Part Inspection	Fuel Pin No.
352471 Rev. A	10	Tube Support	Tungsten sheet .010 thick	Supplied by NASA		EDM	Visual, dimensional	510A & B 603
352472 Rev. A	1	Outlet End Fitting	Rod, T-111 3/4" dia.	Visual, dimensional, dye penetrant, hardness, chemistry, metallography, ultrasonic	9597	Machining	Visual, dimensional	512 A, B, C
352472 Rev. A	2	Separator	Tungsten sheet .050 thick	Supplied by NASA		EDM	Visual, dimensional	"
352472 Rev. A	3	Fuel Spacer, Outlet End	Rod, T-111 3/4" dia.	Visual, dimensional, dye penetrant, hardness, chemistry, metallography, ultrasonic	9597	Machining	Visual, dimensional	"
352472 Rev. A	4	Fuel Pellets	Fab. by ORNL under Contract C-60080-B	Supplied by NASA		Cold isostatic pressing, sintering & machining	Visual	"
352472 Rev. A	5	Fuel Spacer, Inlet End	Rod, T-111 3/4" dia.	Visual, dimensional, dye penetrant, hardness, chemistry, metallography, ultrasonic	9597	Machining	Visual, dimensional	"
352472 Rev. A	6	Inlet End Fitting	Rod, T-111 3/4" dia.	"	9597	"	"	"
352472 Rev A	7	Fuel Separator and Spacer	Tungsten sheet .003 thick	Supplied by NASA		EDM	"	"
352472 Rev. A	8	Fuel Pin Tube	Tube, T-111 .755"OD x .067 wall	Visual, dimensional, dye penetrant, hardness, chemistry, metallography, ultrasonic	8480	Machining and honing	Visual, dimensional dye penetrant, ultrasonic	"

Table G-2. T-111 Raw Material Certified Test Report Summary

Hector Lot No.	Chemical Analysis (ppm)														(%)		
	C	N_2	O_2	H_2	Cb	Fe	Mn	Si	Cr	Mo	Cu	Zr	Co	V	W	Hf	Ta
8480	49	41	< 5	5	150	10			< 1	30		810	< 5	2	7.69	1.96	Balance
9597	26	34	9.2	2.5	<25	5	< 1	27	< 1	40	< 1	510	< 5	2	7.94	1.89	Balance
8435	18	32	13	2.3	500	10				15	< 1	500			7.30	1.93	Balance
65059	60	20	< 50	2.7	810	< 40	< 20	21	< 20	< 20		575	< 10	< 20	8.6	1.9	Balance

APPENDIX H

SPECIAL TASKS PERFORMED UNDER NASA CONTRACT NAS 3-14415

INTRODUCTION

A number of special tests and miscellaneous fabrication operations not directly related to basic program objectives were carried out under this contract. Each of these items are reported separately in this appendix.

HIGH VACUUM FURNACE TEST

A high vacuum furnace test was conducted to study materials compatibility at elevated temperature. Samples included fuel pin 503A and other fuel pin components fabricated under Contract NAS 3-12978. Also included were several materials test capsules with specimen tabs of T-111, tungsten, TZM, and uranium nitride. Some of these were filled with lithium. The test was conducted at 1310°K (1900°F) for 3000 hours at a pressure less than 1.33×10^{-6} N/m^2 (1×10^{-8} torr). Figures H-1 and H-2 show the specimens prepared for testing. All test items were returned to the Materials Division of NASA-Lewis Research Center for evaluation.

REENCAPSULATION OF FUEL PINS 501A, 501B, AND 502A

Fuel pins 501A, 501B, and 502A fabricated and encapsulated in the early phases of Contract NAS 3-12978(1) were reencapsulated with all of the improved fabrication procedures developed in that program. The major modification was a change in the method of installing thermocouples into thermocouple wells from brazing to electron beam welding. Other modifications included the positive backfill of thermocouple assemblies with helium and the addition of an instrumentation slot in the capsule body.

WELD SHRINKAGE TESTS

Precision control of fuel pin length will be required in actual reactor fabrication. Weld shrinkage occurring at the fuel pin tube to end cap joint of test pins has a magnitude (approximately

---

(1) Keeton, A. R., L. G. Stemann, and G. G. Lessman, "Capsule Assembly Fabrication Final Report," NASA CR-72905, December, 1970.

Figure H-1. Specimens Ready for High Vacuum Furnace Test – Top View

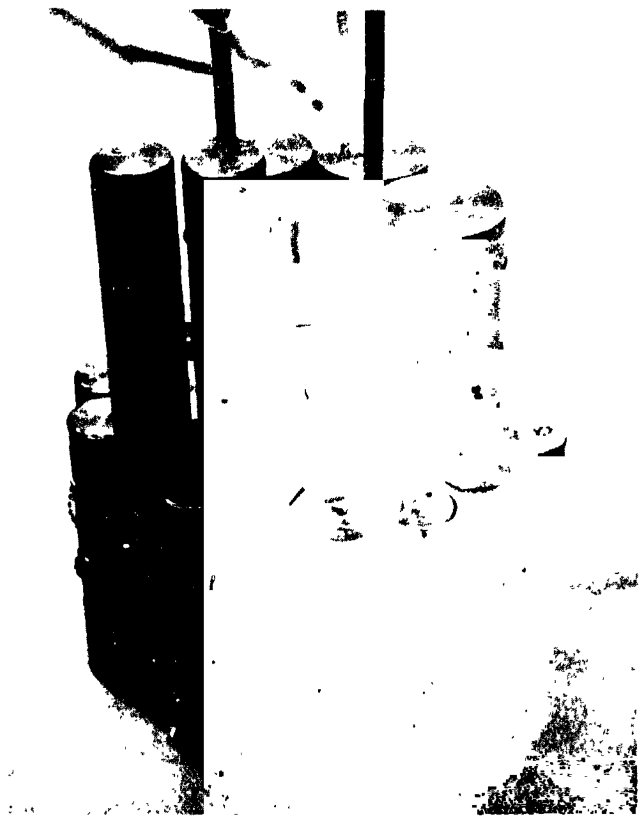


Figure H-2. Specimens Ready for High Vacuum Furnace Test – Side View

.005 in/weld) and variation indicating that post weld sizing may be required to achieve the necessary length control.

NASA Lewis Research Center submitted to WANL six sample weld joints designed to evaluate the possibility of reducing and controling the weld shrinkage. These joints, see Figure H-3, required reduced weld penetration and contained a shoulder designed to restrict shrinkage.

These samples were premeasured, welded, post-measured, and sectioned for metallography. The basic weld parameters were similar to those used in fuel pin welding except for adjustments in current to achieve the desired penetration. Table H-1 presents the shrinkage obtained and the sequence in which the welds were made.

The first three weld joints showed an obvious reduction in shrinkage compared to the allowable (.004 - .005) currently used in fuel pin fabrication. Metallography indicated that the total shrinkage (.0011 to .0022) and variation noted might be related to fit up characteristics. As can be seen in Figure H-4, typical high points had been present in some areas which prevented uniform contact with the restricting shoulder.

As a result of the first three tests, Specimens Nos. 3, 2, and 5 were returned to NASA for hand lapping to assure smooth contact. The data on these joints is somewhat more consistent with a maximum of .0015 inches on a given joint.

Review of the results indicated that shrinkage could definitely be reduced with the design concept explored. It also appears that length tolerance, as a result of welding alone, could be maintained within $\pm$ .001. This, of course, does not include the normal mechanical variations associated with machining and fit up of detail parts which must be considered.

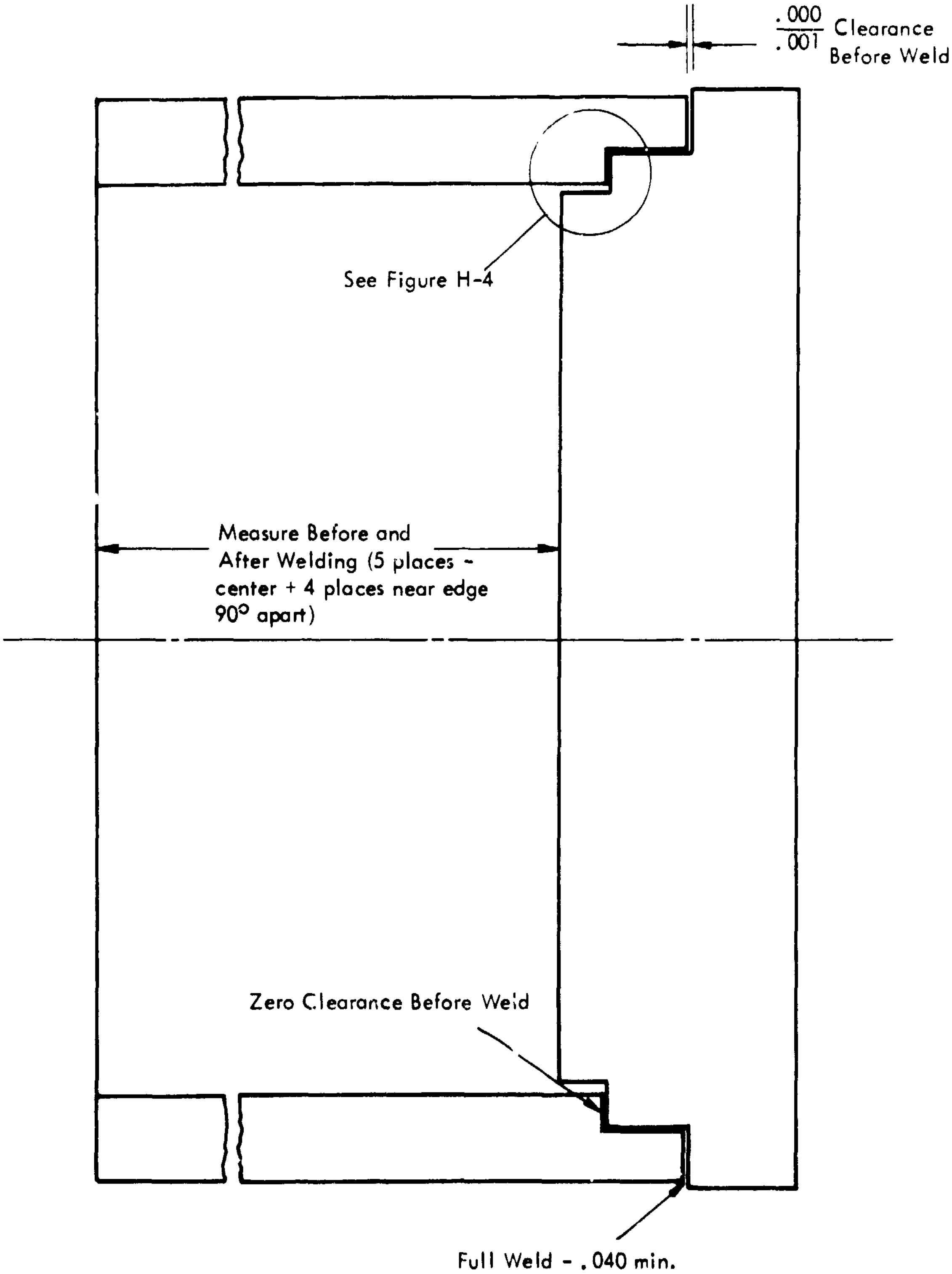
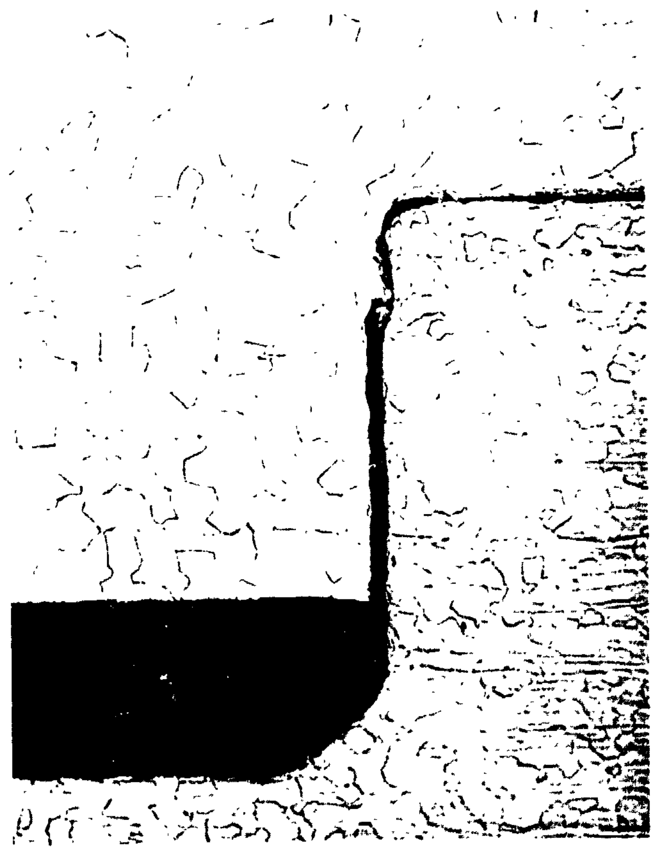


Figure H-3. Weld Shrinkage Test Joint Configuration

Table H-1. Weld Shrinkage

Specimen	0°	90°	180°	270°	Center	End Pressure(lbs)
1	.0020	.0020	.0016	.0019	.0019	3
4	.0013	.0013	.0010	.0008	.0011	6
6	.0017	.0018	.0018	.0024	.0022	6
3	.0015	.0009	.0014	.0014	.0014	6
2	.0009	.0006	.0013	.0009	.0010	3
5	.0015	.0012	.0009	.0009	.0015	3



100X

Figure H-4. Weld Specimen No. 1 - Typical Shrinkage Restricting Shoulder Area. High Points on Contacting Surfaces Leads to Shrinkage Variation (See Figure H-3)

Astronuclear Laboratory

WANL-M-FR-72-004

SUPPLEMENT I

FABRICATION OF ADVANCED POWER REACTOR PROTOTYPE FUEL PINS

Prepared by

WESTINGHOUSE ASTRONUCLEAR LABORATORY
PITTSBURGH, PENNSYLVANIA

for

NASA LEWIS RESEARCH CENTER

under

Contract NAS 3-14415

SUPPLEMENT 1

TITLE:

FABRICATION OF ADVANCED POWER REACTOR PROTOTYPE FUEL PINS FOR IN-PILE TESTING

PURPOSE & SCOPE:

The purpose of these procedures and specifications is to provide detailed information for the fabrication, assembly, and inspection of T-111 alloy clad, uranium nitride fueled prototype fuel pin assemblies as specified in NASA Drawing CD-352472.

APPLICABLE DOCUMENTS:

NASA TM X-67879 - Specifications for Cleaning, Fusion Welding, and Postheating Tantalum and Columbium Alloys

MIL-STD-271D (Ships) - Nondestructive Testing Requirements for Metals

NASA Specification C-393643 - Specifications for Seamless Tubing, T-111

NASA Specification C-393644 - Specifications for Rod, T-111

NASA CR-72764 - Synthesis, Characterization, and Fabrication of UN.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

APPENDICES

1.0 FABRICATION

1.1 Raw Material - Testing Procedures

1.1.1 General

1.1.1.1 All raw materials including government furnished parts shall be characterized by specification, heat number, chemical composition, and mechanical properties.

1.1.1.2 T-111 alloy (Ta-8W-2Hf) tubing shall conform to NASA Specification C-393643, and T-111 alloy rod shall conform to NASA Specification C-393644. A "Certified Test Report" is required from the supplier for each heat or lot of material, and this report shall be compared with the applicable specification for conformance. Material that does not conform to the specification shall be rejected.

1.1.2 Nondestructive Testing

1.1.2.1 Raw materials shall be visually inspected for general appearance in accordance with Section 3.8, "Visual Inspection".

1.1.2.2 T-111 alloy tubing and rod shall be ultrasonically inspected for defects in accordance with Section 3.3, "Ultrasonic Test". Rejected areas shall be cut out of raw material and plainly identified so they will not be used for fuel pin construction.

1.1.2.3 T-111 tubing and rod shall be dye penetrant inspected in accordance with Section 3.4, "Dye Penetrant Test". Rejected areas shall be cut out of raw material and plainly identified so they will not be used for capsule construction.

1.1.3 Metallurgical Examination

1.1.3.1 Metallurgical examination shall be performed on a sample from each heat or lot of T-111 alloy material to determine general structure and condition, lack of contamination, grain size, and hardness. Photomicrographs shall be made of each sample at 100X. Material that is contaminated or defective or that does not comply with specified grain size and hardness shall be rejected.

1.1.3.2 Chemical analysis shall be performed on a sample from each heat or lot of T-111 alloy tubing to determine content of C, O, H, and N. Results shall be compared with applicable specification, and nonconforming material shall be rejected.

1.1.4 Dimensional Inspection

1.1.4.1 Dimensional inspection shall be performed on all raw materials in accordance with Section 3.6, "Dimensional Inspection" to determine that the raw material is of the proper size, shape, and quantity to meet the finished parts requirements of the drawing.

1.1.4.2 Straightness measurements shall be made of each length of T-111 tubing in accordance with Section 3.9, "Straightness Measurements" to determine areas from which fuel pin tubes can be fabricated to meet requirements specified on the drawing.

1.1.5 Helium for backfill of fuel pins.

1.1.5.1 Helium shall be equivalent to Mathieson Company ultra-high purity (gold label) helium which has the following typical impurity concentrations in ppm: H_2 - 0.1, CH_4 - 0.0, H_2O - 1.5, Ne - 8.0, N_2 - 5.0, O_2 - 0.6, Ar - 0.05, CO_2 - 0.05.

1.1.5.2 A chemical analysis shall be made on a sample from each lot or batch of helium, and this analysis compared with the typical concentrations above. Deviations shall be submitted to the project manager for approval.

1.2 Machining - Piece Part

1.2.1 All machining of T-111 parts shall be accomplished with conventional machining methods and equipment (i.e., lathes, milling machines, drill presses, honing machines, etc.) as opposed to less conventional methods such as EDM, ECM, etc. EDM particularly should not be used on T-111 due to possible contamination from the coolant and and electrode as a result of the electrical discharge.

1.2.2 T-111 alloy (Ta-8W-2Hf) can be machined with ordinary tool steels, but many prefer high speed or carbide tools. All tantalum base alloys have a tendency to tear or gall easily so tools must be kept sharp and work flooded with tap magic, carbon tetrachloride, or similar lubricant. Single-point turning tools should be ground to 10° back rake, 5° side rake, 5° side clearance, 45° trail angle, and 0.020 in. nose radius. Cutting speeds of 50-60 SFPM with roughing feeds of 0.008-0.012 ipr and finishing feeds of 0.005-0.006 ipr with a depth of 0.015"-.060" may be used.

Conventional roughing cuts followed by light finishing cuts do not produce finishes as satisfactory as those obtained by using sharp tools and fine feeds and finishing the work with a reasonable heavy cut.

For shaping and milling, the tools should be kept sharp with generous rake and clearance angles as used for soft metals such as copper and aluminum. Broaching operations should be avoided since the tool has a tendency to tear the material. Grinding is not recommended.

Honing can be accomplished using conventional honing machines with diamond honing stones or stones such as Sunnen Y20J67 and L20A69. High RPM should be used. Lapping compound can be used to produce a high quality surface finish.

1.3 Inspection, Piece Part - After Machining

1.3.1 Each piece part machined or fabricated for assembly and construction of fuel pins shall be 100% inspected for conformance with all drawing requirements.

1.3.2 Each fuel pin tube shall be ultrasonically inspected for defects in accordance with Section 3.3

1.3.3 Each fuel pin tube shall be dye penetrant inspected in accordance with Section 3.4.

1.3.4 Each fuel pin tube shall have wall thickness measurements performed in accordance with Section 3.10. Wall thickness variations greater than 4% of total wall thickness shall be cause for rejection.

1.3.5 Each fuel pin tube O.D. shall be measured and recorded at 0^{o} and 90^{o} at every axial position. Axial positions for measurements shall be 1/2 inch increments along the entire tube length.

1.3.6 Straightness measurements shall be made on each fuel pin tube in accordance with Section 3.9.

1.4 Tungsten Liner - Bonding Description and Procedure

A differential thermal expansion process was developed to bond tungsten liners to the inside surface of T-111 tubes. A one mil thick tungsten sheet rolled into a cylindrical form was inserted into the T-111 tube. A close fitting low carbon steel mandrel coated with aluminum oxide (Al_2O_3) was then inserted into the ID of the rolled tungsten sheet. Upon heating in a vacuum furnace the low carbon steel mandrel having a high thermal expansion relative to the T-111 tube forces the tungsten sheet diametrically outward against the inside surface of the T-111 tube. The tubes were heated in a vacuum of at least 3×10^{-6} torr. The combination of temperature and pressure for a period of time causes bonding between tungsten layers and also between the tungsten and T-111. It was necessary to coat the mandrel with Al_2O_3 to prevent the tungsten from adhering to the steel. Tube size, furnace temperature, and assembly clearance are critical variables determining the force exerted against the W sheet. By trial and error, a 5 mil room temperature assembly clearance and a furnace temperature of 2200°F were determined to be proper for bonding a .005 in. thick liner into a nominal .636 ID T-111 tube. If too low a temperature or too much clearance is allowed, bonding does not occur. If too little clearance or too high a temperature is used, a barreling distortion of the T-111 results. Ideally, at furnace temperature the clearances between the five tungsten layers and the clearance between the T-111 and tungsten should be just reduced to zero thereby developing sufficient pressure to bond the liner without further stressing of the T-111 tube. To achieve the above requires close tolerances on dimensions of assembly parts and close control of furnace temperature.

The procedure outlined below assumes a clean vacuur urnace previously qualified for use with the materials involved. A small control sample assembly similar to the assembly being bonded should be carried through each step outlined. This control can then be analyzed for contamination to give added assurance of the quality of the lined tube.

1.4.1 Steel Mandrels

1.4.1.1 1020 steel rods 18.0 inches long by .610 $\pm$ .001 inches in diameter shall be used for both the "L" size tubes and the "L/3" size tubes.

1.4.1.2 Holes to accept a 1/8 in. diameter tungsten pin shall be drilled 1/4 in. from each rod end. The mandrels for the "L/3" tubes shall have two additional holes of the same diameter spaced such to divide the rods into three equal portions.

1.4.1.3 The mandrels shall be etched in 80 v/o H_2O and 20 v/o HCl.

1.4.1.4 All handling of the mandrels after step 1.4.1.3 shall be done with nylon gloves worn over pylox gloves or with clean tools.

1.4.1.5 The mandrels shall be vacuum annealed at 1800°F for 4 hours in in a vacuum of 10^{-4} torr.

1.4.1.6 The mandrels shall be flame sprayed with aluminum oxide, Al_2O_3 (99.53% pure) to a diameter of .630 $\pm$ .002 inch. The mandrel ends shall also be coated to an Al_2O_3 thickness of at least .005 inches.

1.4.1.7 The coated mandrel shall be centerless ground to a diameter of .621 $\pm$ .0005 inches using a silicon carbide wheel with noncirculating flowing tap water as the grinding lubricant. The Al_2O_3 thickness after grinding is approximately 5-1/2 mils.

1.4.1.8 The coated mandrels shall be ultrasonically cleaned in alconox for 1/2 hour.

1.4.1.9 The mandrels shall be rinsed in tap water for 1 minute.

1.4.1.10 The mandrels shall be ultrasonically cleaned in ethyl alcohol for 1/2 hour.

1.4.1.11 The mandrels shall be hot air dried and stored in desiccant bags until used.

1.4.1.12 Immediately before use, the coated mandrels shall be outgassed at 1000°F for 1 hour in a vacuum of 1 x 10^{-5} torr or better.

1.4.2 The T-111 tubes to be lined shall be machined to dimensions specified on drawing and cleaned as described in Section 1.5.

1.4.3 Liner Material

1.4.3.1 The liner material shall be tungsten, .001 inch thick sheet. Sheet with excessive wrinkles or variations in thickness of more than .001 inch shall not be used.

1.4.3.2 The tungsten sheet shall be sheared to a size 16.26 inches x 9.88 inches for the "L" pins, and 3.86 inches x 9.88 inches for the "L/3" pin. These sheet sizes provide a 5 layer, 5 mil thick liner with an end recess of .20 inches for the "L" pins and .15 inches for the "L/3" pins.

1.4.3.3 Sand edges of the tungsten sheets using No. 400 silicon carbide paper to deburr.

1.4.3.4 Ultrasonic clean the tungsten sheets in alconox for 1/2 hour.

1.4.3.5 Handle tungsten sheets with clean tools or lint free nylon gloves worn over pylox gloves in all following steps.

1.4.3.6 The tungsten sheets shall be rinsed in running tap water for 30 seconds.

1.4.3.7 Ultrasonic clean the tungsten sheets in M-6 solvent for 1/2 hour.

1.4.3.8 The tungsten sheets shall be pickled in nitric, hydroflouric, sulfuric acid solution, 20-15-10%, balance H_2O by volume for 1 minute.

1.4.3.9 Fast transfer the tungsten sheets from the pickle bath to boiling distilled water without any surface drying of the pickle solution. Allow sheets to remain in boiling water for 30 seconds.

1.4.3.10 The tungsten sheets shall be rinsed in cold flowing tap water for 1 minute.

1.4.3.11 The tungsten sheets shall be boiled in clean distilled H_2O for 5 minutes.

1.4.3.12 The tungsten sheets shall be fast rinsed in ethyl alcohol, and immediately hot air dried.

1.4.3.13 Store cleaned tungsten sheets in clean glass containers.

1.4.3.14 The tungsten sheet shall be preformed by rolling the tungsten and inserting it into a cleaned T-111 tube .600 ID and heat treated at 1600°F for 1 hour in a vacuum of 5×10^{-6} torr or better.

1.4.3.15 The vacuum can be broken and the liner material removed from the T-111 tube when the furnace temperature is less than 100°F.

1.4.3.16 The tungsten sheet, now permanently set in cylindrical shape, shall be rerolled such to reverse the inner and outer layers. It is desirable to have the more cylindrically shaped outer layer of tungsten on the inside surface of the cylinder when inserting the close fitting mandrel into its ID.

1.4.4 Assembly of Components

1.4.1.1 All handling of components shall be with clean tools, or with nylon gloves worn over pylox gloves.

1.4.4.2 The reverse rolled liner shall be inserted into the T-111 tube.

1.4.4.3 The liner shall be rotated in the tube such to tighten the liner against the T-111 tube wall.

1.4.4.4 A T-111 plug .6355 inch OD cleaned as described in Section 1.5 shall be inserted into the tube to square the ends of the multilayered liner. A stop machined on the plug gives the proper liner recess from the ends of the T-111 tube as specified in 1.4.3.2.

1.4.4.5 With the T-111 plug in place on one end, the mandrel is inserted from the opposite end until it contacts and pushes the plug out of the tube. One "L" size tube or three "L/3" size tubes are spaced on one steel mandrel.

1.4.4.6 Clean tungsten pins 1/8 in. in diameter shall be placed through the holes drilled through the mandrel diameter to hold the tubes in position on the steel mandrel. The pins are wired in place using clean tantalum wire.

1.4.4.7 The assembly shall be wrapped in clean tantalum foil.

1.4.5 Bonding

1.4.5.1 The assembly is placed vertically into the furnace.

1.4.5.2 The furnace shall be pumped to a vacuum of 3×10^{-6} torr or better and held for 24 hours before power is turned on.

1.4.5.3 The temperature shall be increased at a rate to maintain a vacuum of at least 3×10^{-6} torr but not exceeding 300°F per hour.

1.4.5.4 Temperature shall be held at 2200°F for 1 hour.

1.4.5.5 The furnace vacuum shall not be broken until the furnace temperature is below 100°F at which time the assembly is removed from the furnace.

1.4.6 Storage

1.4.6.1 The outer layer of tantalum foil and the mandrel shall be removed.

1.4.6.2 The tungsten lined T-111 tube shall be wrapped in clean tantalum foil to await use.

1.5 Cleaning and Handling - T-111 Alloy and Tungsten Parts

1.5.1 All T-111 alloy and tungsten parts shall be cleaned in accordance with NASA-Lewis TMX 67879 Specification No. RM-1, "Chemical Cleaning of Columbium, Tantalum, and Their Alloys" with the exception that the composition of the solution shall be 20% nitric - 15% hydrofluoric - 10% sulfuric acid, and the balance water by volume. Tungsten parts shall be cleaned using the same procedure as tantalum parts. After cleaning, each part shall be vacuum heat treated at 2400°F for 1 hour in a vacuum of 10^{-5} torr or better,

1.5.2 T-111 and tungsten parts should NEVER be exposed to temperatures above 150°C (300°F) unless they have been cleaned as specified in Paragraph 1.5.1 above and are enclosed in a vacuum better than 1×10^{-4} torr or high purity inert gas with O_2 and H_2O content 5 ppm or below.

1.5.3 Handling or contact with cleaned T-111 or tungsten parts shall only be with clean, lint free gloves, clean glass, clean refractory metal, or clean teflon. T-111 alloy is particularly sensitive to metallic contamination so avoid any metallic contact during or after cleaning except with refractory metals.

1.5.4 Tools and equipment for use in handling T-111 and tungsten parts are to be cleaned prior to use by the methods described below.

1.5.4.1 Small tools and equipment are to be degreased by ultrasonic cleaning in fresh clean M-6 (oxylene) or by M-6 rinse, then rinsed with ethyl alcohol and air dried.

1.5.4.2 Large tools and equipment are to be degreased by wiping with a rag or Kim Wipe saturated with M-6 (oxylene), wiped dry with a clean rag or Kim Wipe, and final wiped with rag or Kim Wipe dampened with ethyl alcohol and air dried.

2.0 ASSEMBLY

2.1 Fuel Pellets, Uranium Nitride - Handling

2.1.1 Uranium nitride fuel pellets shall be fabricated in accordance with procedures for cold isostatic pressing of UN described in NASA Contractor report CR-72754 and prefinished to the drawing specifications and hermetically sealed in an argon atmosphere. Fuel shall not at any time be exposed to ambient air.

2.1.2 Fuel pellets shall be handled only in an inert atmosphere chamber with the same handling precautions as described for handling T-111 and tungsten in Section 1.5.3 and 1.5.4.

2.1.3 Fuel pellets shall be degassed at a temperature of 150 to 400°F using heating lamps for a minimum of 12 hours in vacuum of 1×10^{-4} torr or better then backfilled with high purity helium containing less than 5 ppm H_2O and O_2 before encapsulating in a fuel pin.

2.1.4 Fuel pellets shall be inspected visually for cracks, chips, or any anomaly and these observations shall be recorded and reported to the project manager for disposition.

2.2 Welding, Electron Beam - Specification and Weld Qualification

2.2.1 Electron beam welding shall be performed in accordance with NASA-Lewis TMX 67879 Specification No. RM-3, "Electron Beam Welding of Columbium, Tantalum, and Their Alloys".

2.2.2 Sample electron beam welds shall be made before and after welding end caps to each fuel pin. The sample weld joint should duplicate as closely as possible the end cap to fuel pin tube weld joint. These samples shall be sectioned both perpendicular and parallel to the weld and metallographically examined for crack, porosity, fusion depth, or other anomalies.

2.2.3 Attached in Appendix I is a Welding Procedure sheet giving the parameters for the fuel pin end cap - tube weld. It should be noted that each welding machine must be qualified in accordance with NASA-Lewis Specification No. RM-3 and these parameters developed for each machine.

2.3 Welding, Fuel Pin Closure - Specification and Procedure

2.3.1 Fuel pin closure welds (i.e., sealing of the .029 dia. closure hole with UHP helium at (1) atmosphere) shall be accomplished in accordance with NASA-Lewis TMX Specification No. RM-2, "Gas Tungsten-Arc Welding of Columbium, Tantalum, and Their Alloys" except that a minimum penetration depth of .020" shall be required.

2.3.2 Sample closure welds shall be made before and after each group of fuel pins are welded. The sample shall duplicate as closely as possible the fuel pin closure weld. The sample welds shall be sectioned and metallographically examined for cracks, porosity, fusion depth, or other anomalies.

2.3.3 Attached in Appendix I is a Welding Procedure sheet giving the parameters for this fuel pin final closure weld. It should be noted that each welding machine must be qualified in accordance with NASA-Lewis TMX 67878 Specification No. RM-2 and these parameters developed for each machine.

2.4 Assembly Procedure - Fuel Pin

2.4.1 The fuel pin shall be assembled in accordance with the "Fuel Pin Assembly Checkoff" sheet attached in Appendix III in the sequence indicated.

2.4.2 The "Pre-irradiation Fuel Pin Data" record attached in Appendix IV shall be completed as necessary for fuel pin construction.

2.5 Inspection, Fuel Pin - After Assembly

2.5.1 Fuel pin shall be helium leak tested per applicable parts of Section 3.2 within 4 hours after removal from welding chamber after final seal weld. Record leak detector calibration and fuel pin leak rate.

2.5.2 Fuel pin welds shall be visually inspected for conformance with Section 2.2 and 2.3 Welding.

2.5.3 Fuel pin welds shall be dye penetrant inspected per Section 3.4.

2.5.4 Fuel pin shall be x-rayed at 0° and 90° in accordance with Section 3.5, Radiographs.

2.5.5 Fuel pin overall length shall be measured and recorded.

2.5.6 Fuel pin straightness and O.D. shall be measured as required in Appendix IV Section C-5 of Pre-Irradiation Fuel Pin Data Sheet.

2.5.7 NASA identification number on inlet end plug shall be checked for clarity and accuracy.

2.5.8 Fuel pin weight shall be recorded to nearest gram.

2.5.9 Fuel pins that are to be encapsulated shall be matched drilled in accordance with Note 9 NASA Drawing CD-352472.

2.6 Final Cleaning, Fuel Pin

2.6.1 Each fuel pin shall be cleaned in accordance with Section 1.5 after completion of inspection required in Section 2.5. This final cleaning shall be performed as near to time of use as practical, and extreme caution shall be exercised to prevent contamination of fuel pin during handling and storage.

2.7 Post Weld Anneal

2.7.1 After final cleaning the fuel pins shall be wrapped in tantalum foil and post weld annealed by vacuum heat treating at 1100°C (2012°F) for 1 hour in a vacuum of 5×10^{-5} torr or better.

2.8 Inspection, Fuel Pin - After Post Weld Anneal

2.8.1 Each fuel pin shall be helium leak tested after the post weld anneal as per applicable parts of Section 3.2. Maximum allowable leak rate is 5×10^{-7} std. cc/sec of helium. Extreme care shall be exercised in handling the fuel pin during leak check operation to prevent contamination.

3.0 QUALITY ASSURANCE/INSPECTION

3.1 General

3.1.1 Quality Assurance shall assure that fuel pin parts, materials, assembly and tests comply with the technical requirements of the applicable drawings and specifications as well as the inspection and documentation requirements of the contract. This effort shall be directed by the cognizant project Quality Engineer who will provide the required ordering document reviews, inspection and test planning/instructions, development/procedures for nondestructive testing, designs for any special mechanical or electrical measurement tools or equipment, evaluations and disposition of nonconformities, and participation and review of pin assembly final data package (assembly procedures and all test results) to insure pin assembly compliance and acceptability.

3.1.2 Quality Assurance shall maintain records of all inspections and tests performed. The records must include all details pertinent to the inspection or test performed, such as part identification, ordering document number, a description of the inspection or test, quantities inspected/tested, quantities accepted or rejected, and identification of the individual performing the inspection or test. Actual measurements and observations shall be recorded whenever required and whereever the inspection and test equipment is capable of supplying variable data.

3.1.3 Quality Assurance shall assure that all inspection tools and gages and test equipment are initially and periodically calibrated per the established procedures of an approved Calibration Control System. All calibrations shall be performed against standards which are traceable to the National Bureau of Standards. Quality Assurance personnel shall be required to insure, just prior to use, that all inspection tools and test equipment to be used are within their calibration interval.

3.2 Helium Leak Test

3.2.1 Each fuel pin is required to be helium leak tested twice: first within 4 hours after removal from glove box where fuel pin is sealed in helium (Section 2.5) and second after the post-weld anneal (Section 2.8). The maximum allowable leak rate is 5×10^{-7} std. cc/sec of helium in both instances.

3.2.2 The first helium leak check shall be performed in accordance with WANL Process Specification 294502 Rev. No. 1 except that Section 5.1 "Pressurizing Operation" shall be omitted.

3.2.3 The second helium leak check shall be performed in accordance with WANL Process Specification 294502 Rev. No. 1. Extreme care should be exercised during this test to prevent contamination of fuel pin. (See Section 1.5 of these procedures and specifications "Cleaning and Handling - T-111 Alloy and Tungsten Parts".)

3.3 Ultrasonic Test (for defects)

3.3.1 Ultrasonic inspection of materials for hidden flaws or defects shall be performed in accordance with MIL-STD-271D (Ships) Paragraph 7. Any indication greater than 5% of the wall thickness shall be cause for rejection of the finished part or that section of pipe.

3.4 Dye Penetrant Test (Liquid Penetrant Inspection)

3.4.1 Liquid penetrant inspection shall be performed in accordance to WANL Process Specification 294564 Rev. No. 4 to the general acceptance level of Class 00 given in Appendix V.

3.5 Radiography

3.5.1 Radiographic inspection of fuel pins is primarily for the examination of the arrangement and condition of internal parts after construction. However, any flaw or defect indicated in weldments, fuel pin tube, or end caps shall be fully investigated.

3.5.2 Radiography shall be performed to MIL-STD-271D (Ships) Paragraph 3.

3.6 Dimensional Inspection

3.6.1 Dimensional inspection shall be performed with precision instruments that can be read accurately to the degree required on the drawing for the part being inspected. All instruments shall be periodically calibrated to maintain accuracy.

3.6.2 Measurements shall be made in such a manner as not to scratch, mar, bend, distort, or damage parts being inspected.

3.6.3 Dimensional inspection (unless otherwise specified) shall be performed at an ambient temperature of 75 $\pm$ 3°F.

3.7 Furnace Qualifications

3.7.1 Any equipment used for heating fuel pins or fuel pin parts must first be qualified and operated in accordance with NASA-Lewis TMX 67879 Specification No. RM-5, "Post-heating of Cb-1Zr and T-111 (Ta-8W-2Hf) Weldments".

3.8 Visual Inspection

3.8.1 Visual inspection shall be interpreted as the careful, minute examination by the unaided eye or up to 10X magnification of all of the visible areas of a component or part. Examination shall be made in a well lighted area.

3.8.2 Visual inspection shall include the comparison of the part with the drawing or other description and noting any anomaly.

3.9 Straightness Measurements

3.9.1 Straightness of fuel pins or tubes shall be determined by two methods. Method (1) is by axial traverse with dial indicator from a flat parallel surface and (2) by T.I.R. (Total Indicated Runout).

3.9.2 Method (1) - Place fuel pin or tube on Vee blocks of uniform height at intervals no more than 12" apart. (Vee blocks should not be located at a weld or any other location distortion.) Record dial indicator readings made from a flat parallel surface to the highest point on tube within 1/2" from each end and at every 2" interval along entire length. Rotate tube 90° and repeat above measurements. Overall straightness is the algebraic difference between the two points with the greatest difference in any one plane.

3.9.3 Method (2) - Place fuel pin or tube on Vee blocks as indicated in Method (1). Measure T.I.R. (Total Indicated Runout) with a dial indicator at points within 1/4" from each end and at every 2" interval along entire length by rotating fuel pin or tube 360° and recording high and low points. Overall straightness is 1/2 the T.I.R. at the point with the largest T.I.R.

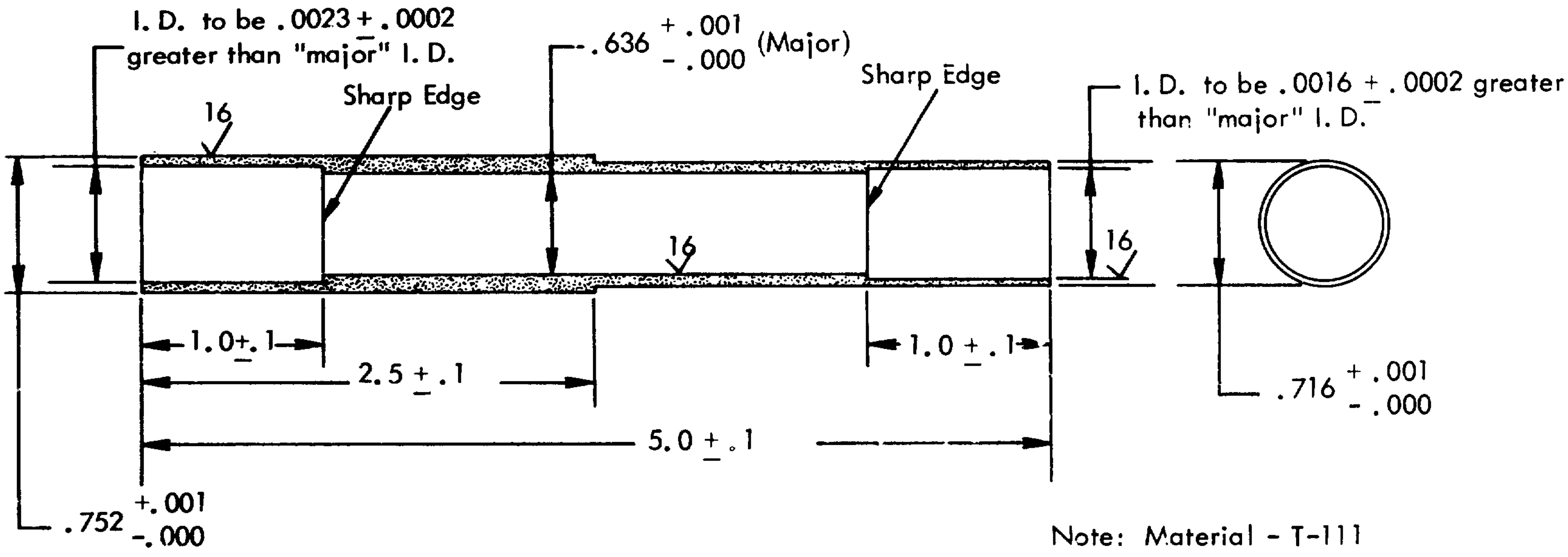
3.9.4 Overall straightness of the entire fuel pin or tube is construed to be the larger straightness measurement of the two methods.

3.10 Wall Thickness Measurements

3.10.1 Wall thickness variation measurements of fuel pin machined T-111 tubes shall be mapped and evaluated utilizing Ultrasonic Immersion Inspection Equipment, methods and techniques compatible with the requirements of MIL-STD-271D. Wall sections having thickness variations >4% from nominal shall be considered unacceptable for pin assembly fabrication. Equipment required to perform this inspection shall be as specified below or the direct equivalent:

(a) Sperry Reflectoscope Model 721
(b) 15 MHZ Transducers with 187 mill dia. window, Type SIL.
(c) Water immersion
(d) Water path .4 inches
(e) Sperry Pulser Receiver, Model 50 W.
(f) Thickness Readout Unit, Automation Ind., Type UM
(g) Brush Recorder, Mark II
(h) Rotating Apparatus and Speed Control System to facilitate 360° inspection capability thru generation of transversing helixing rate of approximately 10 rev./inch
(i) Calibration Standard of T-111 tube materiel per the attached sketch.

WANL U. T. Calibration Standard



Note: Material - T-111

Fuel Pin Wall Thickness Mapping

C2

APPENDIX I

Welding Procedure Sheet, Fuel Pin End Cap-Tube Weld

Procedure No.: 70821-1

Date: 3-24-71

WELDING PROCEDURE

Name of Part: Fuel Pin End Cap to Fuel Pin Tube   Drawing No. CD-352466, 71, 72

Welding Spec. No. --

Material: T-111 Alloy   Material Spec. No. --

Description of Welds Covered by this Procedure: Shoulder Joint - .058 in. wall tube to cap approx. 3/4 in. dia.
(type, size, location)

Welding Process: Electron Beam

Welding Machine: Sciaky 30KW   Type Current: --

Electrode - Type: --   Size: --   Spec.: --

Filler Material - Comp.: --   Spec.: --

Shielding Gas: --   Backup Gas: --

Cleaning Prior to Welding: --

Detailed Procedure:

	Pass	A Pass	B Pass
Current		90 milliamps	
Voltage		20 KV	
Filler Wire Size			
Filler Feed Rate			
Travel Speed		15 RPM	
Interpass Temp.			
Weld Position		Fuel Pin Horizontal	

Remarks (include details of fixturing, tacking where required, chills, etc.)

Weld Program: Initial and final current, 5 ma., initial slope rate - 300, final slope rate - 900, initial and final voltage - 14 KV, high voltage slope - 2.0, high voltage start delay .3 sec., run time 7.0 sec., decay time 2.0 sec.

Work Distance: 2 in. to bottom of scanner coil.

APPENDIX II

Welding Procedure Sheet, Fuel Pin Final Closure Weld

Procedure No.: 70821-2

Date: 6-16-71

WELDING PROCEDURE

Name of Part: Fuel Pin Final Closure   Drawing No. NASA-CD-352466, 71, 72

Welding Spec. No. --

Material: T-111 Alloy   Material Spec. No. --

Description of Welds Covered by this Procedure: Arc spot seal of .029 in. dia. hole
(type, size, location)

Welding Process: Tungsten Arc

Welding Machine: Merrick 300 Amp Welder--Amp Trak   Type Current: DCSP

Electrode - Type: w (2% Thoria)   Size: 3/32 in.   Spec. --

Filler Material - Comp. --   Spec. --

Shielding Gas: UHP Helium   Backup Gas: --

Cleaning Prior to Welding: Pre-cleaned and handled in assembly chamber as defined in checkoff procedure.

Detailed Procedure:

	Pass	Pass	Pass
Current	140 amps.		
Voltage			
Filler Wire Size			
Filler Feed Rate			
Travel Speed			
Interpass Temp.			
Weld Position	Horizontal or Perpendicular		

Remarks (include details of fixturing, tacking where required, chills, etc.)

Weld current, 140 amps for 0.5 seconds then tapers to 50 amps during 0.75 seconds.

Amp-Trak settings: PFT = 0, IC = 140 amps, IT = 1 second, WT = 0.5 seconds.

WC (Pendant) 140 amps, taper = off, FST = 0.75 seconds, PHC = 50 amps, PHT = 0, PFT = 0.

Arc start settings: One shot (reset after each), intensity 60%.

APPENDIX III

Fuel Pin Assembly Checkoff

FUEL PIN ASSEMBLY CHECKOFF
"D" SIZE "L" LENGTH PROTOTYPE
Dwg. 352472 Rev. ________

I. PREPARATION

Initial

________ 1. Fuel pin I.D. No. ________________.

________ 2. Select the following parts and verify complete material certification and identification as designated in the "Pre-Irradiation Fuel Pin Data" section. (Note: Complete necessary sections of "Pre-Irradiation Fuel Pin Data".)

a. One outlet end fitting (Part No. 1).
b. Two separators (Part No. 2).
c. Eleven separators (Part No. 2A).
d. One fuel spacer, outlet end (Part No. 3).
e. One fuel pellet group (Part No. 4).
f. One fuel spacer, inlet end (Part No. 5).
g. One inlet end fitting (Part No. 6).
h. Weld shrinkage spacers as required (Part No. 7).
i. One fuel pin tube (Part No. 8). (Tube was cleaned before bonding liner).

________ 3. Measure each fuel pin component and determine that required stack length is within drawing tolerance.

________ 4. Clean parts (a) thru (h) above (except Item (e)) as specified in Section 1.5 Cleaning and Handling - T-111 Alloy and Tungsten Parts. (Note: All cleaning is to be accomplished as near to time of use as practical). Handle refractory metal parts only with refractory metal tools.

________ 5. Clean equipment, tools and storage containers as specified in cleaning section 1.5.

________ 6. Load parts for one or more fuel pins into glove box.

________ 7. Load clean fuel pin assembly plug into glove box.

________ 8. Load clean handling tools and welding fixtures into glove box.

NOTE: All surfaces that will contact fuel pin parts during assembly and welding must be constructed from or coated with refractory metal.

________ 9. Load sample weld pieces into weld box and set up for welding.

II. PUMPDOWN

Initial

_________ 1. Evacuate glove box to at least 5×10^{-5} torr. Press _________.

_________ 2. Backfill glove box with UHP helium to 1 atmosphere.

_________ 3. Open fuel container and make visual check of fuel. Set fuel out of container so that it will degass properly.

_________ 4. Evacuate glove box to the 10^{-6} torr range while heating fuel and fuel pin parts to $\sim 200^{\circ}F$ with heating lamps. Pressure _________. (Normally an overnight pumpdown is desirable).

_________ 5. Make sample end cap to fuel pin tube weld immediately before backfill in accordance with Section 2.2.

_________ 6. Backfill with UHP helium to atmospheric pressure. Note: Helium must be from a batch analyzed in accordance with Section 1.1.5.

_________ 7. Monitor and record O_2 and H_2O level in glove box.

O_2 _________ PPM H_2O _________ PPM

NOTE: Impurity level must be below 5 PPM for both O_2 and H_2O before proceeding.

III. FUEL PIN ASSEMBLY

_________ 1. Insert stepped plug into outlet end of fuel pin tube liner subassembly and hold in the horizontal position.

_________ 2. Insert outlet fuel pellet and separator (see Pre-Irradiation Fuel Pin Data for order) and push until separator is just inside the inlet end of fuel pin tube.

_________ 3. Insert next fuel pellet and push pellet column until end is just inside inlet end of fuel pin tube then load another separator.

_________ 4. Continue loading in this manner until all pellets are in place and a separator is between each pellet.

_________ 5. Insert a separator (Part No. 2A), fuel pin spacer - inlet end, a separator (Part No. 2), necessary number of weld shrinkage spacers (Part No. 7) and inlet end fitting into fuel pin tube.

III. FUEL PIN ASSEMBLY (Continued)

Initial

__________ 6. Remove plug and insert a separator (Part No. 2A), fuel spacer - outlet end, a separator (Part No. 2) and outlet end fitting into fuel pin tube.

__________ 7. Load fuel pin assembly into EB weld fixture and weld both end caps to fuel pin tube in accordance with Section 2.2.

__________ 8. Backfill chamber with ultra pure helium.

__________ 9. Visually inspect welds.

__________ 10. Load and weld sample weld piece.

IV. FUEL PIN FINAL SEAL

__________ 1. Position fuel pin and welding electrode for final seal.

a. Make a sample seal weld on a practice piece in accordance with Section 2.3 of Supplement 1.

__________ 2. Record chamber O_2 __________ and H_2O __________ (must each be 5.0 PPM or less before proceeding).

__________ 3. Record chamber temperature __________ and pressure __________.

__________ 4. Make seal weld in accordance with Section 2.3.

__________ 5. Visually inspect seal weld.

V. INSPECTION

__________ 1. Remove sealed fuel pin from weld chamber and immediately helium leak check fuel pin in accordance with applicable parts of Section 3.2.

_____ a. Leak detector calibration - minimum detectable leak ____________ Std. cc/sec.

_____ b. Fuel pin leak rate __________ Std. cc/sec.

__________ 2. Visually inspect fuel pin welds. Result ______________________________

__________ 3. Check NASA identification number on inlet end plug.

__________ 4. Dye penetrant inspect fuel pin welds in accordance with Section 3.4. Outlet end cap________ Inlet end cap________ Seal________

a. Section all sample welds prependicular and parallel to the weld and inspect.

V. INSPECTION (Continued)

Initial

__________ 5. Measure length of fuel pin.

__________ 6. Weigh fuel pin ________________

__________ 7. X-ray fuel pin. 0° and 90°

__________ 8. Measure straightness and OD of fuel pin. (See Appendix IV, Section C-5 of Pre-Irradiation Fuel Pin requirements and Section 3.9, Straightness Measurements.)

__________ 9. Clean fuel pin (in accordance with Section 1.5).

__________ 10. Degass 1 hour at $2000^{\circ}F$ wrapped in Ta foil in vacuum of 5×10^{-5} torr or better. Furnace cool to room temperature before removing.

__________ 11. Pressurizing to 50 psig of helium leak test in accordance with applicable parts of Section 3.2 after 1/2 hour.

a. Leak detector calib. __________ Std. cc/sec.

b. Fuel pin leak rate ____________ Std. cc/sec.

DATE __________________

SIGNED ________________

REMARKS: ____

APPENDIX IV

Pre-irradiation Fuel Pin Data

PRE-IRRADIATION FUEL PIN DATA

A. Fuel Pin Data

Date Completed ___________

1. Fuel Pin Ident. No. ______________
2. Size Designation ______________
3. Assembly Designation ______________
4. Drawing No. ______________ Rev. __________

B. Fuel Pellet Data

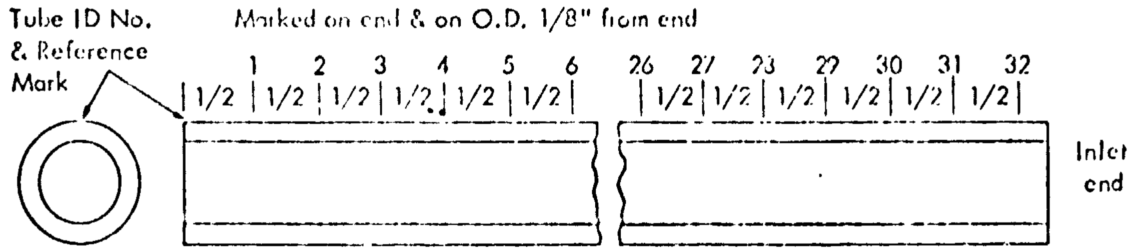
Pellet No.	ORNL No.	Fuel Type	I.D. (in.)	O.D. (in.)	Wt. GMS	Length (in.)	Avg. U-235 Enrichment
(Inlet) 1							
2							
3							
4							
5							
6							
7							
8							
9							
(outlet) 10							
				TOTAL			

Measured Stack Length ______________

C. Fuel Pin Tube

1. Material ______________
2. Ident. No. ______________
3. Heat No. ______________
4. Length ______________

5. Fuel Pin Tube Measurements



ID Dia. Test	Axial Position	After Machining O.D. 0°	After Machining O.D. 90°	Wall Thickness max.	Wall Thickness min.	Straightness (Sec. 3.9, Method 2) T.I.R.	Straightness (Sec. 3.9, Method 2) T.I.R.	Completed Fuel Pin O.D. 0°	Completed Fuel Pin O.D. 90°
	1								
X	2								
X	3								
X	4								
X	5								
X	6								
X	7								
	8								
X	9								
X	10								
X	11								
X	12								
X	13								
X	14								
X	15								
	16								
X	17								
X	18								
X	19								
X	20								
X	21								
X	22								
X	23								
	24								
X	25								
X	26								
X	27								
X	28								
X	29								
X	30								
X	31								
	32								

Straightness (Section 3.9, Method 1)

	Radial Position	(Axial traverse by dial indicator from a flat parallel surface)									
		(outlet) end	2"	4"	6"	8"	10"	12"	14"	16"	(inlet) end
Before Ass'y	0°										
	90°										
After Ass'y	0°										
	90°										

D. Fuel Pin Tube Liner (Between Fuel & Tube)

1. Material ______________

2. Bonded or loose ______________

3. Distance from referenced end of tube to liner ______________

4. Distance from other end of tube to liner ______________

E. End Caps

1. (Inlet) end cap Material ________ Ident. No. ________

2. (Outlet) end cap Material ________ Ident. No. ________

F. Spacers

Material ______________

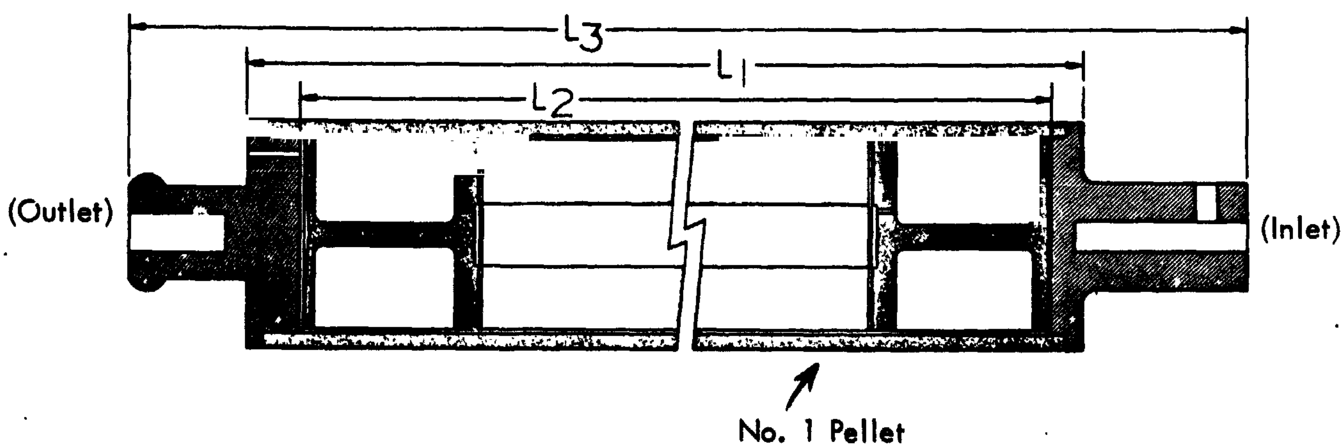
Location	I Dent. No.	Total Height
Inlet		
Outlet		

G. Washers & Separators

Material ____________

Location	No. Washers	Total Thickness	Center Hole Dia.
Inlet next to end cap			
Inlet next to fuel			
Between pellet 1 & 2			
Between pellet 2 & 3			
Between pellet 3 & 4			
Between pellet 4 & 5			
Between pellet 5 & 6			
Between pellet 6 & 7			
Between pellet 7 & 8			
Between pellet 8 & 9			
Between pellet 9 & 10			
Outlet next to fuel			
Outlet next to end cap			

H. Fuel Pin Measurements



1. L_1 Between end cap flats (outside, before welding) ____________
2. L_2 Between end cap flats (inside, before welding) ____________
3. Total internal stack length:
   (a) Fuel ____________
   (b) Spacers ____________
   (c) Washers ____________
   (d) Weld Shrinkage Allowance ____________

4. L_1 Between end cap flats (outside, after welding ________

5. L_3 Overall length (after welding) ________

6. Weight of Assembly ________

7. O.D. measurements (See C-5 of Appendix IV)

8. Fuel Pin overall straightness ________

I. Fuel Pin Closure

1. Helium Pressure (psia) ________ Temperature (°F) ________

2. Helium Purity (ppm) (From supplier certification)

   (a) H ____

   (b) Ne ____

   (c) N ____

   (d) O_2 ____

   (e) A ____

   (f) CO_2 ____

   (g)

   (h)

3. Helium Purity (ppm) @ Spot Check

   H_2O ______

   O_2 ______

J. Inspection

1. Visual ______________ Date ______________ Initial ______________

2. Ident. No. ______________ Date ______________ Initial ______________

3. Helium Leak Check ________ Date ______________ Initial ______________

   Standard Leak Rating __________ Leak Detector Scale Reading __________

   Test Chamber Empty Scale Reading __________ With Fuel Pin __________

4. Dye Penetrant ______________ Date ______________ Initial ______________

5. X-ray ______________ Date ______________ Initial ______________

APPENDIX V

WANL Process Specification 294564 Rev. No. 4,
Liquid Penetrant Inspection

INFORMATION CATEGORY

UNCLASSIFIED

R. Sollandinga 6/11/68
Authorized Classifier Date

Westinghouse Electric Corporation

Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pa. 15236
(Fed. Ident. Code No. 14683)

PROCESS SPECIFICATION 294564 Revision No. 4
(Not for Publication)

June 13, 1968

LIQUID PENETRANT INSPECTION

1. SCOPE

This specification covers requirements for liquid penetrant inspection, designated as follows:

Designation	Description*
294564-1	Method using solvent-removable visible dye penetrant and a penetrant remover (solvent).
294564-2	Method using postemulsifiable visible dye penetrant and an emulsifier.
294564-3	Method using water-washable visible dye penetrant.
294564-4	Method using water-washable fluorescent penetrant.
294564-5	Method using postemulsifiable fluorescent penetrant and an emulsifier.
294564-6	Method using a high intensity postemulsifiable fluorescent penetrant and an emulsifier.

NOTE: Unless otherwise specified, the following requirements apply to all designations.

2. APPLICABLE DOCUMENTS

The following documents, of the issue in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

MIL-STD-23 PS 294584

* Acceptance standards are to be selected from Tables I and II herein.

Printed in U.S.A.
POP/eh

3. REQUIREMENTS

3.1 SAFETY PRECAUTIONS

3.1.1 Penetrant materials shall not be over 100°F and shall not be applied to a surface which is at a temperature greater than 100°F.

3.1.2 Due to the flammable nature of liquid penetrant inspection materials, open flame shall not be used for heating purposes.

3.1.3 (294564-1): Highly volatile solvents shall be used cautiously. Their vapors are relatively toxic and the liquid is a primary skin irritant. Extreme care shall be exercised in handling the volatile solvents as many of them are highly inflammable liquids.

3.2 SUPPLEMENTARY REQUIREMENTS: Areas to be tested and the kind of liquid penetrant, identified by dash number, shall be specified in applicable drawings, specifications, contracts or the purchase order. Penetrant test markings incorporated in drawings shall be in accordance with MIL-STD-23.

3.3 QUALIFICATION

3.3.1 Personnel Personnel performing and interpreting liquid penetrant tests shall be certified according to PS 294584 when specified by the purchase order.

3.3.2 Equipment Requirements: The test equipment in the hands of qualified nondestructive test personnel shall be capable of consistently obtaining results of specified quality level and shall conform to the applicable requirements of PS 294584 when specified by the purchase order.

3.4 SURFACE PREPARATION

3.4.1 Surface Condition: Surfaces to be inspected shall be free from scale, slag, and adhering or embedded sand or other extraneous materials.

3.4.2 As-Welded Surfaces: As-welded surfaces shall be considered suitable for liquid penetrant inspection without grinding, if the slag is removed and surface irregularities do not interfere with interpretation of the test results and if the weld contour blends into the base metal without undercutting.

3.4.3 Surface Blasting: Shot, sand, grit and vapor blasting shall not be done on surfaces which are to be liquid penetrant inspected unless specifically approved by the purchaser.

3.4.4 Finished Surfaces: Surfaces, for which a specific finish is required, shall be given this surface finish prior to the final liquid penetrant inspection prescribed by the applicable specifications. Inspection at intermediate stages of fabrication shall be permitted.

3.4.5 Cleaning: All surfaces being tested shall be thoroughly cleaned of extraneous material. If a nonvolatile liquid is used for cleaning, the surface shall be heated or dried with hot air to assure complete removal of the cleaner. As a final cleaning operation, each surface shall be dipped, sprayed, wiped, or brushed with trichloroethylene, perchloroethylene, acetone, or methyl chloroform and thoroughly dried by removing the excess with a clean, dry cloth or absorbent paper, and allowing the remainder to evaporate for a minimum of five minutes. Prior to liquid penetrant inspection, the surface to be tested and any adjacent area within one inch of the surface to be tested shall be dry and free of any dirt, grease, lint, scale and salts, coatings, or other extraneous matter that would obscure surface openings or otherwise interfere with the test.

3.4.6 Temperature: Maximum penetration into extremely small openings requires that the penetrant and the test surface be maintained at the temperature recommended by the penetrant manufacturer but in no case shall be less than 50°F.

3.5 LIGHTING IN TEST AREA

3.5.1 Visible Penetrants (294564-1, -2, and -3): When visible dye penetrants are used, the test area shall be adequately illuminated for proper evaluation of indications revealed on the test surface.

3.5.2 Fluorescent Penetrants (294564-4, -5, and -6): When a fluorescent penetrant is used, the inspection shall be accomplished in a darkened area using ultraviolet lamp with a brilliance of 90 foot candlos minimum, when measured in the center of the beam at a distance of 15 inches from the lamp using an unfiltered Weston Model 703 light meter, or equal. A minimum of 5 minutes shall be allowed for the lamp to obtain full brilliance before beginning the inspection. This equipment shall be maintained and calibrated in a manner to ensure reliable and uniform operation. This inspection shall be performed at least once a week.

3.6 PROCEDURE ON PENETRANTS

3.6.1 Application: The surface to be tested shall be thoroughly and uniformly coated with penetrant by flooding, brushing, immersing or spraying. The surface shall be kept wetted for the time specified as follows for the method employed:

Penetrant Designation	Min. Penetration Time	Max. Penetration Time
294564-1	15 minutes	20 minutes
294564-2	15 minutes	20 minutes
294564-3	25 minutes	30 minutes
294564-4	25 minutes	30 minutes
294564-5	15 minutes	20 minutes
294564-6	10 minutes	15 minutes

3.6.2 Removal of Penetrant:

3.6.2.1 (294564-1) Solvent Removable: Flushing of the surface with any liquid following application of the penetrant and prior to developing shall be prohibited. The excess penetrant shall be removed from all surfaces as follows:

(a) As much excess penetrant as possible shall be removed by first wiping the surface thoroughly with a clean, dry cloth or absorbent paper.

(b) The remaining excess penetrant shall be removed by wiping the surface with a clean cloth dampened with a penetrant remover. Acetone shall not be used to remove excess penetrant.

3.6.2.2 (294564-3 and -4) Water Washable: The penetrant shall be removed from all surfaces by swabbing with a clean, lint-free cloth saturated with clear water or by spraying with water not exceeding 120°F and 40 psi line pressure.

3.6.2.3 Postemulsifiable:

3.6.2.3.1 (294564-5 and -6): The emulsifier shall be applied either by immersing, flooding or spraying of the part. After a suitable penetration time (See Section 3.6.1) and emulsification period the surface film of the penetrant and emulsifier shall be removed from the part by employing a hot water spray not exceeding 120°F amd 40 psi. After washing, all surfaces shall be checked under a black light to insure complete cleaning of all surfaces. Alternatively, the penetrant shall be removed by use of the cleaner specified by the manufacturer of the penetrant.

3.6.2.3.2 (294564-2): The procedure shall be according to Section 3.6.2.3.1 except that after washing, all surfaces shall be checked under adequate visible light to insure complete cleaning.

3.6.3 Surface Drying:

3.6.3.1 Solvent Removable Penetrants (294564-1): The drying of test surfaces, after the removal of the excess solvent removable penetrant, shall be accomplished only by normal evaporation, or by blotting with absorbent paper or clean, lint-free cloth. Forced air circulation in excess of normal ventilation in the inspection area shall not be used. The time for surface drying after removal of excess penetrant and prior to application of the developer shall be limited to a maximum of ten minutes.

3.6.3.2 Water Removable Penetrants (294564-2, -3, -4, -5, and -6): The drying of test surfaces shall be accomplished by using circulating air, blotting with paper towels or clean, lint-free cloth or by normal evaporation. It is important that during the drying operation no contaminating material be introduced onto the surface which may cause misinterpretation during the inspection operation.

3.7 PROCEDURE ON DEVELOPERS

3.7.1 Dry Developer (294564-4, -5, and -6): Dry developing powder shall be applied only on a dry surface so that matting will be prevented. Immediately after drying of the test surface, the powder shall be thinly but uniformly applied to provide a dusty appearance. The test surfaces shall not be evaluated sooner than 15 minutes after application of the developer.

3.7.2 Wet Developer (294564-3 and -4): This kind of developer shall be uniformly applied to surfaces by dipping, spraying or brushing after removal of all excess penetrant. When using liquid type developers, it is necessary that they be continually agitated in order to prevent settling of solid particles. Concentrations of wet developer in cavities on the inspection surface shall not be permitted, since these pools will dry to an excessively heavy coating, resulting in the masking of indications. The test surfaces shall not be evaluated sooner than 15 minutes after application of the developer.

3.7.3 Nonaqueous Wet Developer (294564-1, -2, -5, and -6): A nonaqueous wet developer recommended by the penetrant manufacturer shall be used. Immediately prior to application, the developing liquid shall be kept agitated in order to prevent settling of solid particles. The developer shall be uniformly applied in a thin coating to the test surfaces by spraying. If the geometry of the item being inspected precludes the use of a spray, a brush or similar applicator shall be used provided it results in a uniform, thin coating of developer. Pools of wet developer in cavities on the inspection surface shall not be permitted since these pools will dry to an excessively heavy coating, resulting in the masking of indications. The test surfaces shall not be evaluated sooner than 15 minutes after application of the developer.

3.8 FINAL CLEANING: The penetrant materials shall be removed as soon as possible after inspection by means of water or solvents in accordance with applicable specifications.

4. QUALITY ASSURANCE

4.1 COMPLIANCE: No change shall be made from these procedures without first obtaining the approval of the purchaser.

4.2 ACCEPTANCE CRITERIA: The criteria for acceptance standards in terms of size and distribution of indications are presented in Tables I and II. Table I shown class numbers for coding various combinations of size of indications and the number of indications of each size. Table II shows code letters which can be used to denote the distribution of indications per total area, per square inch, or along a linear dimension. Some examples of specified classes and the interpretations therof follow:

Class 0 - Surface or edge referenced shall be completely free of penetrant indications.

Class 00 - Surface or edge may have micro-porosity only.

Class 1-1a - Surface or edge referenced may have no more than two indications of 1/16-inch size per square inch and their centers shall be at least 3/8-inch apart.

Class 2-4C - Surface or edge referenced may have no more than two indications of 1/16-inch size per square inch and their centers shall be at least 3/8-inch apart.

Class 3-8K - Surface or edge referenced may have no more than three linearly-oriented indications of 1/8-inch size and the center of any two indications shall be at least 1/4-inch apart.

4.3 REJECTION STANDARDS

4.3.1 Parts showing indications in excess of those permitted by the class number and letter specified according to Section 4.2 on the applicable drawing or other purchasing document shall be subject to rejection.

4.3.2 Weldments and other parts with a relatively rough surface may reveal nonrelevant indications and shall be subject to the following interpretation. All indications in weld craters shall be considered relevant and shall be evaluated in accordance with applicable acceptance standards. If other indications are believed to be nonrelevant at least 10 percent of each type of indication shall be explored by removing the surface roughness or other conditions believed to have caused the type of indication to determine if defects are present. The absence of indications upon reinspection by liquid penetrant inspection after removal of the surface roughness shall be considered to prove that the indications were nonrelevant with respect to actual defects. If reinspection reveals any indications, these indications and all of the original indications shall be considered relevant and shall be evaluated in accordance with the acceptance standards

4.4 RECORDS AND REPORTS

4.4.1 Records: The type of penetrant used, and times for penetration and developing shall be recorded. For each part inspected, its identification and the size, shape, type, and number of defects found and their locations shall be recorded.

4.4.2 Reports: Five copies of the information recorded in compliance with Section 4.4.1 shall be submitted to the purchaser according to instructions on the purchase order.

TABLE I

CLASS NUMBERS FOR THE NUMBER AND SIZE OF INDICATIONS

Class No.	Indications	
	Number	Maximum Size, in.
0	No indications	
00	Microporosity condition (all indications under 1/64 in.)	
1-1	1	1/64
2-1	2	1/64
3-1	3	1/64
4-1	4	1/64
5-1	5	1/64
1-2	1	1/32
2-2	2	1/32
3-2	3	1/32
4-2	4	1/32
5-2	5	1/32
1-3	1	3/64
2-3	2	3/64
3-3	3	3/64
4-3	4	3/64
5-3	5	3/64
1-4	1	1/16
2-4	2	1/16
3-4	3	1/16
4-4	4	1/16
5-4	5	1/16
1-5	1	5/64
2-5	2	5/64
3-5	3	5/64
4-5	4	5/64
5-5	5	5/64
1-6	1	3/32
2-6	2	3/32
3-6	3	3/32
4-6	4	3/32
5-6	5	3/32

TABLE I (continued)

CLASS NUMBERS FOR THE NUMBER AND SIZE OF INDICATIONS

Class No.	Indications	
	Number	Maximum Size, in.
1-8	1	1/8
2-8	2	1/8
3-8	3	1/8
4-8	4	1/8
5-8	5	1/8
1-12	1	3/16
2-12	2	3/16
3-12	3	3/16
4-12	4	3/16
1-16	1	1/4
2-16	2	1/4
3-16	3	1/4
4-16	4	1/4

TABLE II

CODE LETTERS FOR DISTRIBUTION OF INDICATIONS

Class Suffix Letter	Basis of Limits of Indications	Minimum Distance Between Centers, Inches
A	Total area or edge	-----
B	Per square inch	1/4
C	Per square inch	3/8
D	Per square inch	1/2
E	Per square inch	1
F	Per square inch	2
G	Per square inch	3
H	Per square inch	4
J	Per square inch	6
K	Per linear dimension	1/4
L	Per linear dimension	3/8
M	Per linear dimension	1/2
N	Per linear dimension	1
P	Per linear dimension	2
Q	Per linear dimension	3
R	Per linear dimension	4
S	Per linear dimension	6

APPENDIX VI

WANL Process Specification 294502, Rev. No. 1,
Helium Leak Test Process Procedure

INFORMATION CATEGORY

[illegible handwriting]

[illegible signature] [illegible date]

Authorized Classifier Date

Westinghouse Electric Corporation

Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Pa. 15236
(Fed. Ident. Code No. 14683)

PROCESS SPECIFICATION 294502 Revision No. 1 October 13, 1967
(Not for Publication)

HELIUM LEAK TEST PROCESS PROCEDURES

1. PURPOSE

This procedure describes the test methods to be followed in determining the soundness of hermetically sealed vessel assemblies. Its application in no way relieves the supplier of the responsibility of performing any other nondestructive tests (including dye penetrant, ultrasonic, radiography, eddy current, etc.) contractually specified by the purchaser to ascertain the integrity of any component.

2. SCOPE

Two methods of testing are permitted - One involves subjecting (sealed) components to vacuum and, immediately thereafter, to a high pressure of helium in a pressure chamber; then employing a leak detector to detect the existence of any leaks through exceedingly small openings in the envelope or barrier separating two regions of different pressures. When permitted by the applicable drawing, components may be tested with a helium atmosphere while a leak detector is in communication with its inside space (See Section 6).

3. GENERAL REQUIREMENTS

3.1 Scheduling:

3.1.1 Leak testing shall be performed during pre-determined stages of fabrication and shall be preceded by stress relieving of the subassembly when completed vessels are stress relieved before final leak testing.

3.2 Precautions:

3.2.1 The vessel under test shall be absolutely clean and free from water vapor, oil, grease, and other contaminants which might affect leak test data.

3.2.2 The helium employed for testing shall be pure water pumped dry gas having a dew-point of 40°F or lower.

3.2.3 All unused vessel openings shall be sealed leaktight. All sealing material must be readily and completely removable after completion of the test.

Printed in U.S.A.
POP/cas

W form 59504A

C

4. INSTRUMENTATION

4.1 The leak detector used shall have a sensitivity of at least $1x10^{-8}$ standard cc He/sec., as determined with a standard leak, when operated at maximum throttle opening.

4.2 Operation of the leak detector shall be strictly in accordance with the manufacturer's instructions. At no time shall the leak detector pumps be used to evacuate external manifolds or vacuum chambers.

4.3 The vacuum system shall be calibrated daily for helium sensitivity. In calibrating the system the external vacuum pumps shall be blanked off and a standard leak placed at the furthest point from the leak detector. The standard leak used to calibrate the system shall be at least $1x10^{-6}$ standard cc He/sec. and shall be handled with extreme care to prevent plugging or breakage. Calibration shall be concluded as soon as the system sensitivity reaches a minimum of $1x10^{-8}$ standard cc He/sec.

4.4 The leak tester and vacuum system shall be tested for helium background daily. System background with the external pumps blanked off shall be no more than 5% of full scale (when the unit is set at maximum sensitivity) after five minutes of continuous testing. If units with an adjustable zero are used, total system background shall be reduced to below that specified above.

4.5 The components tested shall be free of dirt, grease, burrs, etc. which would either tend to clog defects or damage the pressure and vacuum fittings.

4.6 Leak testing shall be performed in well ventilated areas to minimize the possibility of detecting helium-contaminated air.

4.7 The vacuum system shall be constructed from corrosion resistant materials and kept scrupulously clean at all times. All flexible connections shall be made of neoprene.

5. TEST PROCEDURE

5.1 Pressurizing Operation:

5.1.1 Place component assemblies in pressure manifold and seal. Make certain that all assemblies are clean and free of any porous materials which may absorb helium.

5.1.2 Evacuate the pressure manifold for 20 minutes minimum after attaining a vacuum pressure of 10 to 15 microns of Hg.

5.1.3 Close pressure chamber vacuum valve.

5.1.4 Open helium inlet valve allowing chamber pressure to reach 100 psi, minimum.

5.1.5 Maintain helium pressure at 100 psi. for 20 minutes minimum.

5.1.6 Close helium inlet valve, release pressure and remove the component assemblies from the pressure chamber.

5.1.7 The pressure chamber may be reloaded and operations 5.1.1 through 5.1.6 repeated under continuous operating conditions.

5.1.8 Allow component assemblies to stand in air for a minimum of 10 minutes and maximum of 24 hours before helium leak testing, to allow any residual helium which may be absorbed on the outside surfaces of the component assemblies to diffuse into the air.

5.2 Calibration of Equipment:

5.2.1 General

5.2.1.1 Calibration will be made after each period of shutdown greater than 1/2 hour and a minimum of three times per shift at the beginning of the shift, after the lunch period and at the end of the shift on continuous production. Results of each calibration will be recorded on the production record form.

5.2.1.2 The recorded information will be as follows:

a. Location of calibrated leak tube.

b. Date and time of day.

c. Component assembly batch tested before and after calibration.

d. The magnitude of the output meter deflection at an amplification of 10X, 5X, and 1X.

5.2.1.3 During calibration the calibrated leak tube will be located at the area in which the component assemblies will be tested, or at a point in the chamber furthest from the leak detector.

5.2.1.4 All calibration tests will be conducted with the throttle valve wide open and a manifold pressure of 0.2 microns of Hg or less.

5.2.1.5 To insure that deflection recorded during calibration is not caused by residual helium contained in the system, no deflection of the meter should be evident when the leak source is removed or switched off.

5.2.1.6 The sensitivity of the leak detector should be the same or more sensitive than the limits indicated under paragraph 4.1.

5.2.1.7 If it is found that the leak detector does not meet the calibration standard, all components tested between calibration tests shall be retested.

5.2.2 Procedure for Establishing Acceptance Number

5.2.2.1 Use a known standard glass leak tube; for example, 7.4×10^{-7} cc/sec. This is to be connected to the component testing chamber.

5.2.2.2 When pressure in the empty chamber is less than .2 microns as indicated on the multi-purpose meter on the leak detector, turn on the standard leak.

5.2.2.3 Pump on the standard leak until a stable reading on the output meter is reached. This is indicated by a meter change of less than five per cent in two minutes. All valves between the standard leak and the detector should be wide open.

5.2.2.4 Record the meter reading and scale (Reading "A").

5.2.2.5 Turn off leak, stabilize reading as in paragraph 5.2.2.3 and record meter reading and scale (Reading "B").

5.2.2.6 Then:

$$\frac{\text{standard leak rate}}{\text{"A"} - \text{"B"}} = \text{sensitivity} *$$

$$\text{Example: } \frac{7.4\times10^{-7}}{(21\times10) - (10\times1)} = \frac{7.4\times10^{-7}}{200} = 3.7\times10^{-9} \text{ cc/sec.}$$

5.2.2.7 Calculate the acceptance number as follows:

$$\frac{\text{maximum component leak rate}}{\text{sensitivity}} = \text{acceptance number}$$

$$\text{Example: } \frac{5\times10^{-8}}{3.7\times10^{-9}} = 13.5$$

5.3 Leak Testing

5.3.1 Fill chamber with as many component assemblies as convenient and pump down to low pressure with the roughing pump.

* If unspecified, a figure of 5×10^{-8} cc/sec. shall be considered the minimum acceptable.

5.3.2 Using the same procedure as when determining sensitivity, open valves to the leak detector.

5.3.3 When pressure indicated on multi-purpose meter is below .2 microns, turn on filament.

5.3.4 After allowing meter to stabilize (no more than 5% increase in 2 minutes),record the reading on the output meter if it goes below the previously determined acceptance number, accept all components in the chamber. Record component lot numbers and the reading on the output meter.

5.3.5 If the audible signal is set at less than the acceptance number, it is acceptable to record the reading as less than the audible signal.

5.3.6 If a leak is indicated by a reading greater than the acceptance number, separate the components into smaller batches until the leaking tube is identified.

5.3.7 Record all data that would be required to duplicate the test.

6. ALTERNATE TEST PROCEDURE

6.1 **Section 5 requirements may be waived and components shall be leak tested in accordance with Section 6.3.2 Individual Hood Method and Section 6.4 Probe Method of MIL-STD-271D.**

6.2 **A leak shall be defined as an increase of greater than 5% of full scale reading of the leak rate meter above background (when the leak detector is set at maximum sensitivity) after five minutes of continuous testing.**