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DESIGN OF PRODUCTION TEST IP-490-A-FP
EVALUATION OF DIFFUSION BONDED FUEL ELEMENTS

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# DESIGN OF PRODUCTION TEST IP-490-F-FP
# EVALUATION OF DIFFUSION BONDED FUEL ELEMENTS

March 26, 1962

## SYNOPSIS

I&E uranium cores are to be jacketed by Sylcor and Hanford utilizing the "Solid State Diffusion-Hot Pressure Bonding" process. Hanford will also jacket cores by the "Solid State Diffusion" process, by "Gas Pressure Bonding" and "Hot Die Sizing". In this process, a layer of nickel is placed between the aluminum and uranium to prevent diffusion of the aluminum into the uranium and furnish a layer of metal capable of limiting diffusion with both the aluminum and uranium. The completed fuel element, therefore, consists of a uranium tube, bonded by diffusion to a layer of nickel which, in turn, is bonded to the aluminum can. The bond set up by the "Solid State Diffusion" process has excellent strength, ductility, continuity, heat transfer abilities and, based on off-site experience, should withstand the changes which take place during irradiation. The objectives of this test are to determine gross dimensional stability and bond quality differences between the Al-Si bonds and solid state diffusion bonds.

Irradiation testing will be conducted at C-Reactor and will be carried out in two parts:

Part I

Sylcor and Hanford hot press diffusion bonding processes will be compared to Hanford Al-Si bonding process. Eighteen (18) measured monitor columns of CVNS fuel elements will be irradiated to 800 MWD/T goal exposure in the C-Reactor small, ribless zirconium tube facility.

Part II

Hanford gas pressure and hot die sizing, solid state diffusion bonding process will be compared to the Hanford Al-Si bonding process. Eighteen (18) measured monitor columns of CVNS fuel elements will be irradiated to 800 MWD/T goal exposure in the C-Reactor small, ribless zirconium tube facility.

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INTRODUCTION

Possible limitations to the Al-Si process are being closely examined in an FPD-IPD testing program. An evaluation is expected about January, 1963. The results from this testing program should provide valuable information as to the capabilities of the Al-Si bonded fuel elements at programmed operating conditions. If the Al-Si test should demonstrate that Al-Si bonding is limiting, then an alternate bonding process technology will be needed in a relatively short period of time.

At this time, there are four potential alternate processes. These include: (1) Sylcor Hot Press, (2) Hanford Hot Press, (3) Hanford Gas Pressure, and (4) Hanford Hot Die Sizing. The first two are essentially ready for reactor testing, whereas the gas pressure bonding and hot die-sizing processes are still under development. This report outlines the program for the preliminary evaluation of these processes as potential replacements for the Al-Si process.

OBJECTIVE

The objectives of this test are to determine gross dimensional stability and bond quality differences between Al-Si bonds and solid state diffusion bonds.

TEST SUMMARY

Irradiation testing will be conducted at C-Reactor and will be carried out in two parts:

Part I

Sylcor and Hanford hot press diffusion bonding processes will be compared to the Hanford Al-Si bonding process. Eighteen (18) measured monitor columns of CVNS fuel elements will be irradiated to 800 MWD/T goal exposure in the C-Reactor small, ribless zirconium tube facility.

Part II

Hanford gas pressure and hot die sizing solid state diffusion bonding processes will be compared to the Hanford Al-Si bonding process. Eighteen (18) measured monitor columns of CVNS fuel elements will be irradiated to 800 MWD/T goal exposure in the C-Reactor small, ribless zirconium tube facility.

BASIS AND JUSTIFICATION

Examination of available pre-irradiation data on Hanford fuel element external bond strengths indicates the strength of the Al-Si bond is relatively low. The average and maximum strengths of Al-Si bonds are 13,500 psi and 20,000

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psi, respectively, whereas, for nickel diffusion bonds, the average strength is 21,000 psi and the maximum strength is 30,000 psi. In addition to being stronger, the nickel diffusion bond is reported to be tougher,(1) and to contain no porosity. The process will permit close control of can wall thickness and will increase the uranium to aluminum weight ratio as a result of replacing the equivalent of the Al-Si bonding annulus with uranium.

The ultimate limit of the Al-Si process has never been determined. Should the Al-Si bonds undergoing evaluation at high specific powers and exposures(2) indicate a tendency to contribute to poor heat transfer, it will be necessary to have a replacement process ready to go or developed to the stage where it will replace the AlSi process before Al-Si bond quality becomes a serious problem.

TEST DETAILS

A. Part I - Fuel Elements

1. Components

All aluminum components will be fabricated from X-8001 aluminum alloy by Alcoa. These components will meet the requirements in HAPO Product Specifications(3) as to alloy type, chemical composition, and fabrication technique.

2. Cores

Dingot uranium cores, rolled at NLO, will be utilized in this part of the test.* All cores will be shipped to Hanford for UT-2 testing and metallographic inspection prior to canning. These cores will conform to Hanford requirements(4) as modified by supplemental instructions as to fabrication technique, chemical composition, density and reactivity.

*NOTE - There may be a change from dingot to ingot cores for the second part of this test.

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(1) HW-65759, "Proposed Solid State Diffusion Bonding (SSDB) Process-Gas Pressure Bonding". E. A. Weakley. 6/22/61.

(2) HW-64870 A REV, "Design of Production Test IP-344-A-FP, Evaluation of Al-Si Bond Characteristics". W. H. Hodgson and M. A. Clinton. 7/10/61.

(3) HW-66455, "Product Specifications for Solid State Diffusion Bonded Fuel Elements (Sylvania-Corning, Hot Die Method)". C. A. Burgess. 9/15/60.

(4) HW-37677, "Producer Site Specifications for Uranium Fuel Element Cores". J. T. Stringer. 10/30/61.

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B. Part II - Fuel Elements

Components and cores for gas pressure bonding and hot-die sizing will be procured when the various fabrication parameters are established. Cores for this part of the test may be fabricated from either ingot or dingot uranium.

C. The following table shows the various dimensions for the bare core, finished fuel element with and without projections attached:

| | Hanford AlSi | Hanford HP | Hanford GPB | Hanford HDS | Sylcor HP |
|---|---|---|---|---|---|
| a) Nominal Core OD | 1.406" | 1.432" | 1.432" | 1.432" | 1.434" |
| " " ID | 0.488" | 0.427" | .437" | .437" | .436" |
| " " Length | 8.378' | 8.400" | 8.365" | 8.600" | 8.455" |
| b) Nominal Finished Element OD | 1.499" | 1.494" | 1.494" | 1.494" | 1.499" |
| " ID | 0.375" | 0.375" | 0.375" | 0.375" | 0.375" |
| " Length | 8.965" | 9.000" | 9.000" | 9.000" | 9.080" |
| Component Code | W | ------ | ------ | ------ | ------ |
| Nominal Rib Height | 0.082" | 0.082" | 0.082" | 0.082" | 0.082" |
| Maximum Circumscribed circle | 1.660" | 1.660" | 1.660" | 1.660" | 1.660" |

D. Assembly

1. Al-Si Bonding

The Al-Si bonded control elements will be fabricated by the modified "F" process utilized for fabrication of fuel elements for the Al-Si evaluation test.(5)

2. Hanford Hot Pressure Bonding

Hanford Hot Press Bonding processes will take place in the HLO facilities in the 306 Building in accordance with the Laboratory Specifications(6) as modified(7) for CVNS self-supported I&E fuel elements.

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(5) op cit HW-65870 A REV.

(6) HW-61995, "Specifications, Laboratory Hot Press Process for "C" Size I&E Fuel Elements". J. C. Tverberg. 9/25/59.

(7) HW-73111, "Supplemental Specifications, Laboratory Hot Press Process for CV Size Self-Supported I&E Fuel Elements". C. A. Burgess. (To be issued)

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3. Sylcor Hot Pressure Bonding

Following UT-2 testing at Hanford, the Sylcor core blanks were shipped to Sylcor for hot press bonding of all pieces. Closure welding of fifty percent of the elements was performed at Sylcor and the remaining elements were welded at Hanford in accordance with Product Specifications[8] with the following exceptions:

1) The penetration of weld beads produced by Sylcor had a minimum of 0.042 inch, whereas the specified minimum was 0.050 inch. These pieces will not be used in the test.

2) The guaranteed minimum tube (spire) wall thickness of Sylcor pieces is 0.015 mils, whereas the specified minimum was 0.020 inch.

3) The nickel plate on Sylcor pieces was found to have "micro-cracks" near the center of the pieces. Since these cracks do not completely penetrate the nickel, their presence is not, at this time, considered detrimental to the quality of the bond.

4) The nominal outer diameter and length of Sylcor pieces is over the specified nominal amount by 0.080 inch ± 0.060 inch on the length and 0.005 inch ± 0.003 inch on the outer diameter. Since Hanford Al-Si bonded fuel are approximately 0.005 inch ± 0.007 inch over the specified nominal outer diameter, the larger OD on the Sylcor pieces will not seriously affect the test.

Attachment of projections and autoclave testing of all Sylcor pieces was performed at Hanford.

4. Gas Pressure Bonding

Fuel cores for gas pressure bonding will be sealed in vacuum at Hanford prior to shipment to Battelle Memorial Institute for bonding. Process temperatures and pressures are to be established by interim testing.[9] After bonding, fuel elements will be sent to Hanford for finishing.

5. Hot Die Sizing

The preliminary technology for the Hot Die Sizing process has been developed.[10] The complete process will be performed at Hanford.

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(8) Op cit HW-66455.

(9) HW-72407, "Fluid Pressure Bonding Test". C. A. Burgess. 1/23/62.

(10) HW-72848, "Technology, Economics and Incentives for Solid State Diffusion Bonding Process--Hot Die Sizing". C. A. Burgess. (To be issued)

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F. Quality of Material

Quality Control measures in force at the time of this test will be applied to the fuel element fabrication, excluding those steps specifically modified in this test.

F. Quantity of Material

Quantities of acceptable fuel elements for three categories required in Phase I of this test are shown below:

| | | |
|---|---|---|
| Sylcor Hot Press | (A) | 192 |
| Hanford Hot Press | (B) | 192 |
| Hanford Al-Si | (C) | 192 |

For Phase II, the three categories are listed and the fuel requirements for each are shown below:

| | | |
|---|---|---|
| Hanford Al-Si | (D) | 192 |
| Hanford Gas Pressure | (E) | 192 |
| Hanford Hot Die Size | (F) | 192 |

In all cases, the Hanford Al-Si bonded fuel elements will serve as controls.

TESTING

Pre-Irradiation Testing and Measurements

The following tests and measurements are to be made on cores and fuel elements prior to irradiation:

| | TEST | PURPOSE | CORE STATUS | DATA |
|---|---|---|---|---|
| 1. | UT-2 | Measure Grain Size | Bare | Record Data |
| 2. | Surface Test | Core Surface Quality-Visual | Bare | |
| | | After Ni Plate | Ni Plated | |
| 3. | Length | Core Dimensions | Bare & Canned | Record Data |
| 4. | Outer Diameter (3) | " " | " " " | " " |
| 5. | Inner Diameter (2) | " " | " " " | " " |
| 6. | Warp Ellipticity | " " | Canned | " " |
| 7. | Weight (1-23) | Corrosion | " | " " |
| 8. | Bond Test | Braze Porosity | " | " " |
| 9. | Stud Pulling | Bond Strength | " | " " |
| 10. | Metallography | Bond Quality | " | Photomicrographs |

11. Identity - Identity and position of measured fuel elements will be recorded by a series and position number stamped on the base of each fuel element.

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12. Column Make-Up - Columns will be made by alternating fuel elements from two of the three groups in each phase. To simplify the description, the following code will be used:

A - Sylcor Hot Press
B - Hanford Hot Press
C - Hanford Al-Si (1st Part)
D - Hanford Al-Si (2nd Part)
E - Hanford Gas Pressure
F - Hanford Hot Die Size

The elements will be made into columns as listed below:

| | NO. OF CHARGES | GROUPS REPRESENTED | NO. OF PIECES |
|---|---|---|---|
| (Part I | 6 | AB, AB, AB . . . . | Through 32 pieces |
| | 6 | AC, AC, AC . . . . | " " " |
| | 6 | BC, BC, BC . . . . | " " " |
| (Part II | 6 | DE, DE, DE . . . . | Through 32 Pieces |
| | 6 | DF, DF, DF . . . . | " " " |
| | 6 | EF, EF, EF . . . . | " " " |

Thus, in the event one type should prove dimensionally unstable or rupture prone, the test of the other types will not be in jeopardy and the comparison of the processes will be on a statistical basis.

Columns will be placed in specially identified shipping pallets in charging order.

## IRRADIATION

### A. Charging

All test columns will be charged in numerical order with piece number one downstream. Each column will have the fuel identification number (series and/or lot number) recorded opposite the tube number on the front face sequence sheet. Charging of material from both phases of this test will be followed by a representative of Research and Engineering. Test columns will be charged into locations which will provide similar irradiation conditions for all tubes. Locations will be selected by the assigned Process Engineer and Physicist with the concurrence of the irradiation test author and will be selected from those tubes nearest goal exposure.

### B. Goal Exposure

Goal exposure for all test columns is 800 MWD/T.

C. Discharge

All test columns containing one type may be discharged prior to reaching goal exposure after two failures have occurred in that type provided all columns can be specially picked up.

D. Operating Conditions and Limits

The operating limits and conditions which are in use for normal production CIVNS fuel will apply toward this material.

GENERAL

A. Schedule

Fuel Elements for Phase I are being fabricated and will be ready for reactor charging in March, 1962.

Further development work on Phase II fabrication processes will require 3 to 4 months. Fuel elements for evaluation under Phase II are expected to be ready for charging in August, 1962.

B. Duration

Irradiation of each phase of this test is expected to require about 4 months.

C. Post-Irradiation Examination

All pre-measured fuel elements will:

1) be weaseled and visually inspected for surface conditions,
2) be measured for length, warp, and diameter changes ($OD_1$, $OD_2$, $OD_3$, $ID_5$, and $ID_7$),
3) have weight recorded (pieces 1 - 23),
4) be bond tested if equipment is available

Selected pieces may be set aside for stripping and bare core measurements depending on either the preliminary visual examination results or a later analysis of the measurement data. Also, selected elements may be sent to Radiometallurgy for destructive examination.

TEST AUDIT

Notebook HW-73093 will be utilized to store pre-irradiation data pertinent to this test. The appendix to this report contains a list of items to be recorded in the notebook. Any incidents which occur, whether they seem important or not at the time must be recorded in the notebook.

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HAZARDS

No unusual hazards are associated with this test.

W. H. Hodgson

W. H. Hodgson, Engineer
Fuels Engineering
FUELS PREPARATION DEPARTMENT

M A Clinton

M. A. Clinton
Research and Engineering
IRRADIATION PROCESSING DEPARTMENT

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## APPENDIX A

Data to be recorded in Production Test Notebook:

I. Fuel Element Core

A. Lot Numbers

1. Ingot Numbers and Chemical Analysis
2. Unusual Treatment

B. Finished Dimensions (Pre-Assembly)

II. Aluminum Components

A. Lot Numbers

1. Alloy Type
2. Unusual Treatment

B. Finished Dimensions (Pre-Assembly)
C. Pre-Assembly Treatment (Cutoff, Sizing, Inspection, Nickel Plating - vendor, thickness, etc.)

III. Pre-Assembly treatment of Cores (All Pieces for Measured Columns)

A. UT-2 Record Data
B. Nickel Plating - Conditions
C. Surface Inspection Record Data
D. Measure Length, OD, ID, and Warp of Hanford Cores

IV. Assembly Process

A. Process Used
B. Brief Explanation of Each Process
C. Attendant Conditions
D. Total Bond Count (All Pieces for Measured Columns)

V. Post-Assembly Treatment

A. Support Attachment
B. Autoclaving
C. Other Treatment
D. Inspection

VI. Pre-Irradiation Examination and Measurements (All Pieces for Measured (Monitor) columns)

A. Dimensions, Length, OD, ID
B. Warp
C. Weight (1 - 23)

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VII. Irradiation

A. Coolant Temperature

1. Inlet
2. Outlet

B. Panellit and Crossheader Pressures
C. Number of Shutdowns (Controlled and Scram)
D. Other

VIII. Post-Irradiation Examination

A. Visual
B. Warp (And Other Profilometer Data)
C. Bond Count - If Possible

IX. Log - Running account with dates recording the progress of the PT, unusual incidents (such as slight change in process during assembly), and other deviations whether or not they seem pertinent at the time of occurrence.

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