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HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

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REVIEW - PROCESS DEVELOPMENT
1.25% ENRICHED CO-PRODUCT DRIVER FUEL

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1.25% ENRICHED CO-PRODUCT DRIVER FUEL

by

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REVIEW - PROCESS DEVELOPMENT
1.25% ENRICHED CO-PRODUCT DRIVER FUEL

INTRODUCTION

Engineering Specifications for fabrication of the present standard fuel designs must be modified for fabrication of 1.25% enriched co-product driver fuels. To provide a basis for these modifications, a general review of the process development work completed and in progress in those areas where major processing or design changes occurred is presented. It is not intended that this report replace formal topical reports on those areas of work where major changes to the standard process were required, but only to provide an interim summary of the information available at this time. The process areas of prime concern include the billet assembly-extrusion area, the end closure area, and the support system-final assembly area.

A review of specific exceptions to the present Quality Control Standards required for driver fuel fabrication is also included in this report for production control purposes.

SUMMARY - PROCESS DEVELOPMENT AND MODIFICATION

A. Billet Assembly and Extrusion

The primary modifications to the standard process, other than end closure dimensional changes, in the billet assembly and extrusion area are: (1) the use of thin wall uranium sleeves to convert the uranium billet core ID from NOE dimensions to driver fuel dimensions and (2) the use of a zircaloy sub-assembly billet design to minimize potential extrusion unbonding problems that exist due to the reduced extrusion reduction ratio of the driver tube.

The detailed billet design is as shown in Figure 1.

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Figure 1

Coextrusion Billet Design

<p>A. Copper Sleeve - Outer
Length $20.508 \pm .005$
OD $7.410 \pm .010$
ID $7.374 \pm .006$</p> <p>B. Copper Sleeve - Inner
Length $20.508 \pm .005$
ID 1.500</p> <p>C. Copper End Plates
OD $7.365 \pm .005$
ID $1.612 \pm .005$</p> <p>D. Outer Clad - Zircaloy
Length $19.720 \pm .015$
OD $7.329 \pm .005$
ID $6.975 \pm .005$</p> | <p>E. Inner Clad - Zircaloy
Length $19.720 \pm .015$
OD $2.340 \pm .010$
ID $1.654 \pm .010$</p> <p>F. Zircaloy End Plate
1/4" Thick
OD $6.970 \pm .005$
ID $2.154 \pm .005$</p> <p>G. Uranium Sleeve
Length $19 \pm .015$
OD $2.780 \pm .010$
ID $2.380 \pm .010$</p> <p>H. Uranium Billet Core
Length $19 \pm .015$
OD $6.900 \pm .010$
ID $2.800 \pm .010$</p> | <p>I. Evacuation
Tube</p> |
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1. Uranium Sleeve Fabrication

The thin wall uranium sleeves required for billet assembly are fabricated on site by extrusion of standard NOE billets to sleeve dimensions plus 0.100 inch (nominal) of stock for machine clean-up. The billets are canned in copper, heated to 1170°F, and extruded at 14 inches/minute ram speed. The reduction ratio (tooling) is 9.8/1. A typical grain size macrophotograph of a sleeve cross-section is shown in Figure 2.

Uranium sleeves will be fabricated under the direction of N-Fuels Engineering and, in turn, certified for production use.

2. Billet Assembly - Zircaloy Sub-Assembly

The use of a zircaloy sub-assembly billet design is dictated by the driver tube extrusion experience to date. The limited number (17) of extrusions that have been made show a very high incidence (23%) of unbonding and on two occasions zircaloy breakthrough occurred at the front of extrusions made without zircaloy sub-assemblies. In general, however, the zircaloy-to-uranium bond appears to be the most potential problem.

The poor bonding performance to date could have been caused by inadequate vacuum, ruptured zircaloy and copper welds at upset, oxidized billet components, or the low reduction ratio. Steps have been taken to eliminate all of these potential trouble sources except the low reduction ratio.

All zircaloy subassemblies to date have been welded in an electron beam welder as soon as the chamber was evacuated to the 10^{-4} micron range. The components were cooled in a vacuum before removal for completion of the assembly. The 100 zircaloy assemblies

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Figure 2

Photomicrograph - Billet Sleeve Cross Section - 2.5X

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for the production run of driver tubes will be TIG welded in an argon atmosphere which should promote faster cooling and reduce oxidation upon exposure of the assembly to the atmosphere during final assembly. Following final assembly, the billet is evacuated and held long enough to insure complete evacuation. The time required for this evacuation has not been established to date. The zircaloy subassembly is then sealed with a zircaloy electrode and at this point is ready for assembly in copper.

The electron beam welder used previously for all test extrusions was not designed for heavy billets. Therefore, the welds were uneven and the penetration questionable, and could explain the bonding problems experienced on some of the test extrusions. The TIG welder to be used for production fabrication of driver tubes should provide greater penetration and a more consistent weld.

3. Extrusion

Seventeen standard dimension driver tube extrusions have been made. The first two of these extrusions were aimed at evaluating the sleeved billet approach for converting NOE to driver fuel billets and also improving inner clad thickness variation. The .947 enriched uranium-to-uranium bonds on these extrusions were excellent and the ID clad variation was low. These two extrusions were made using zircaloy subassemblies and are summarized in HW-80198. The next four driver tube extrusions were non-sleeved 1.25% enriched uranium billets primary extruded on-site. Zircaloy subassemblies were also used on these extrusions. One of these

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extrusions was unbonded on the ID at the middle and front of the tube. The other three extrusions passed both the ID and OD peel test.

Two more .947% enriched driver tube billets were assembled using sleeves without zircaloy subassemblies. These two billets were otherwise similar in design to a standard NOE billet. When extruded, the zircaloy clad broke through the copper can at the front of the extrusion. The copper surface was heavily blistered and both extrusions were unbonded on both the ID and OD. It is of interest, however, that the uranium-to-uranium interface was bonded and uranium grains extended across the bond line.

Nine additional .947% enriched standard driver tube billets were extruded to obtain process development material. Four of these extrusions were non-sleeved billets primary extruded on-plant. The remaining five extrusions contained sleeves. All nine extrusions were zircaloy subassemblies. One of the extrusions was unbonded on the OD interface at the front of the tube. The remaining eight extrusions were fully bonded. All five of the sleeved extrusions were bonded at the uranium-to-uranium interface.

In addition to the foregoing standard driver tube extrusions, four non-standard but similarly dimensioned extrusions have been completed. Two of these billets were extruded over a tipped mandrel to explore an alternate method of utilizing NOE billets for driver tube coextrusions. The other two billets were thick and thin clad standards for the non-destructive testers. The analysis of these extrusions is not complete but general appearances were good and all are bonded.

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The uranium-to-uranium bond does not appear to be a problem. The first two sleeved billet extrusions were sampled between every fuel and on all samples the bond line consisted of a fine line of inclusions with uranium grains extending across the bond. Beta heat treatment did not change the character of the bond and recrystallization again crossed the bond line. The next seven sleeved extrusions also exhibited favorable bonds. The bond line was heavier on some than on the original two extrusions but uranium grains always crossed the bond line and no cracks or voids were observed on any of the sleeved extrusions. Photomicrographs of typical uranium-to-uranium bonds are shown in Figure 3.

The bond results and dimensional characteristics of the test extrusions are summarized in the appendix.

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Best Case to Date

Worst Case to Date

Figure 3

Photomicrographs (250X) - Typical Uranium-to-Uranium Bonds, Sleeved Billet Coextrusions

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B. End Closure

The end closure for the co-product driver fuel is a basic design change from the present production fuel. This design features a shaped uranium-cap interface instead of the flat interface in current production models. The need for an improved closure design is based on a fundamental weakness inherent in the flat interface. This weakness results from a temperature incompatibility or high temperature expansion differential which would operate to produce plastic strain of the clad and ultimate failure of the fuel if the cap-to-core bond is fractured during irradiation, freeing the core and cap to expand and contract independently during thermal cycling. The chevron closure lengthens the zone of temperature differential and shapes the uranium in such a manner that clad strain will be distributed over a larger area if cap-to-core bond failure occurs.

The development work for the driver fuel end closure consisted of establishing component design and fabrication processes for end recessing, brazing, and welding which would meet acceptance criteria now used for end closures on production fuels.

1. End Recessing

The chevron recess was machined to a nominal depth of .446 inch. The cutting tool used was a 90° chevron cutting face with sufficient width to remove all but .020-.030 inch (nominally) of uranium next to the fuel cladding (Figure 4.a). It was necessary to leave residual uranium, as the dimensional variation in the tube does not permit machine removal of uranium without cutting into the cladding. Residual uranium was removed by chemical milling for 20 minutes. The chevron feature in the uranium becomes slightly

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(a) As-Machined - End Closure Recess (Nominal)

(b) As-Chemically Milled - End Closure Recess (Nominal)

Figure 4

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dished but not sufficiently to cause an excessive braze width between the cap and core (Figure 4.b.).

Details of tool design and process development work for machine recessing of production fuels and driver fuels are reported in HW-81021.

2. Inspection Criteria - End Recessing

Some of the process problems encountered have a critical effect on the end closure quality. If the machining operation is not closely controlled with respect to (1) tool wear, (2) milling speed, and (3) coolant flow, the recess may have gross quality defects (Figure 5.a. and 5.b.). These samples were machined with a single cutting tool. Shifting of the tool holder during machining can result in excess metal removal on the cladding. In Figure 5.a. residual uranium on the OD clad was not removed during the 20 minute chemical milling cycle, which was not detected prior to brazing. This points to the need for rigid inspection requirements after end recessing, probably by Quality Control Inspectors. In Figure 5.b. tool drift to the OD resulted in almost complete removal of the OD clad. This condition was detected prior to brazing; however, less severe clad thinning could escape visual inspection.

Tool dimensions are such that 20 mils (nominal) of uranium are left on the OD clad and 30 mils (nominal) on the ID clad. Chemical milling for 20 minutes with a milling rate of between 1-1/2 and 2 mils per minute, is adequate to remove residual uranium when machine recessing is within established control limits.

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(a) Residual Uranium on the Recess Sidewall.

(b) Excess Machine Removal of End Recess Zircaloy Clad.

Figure 5

Problem Areas - End Closure Recessing

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3. End Closure Components

End Caps - In the selection of the end cap design the basic characteristics of current production fuel end caps were retained. Recognizing that cap costs would be substantially increased if the flat cap machined groove was incorporated into the design, the purpose and need for this feature was re-evaluated. Requirements of a wide braze for welding and crimping the clad for braze flow, dictated the cap groove feature. When production fuel cap design was modified to a beveled top to eliminate crimping, the wide braze feature was retained by preserving the original cap dimensions at the base and reducing the dimension at the top. The final design of the chevron cap exploited the recess in the uranium to center the cap, permitting a flat side wall design. The present driver tube end cap Drawing No. H-3-23014 may be described appearance-wise and functionally as having a beveled top, flat side wall, and chevron bottom. Figure 6.a. represents a brazed, welded driver tube and closure using the described end caps. Figure 6.b. represents the same cap modified by radiusing the chevron angle to conform to the chemically milled radius of the uranium. This allows better cap seating with a reduction of cap-to-core braze width.

Braze Rings - The braze rings for the driver tube end closure have the same design features as those used in current production brazing except for weight and dimensional modifications. These were modified for both material and functional reasons: (1) more braze

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(a) Sharp "V" Cap Design.

(b) Radius "V" Cap Design.

Figure 6

Typical Brazed Closure Cross Sections

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was required because of the increased end recess dimension and (2) increasing the braze ring diameter to that of the end cap promotes braze flow without the use of flow wires normally used with bevel top end caps. The weight of the ring was increased beyond that required due to the difference in end recess dimension since initial brazing of some 30 driver tubes in the 306 pilot plant with braze rings increased in dimension and weight only in proportion to end recess dimension, did not flow consistently without flow wires and a braze insufficiency was indicated visually by the protruding cap apex in the as-brazed condition. Normally this should be covered by braze material to produce a "hot top" reservoir to reduce braze porosity.

Braze rings for the 9-extrusion production test were increased in weight by 20% and the OD dimension increased by 30 mils. In this test 180 brazes were made with only one non-flow braze station reject. None of these were rejected for braze voids after facing and step cut. Over-all braze porosity was substantially improved as evidenced by only one definite blowout experienced in end welding (320 welds).

4. Brazing

Initial brazing of driver fuels was performed in the 306 pilot plant braze station. The production outer fuel coil was used with the same current, power input, and cycle time as for production fuels. Because of the driver fuel OD and the increased wall thickness, both conditions tending to decrease the heating rate, additional time was required to melt the braze - 50-60 seconds as compared to 40-45 for the outer fuel. Installation of a smaller

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coil, fitted as close to the bell jar as possible, and the use of the larger OD braze rings reduced this time to 30-35 seconds. However, since the production of the co-producer fuel will be in the production plant, the 9-tube test production was brazed in the 333 brazing station and the Pilot Plant work served only to demonstrate the added heat input rate required for the driver fuels versus outer fuel.

The same coil diameter as for production outer fuels was used. The principal problem was to determine the induction coil height. Specifications for coil height for production fuels is that required to produce one inch of uniform redness at the top of the fuel. This requires a coil height of 1-1/2 inches measured from the top of the fuel to the bottom of the coil. Two coil heights were used for the driver tube - 1-3/4 and 2 inches. Fuels were brazed at these positions and the ends were sectioned for bond examination. This was done by syntron polishing of cross-sectioned brazes and reading the braze-uranium interface for diffusion bonding versus non-diffusion (mechanical) bonding and an interface void count as compared to present production fuels. Braze flow time at 1-3/4 inches was uniformly between 40-45 seconds with few exceptions. At 2 inches the time was increased to 50-55 seconds. The 1-3/4 inches height was selected as optimum for control within the 90 second cycle. This choice was strengthened by good experience with braze filling and preliminary data on average diffusion bonding characteristics. Bond characteristics have not been fully evaluated to date since most of the fuels brazed are being processed through the remainder of the process for "shake-down" purposes. Additional

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data will be developed as the 9-extrusion test is complete and fuels become available for destructive examination and reprocessing at shorter lengths. Time and temperature control and melting temperatures as recorded by control charts were uniform and all within the present specifications established for production fuels.

5. End Machining

Initial facing and step cutting of driver tubes was performed on the 306 turret lathe. Tool adjustment of production plant lathes was checked and found adequate for facing and step cutting of the driver fuel. Nine extrusions (180 ends) were faced and step cut with all dimensions within the present specification limits established for production fuels.

6. Welding

Welding of the driver fuels with the conventional step cut was mainly a matter of providing the proper heat input. Welding current was unchanged from the 100 amps presently used for production fuel. Welding speed variations were made. Heat input as measured in RPM was adjusted from 5 to 4 on the inner weld and 3 to 4 on the outer weld. Criteria for measuring the optimum heat input were (1) conformance to visual inspection standards, (2) depth of penetration of the recast zone.

The welding speed chosen as optimum was 4-1/2 RPM for the inner weld and 3-1/2 RPM for the outer weld.

Production welders were modified to meet driver dimension. These modifications consisted of fabricating new collet brushing, collet liner tube, weld chamber gasket, and gas seal plugs. In addition, the fuel insert cylinder was moved out two inches for

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the extra fuel length, the speed change control limit switch was adjusted to give the different welding speeds, and a change gear was installed in the great box to provide the reduced spindle speed.

7. Weld Contamination

The levels of weld contamination as measured by autoradiograph and alpha count technique are comparable to production fuels. No driver fuels were rejected for excessive contamination (above 10,000 ppm).

C. Support System - Final Assembly

The fabrication and attachment processes for support hardware and the final assembly procedures for driver and target are still in the development stages. Preliminary evaluation of all details associated with this area has been made, but firm procedures will not be finalized until late May. The evaluation results and information developed to date are outlined in the following discussions.

1. Fabrication

Outer Supports - The outer support is as shown on Drawing No. H-3-23062. Die inserts have been fabricated for producing this support. The inserts are intended to be fitted into the die set normally used for producing production 0.050 inch thick supports.

Deflection tests on the driver support show it to be approximately 50 per cent stronger than the production 0.040 inch thick support. At equivalent loads, deflection is two-thirds of the deflection given by 0.040 inch supports.

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The weld projections are close to the support legs when compared to the present support design. Originally it was hoped that this would decrease support deflection, however, no appreciable increase in support strength was obtained by this modification. The projections have not and will not be moved to the tab center due to the additional time which would be involved in making this change and in evaluating its effect on welding.

Support height was somewhat low on the initial run of driver fuels (KER loop charge). Support height has since been raised 0.003 inch. A support height of 0.177 inch or 0.174 inch as measured at receiving inspection may be required to obtain the correct support circle diameters at final assembly. The proper as-received height will be verified on the next test run of driver fuels.

Locking Clips - Normal production locking clips are used in driver fuels with additional hand grinding requirements as outlined in the Quality Control Standards section of this report. The grinding on the base of the locking clip is required for satisfactory welding performance and it is quite important. The grinding on the underside of the locking clip legs is to facilitate locking during assembly and it is of lesser importance. Both requirements are preliminary at this time, neither requirement has been proven conclusively in practice.

Shoes - Shoe skirt length requirements have been increased 0.010 inch to compensate for the 0.010 inch increase in support thickness. Again it has not been demonstrated conclusively that this modification was necessary. Shoes with normal skirt lengths

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have come off driver supports during vibration loop testing but this has also happened with 0.040 inch production supports. It is primarily the appearance of a shod 0.050 inch support which indicates the need for the longer skirt.

2. Welding

Outer Supports - Across the base of the legs the driver support is approximately 0.100 inch wider than the regular production support. In addition, the projections are very close to the support legs, and the electrode must exert pressure on these projections. The electrode gap, therefore, has been widened to allow room for the support but this widening has been limited to maintain the electrode over the projections as much as possible. The required electrode gap is 0.890 inch to 0.900 inch. The normal production electrode is shown on Drawing No. H-3-18248. The gap is the only modification which has been made in this electrode.

Some excessive weld spatter was encountered on welding the first fuels and a modification to the weld cycle was required to eliminate this. Electrode pressure was changed to 45 psi and magnetic force gap was changed to 19/32 inch. Neither of the above changes has had much influence on weld penetration or shear strength.

Weld penetration has been on the order of 50-60 per cent. Sufficient data has been collected in this area at this date.

Welder cradle pad thickness is increased by 0.050 inch when welding drivers to provide the correct circumferential spacing of supports.

Equipment Engineering is modifying the cradle end stops to provide end-to-end support alignment.

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Locking Clips - The air stop must be moved to provide clearance for driver fuels. This modification is now being made. An electrode has been modified to provide clearance for entering the driver tube. This modification was essentially that of removing a segment of metal 0.065 inch to 0.085 inch deep from the entire top length of the electrode.

Weld settings are unchanged.

Equipment Engineering is now fabricating new welder pads for driver fuels on the locking clip welder.

The gap settings and distance of the outside clip from the end of the fuel have been changed. The change arises due to a difference in inner support geometry on the target fuels. The new dimensions were calculated from rather limited data but they appeared satisfactory in the initial test run of driver fuels.

3. Assembly

Outer Supports - No significant changes.

Locking Clips - The locking pliers must be modified. Work on this design has not been initiated at this date.

Shoes - New shoeing pliers are required. One acceptable set has been made. Two more sets are now being modified.

Targets - Inner Supports - The inner supports on the target fuels are such that they cannot be effectively sized after assembly. The fuels are therefore assembled using an interference fit. Support height plus target diameter is controlled between 1.007 inch and 1.015 inch. Inner support circle diameter should also be controlled and values for this number are proposed to be between

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1.450 inch and 1.465 inch. These values will require some sizing up and down of supports at final assembly.

The assembled target deflection values or spring constants have not been determined. Equipment has been fabricated to obtain this information and results will influence the above support heights and sizing dimensions.

It is difficult to twist the target into the locking clip. A special tool is required to perform the task. One such tool has been fabricated and at least one additional will be. As yet, no inner supports have been sheared from the target during this operation.

The inner surface of the driver fuel can be severely scratched by the assembly operation. To minimize this scratching, a steel shoe is crimped over each of the inner supports. This procedure has been quite satisfactory in minimizing scratching so far. No tools are available in N-RD for performing the shoeing, this work will be performed using HL tooling.

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EXCEPTIONS TO QUALITY CONTROL STANDARDS FOR DRIVER FUEL FABRICATION

A. Essential Material Standards

There are four major design changes in the components for the driver fuel element as compared to the standard outer fuel element. The major changes are:

1. Uranium enrichment - 1.25%.
2. Uranium billet will be an NOE with a sleeve.
3. The billet will be enclosed in an evacuated zircaloy sub-assembly.
4. The chevron end closure will be used.

The chemistry, grain size, and corrosion test criteria will be the same as standard production material. The dimensions will be the only exception to present acceptance criteria. Listed below are the engineering prints to be inspected, with the exceptions listed if there are deviations.

<u>Dimensions</u>		
<u>Component</u>	<u>Print No./or Dimensions</u>	<u>Exceptions to Print Listed</u>
Zircaloy Outer Sleeve	H-3-21448 1/2 Rev 0	None
Zircaloy Inner Sleeve	H-3-21448 1/2 Rev 0	None
Zircaloy Front and Rear Plates	H-3-21448 2/2 Rev 0	None
Zircaloy End Caps	H-3-23014 1/1 Rev 0	None
Zircaloy Supports	H-3-23062 1/1 Rev 0	None
Zircaloy Locking Clips	H-3-17469 1/1 Rev 5	(See Note 1)

(Note 1) .002 inch must be hand ground from the full length of both sides of the locking clip base, on the projection side. The bottom of each clip leg at the outside should be touched on a grinding wheel to remove a triangle of metal approximately 0.030 inch deep. 100% part inspection should be performed on the clips to insure that the above grinding has been done.

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Dimensions (Continued)

| <u>Component</u> | <u>Print No./or Dimensions</u> | <u>Exceptions to
Print Listed</u> |
|---------------------|--|---|
| Braze Rings | Outer diameter $2.200 \pm .015''$
Inner diameter $1.560 \pm .015''$
Wall variation .025 max.
Weight 20.5 ± 1.0 g. | |
| Steel Shoes | H-3-17690 1/1 Rev 2 | Skirt length
$0.135-0.145''$ |
| Uranium Billets | H-3-17540 4/7 Rev 2 | Length -
$19.000 \pm .016''$
OD -
$6.900 \pm .010''$ |
| Uranium Sleeves | OD $2.780 \pm .010''$
ID $2.380 \pm .010''$
Length $19.000 \pm .016''$ | |
| Outer Copper Sleeve | H-3-17540 6/7 Rev 4 | |
| Inner Copper Sleeve | H-3-17540 7/7 Rev 2 | ID -
$1.500 \pm .004''$ |
| Front Copper Plate | H-3-17540 5/7 Rev 5 | ID -
$1.621 \pm .004''$ |
| Rear Copper Plate | H-3-17540 5/7 Rev 5 | ID -
$1.621 \pm .004''$ |
| Evacuation Tube | Std tubes (there is no print
presently) | |
| Die | H-3-23050 1/1 Rev 0 Part 1 | |
| Mandrel | H-3-23049 1/1 Rev 0 Part 1 | |
| Graphite Cut-Off | H-3-16912 1/1 Rev 3 Part 1 | Wall thickness
$3.00 \pm .010''$ |
| Follower Block | H-3-17314 1/1 Rev 0 | |

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B. Processing Standards

CX-401 - Billet Assembly - This standard applies to the copper welding of driver tube billets with the following exceptions:

1. There is no time limit from billet pickle to completion of the leak test.
2. Billet re-oxidation requirement does not apply at this stage of assembly.

QC Standards and Operating Procedures for standard extrusions do not cover the following necessary steps in the assembly of a driver tube billet.

1. TIG weld the front zircaloy end plate to the outer and inner zircaloy sleeves in a chamber which has been evacuated and backfilled to atmospheric pressure with argon, helium, or a mixture of the two. Allow the welded components to cool enough to prevent rapid oxidation upon exposure to the atmosphere.
2. Assemble the uranium billet and sleeve and rear end plate (containing the evacuation hole) without the use of undue force.
3. During assembly, all components shall be protected from contamination of all kinds.
4. Billet cores and sleeves which exhibit re-oxidation and indicated by colors darker than light golden shall be re-etched before assembly.
5. Place the complete zircaloy subassembly in a weld chamber which shall be evacuated and back-filled to atmospheric pressure with argon, helium, or a mixture of the two.
6. TIG weld the zircaloy rear end plate to the outer and inner zircaloy sleeves.

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7. Evacuate the weld chamber to 5×10^{-4} microns or less and hold until maximum billet evacuation has been obtained. This requirement may be modified as experience is obtained.
8. Seal the zircaloy subassembly by melting a zircaloy seal pin into the evacuation hole in the rear end plate.
9. The total elapsed time from billet and sleeve pickle until entrance of the billet and sleeve into the protective atmosphere of the weld chamber shall not exceed one hour.

CX-501 - Extruded Tube Sectioning - This standard applies with the exception of the following new driver fuel piece lengths after sectioning and squaring:

Driver tube - 26.1 inch plus standard allowance for end facing after brazing.

CX-502 - Extrusion Sample Evaluation - This standard applies with the following additions:

1. The inner bond peel test saw cut shall be made at least 50 mils from the zircaloy clad to test the uranium-to-uranium bond as well as the uranium-to-zircaloy bond.
2. The same reject criteria covering the uranium-to-zircaloy bond applies to the uranium-to-uranium bond.
3. The three metallurgical samples from the front, middle, and rear of each tube shall be examined on 100 per cent of the first 20 extrusions to determine the reliability of the uranium-to-uranium bond. The remainder of the extrusions will be tested as dictated by results from the above.
4. The uranium-to-uranium bond shall consist of a line of inclusions and show no signs of excessive contamination, cracking or separation.

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5. Grains shall cross the uranium-to-uranium bond line and four fields of vision 90° apart at 100X magnification shall be inspected to insure that the uranium-to-uranium bond line shall not coincide with grain boundaries for more than two grains in a row.
6. Extrusions whose metallurgical samples do not meet the requirements outlined above shall be referred to Process Engineering for further evaluation.

CX-505 - Pre-Mill Inspection - This standard applies with the following exceptions:

1. Pieces shall be rejected if the variation in wall thickness exceeds 0.035 inch.
2. The maximum depth of the machined counterbore shall be $0.446 \pm .015$ inch.

CX-506 - Chemical Milling - This standard applies with the following exceptions:

1. The maximum depth of the counterbore shall be $0.486 \pm .015$ inch.
2. An additional inspection step is required at this point to check for uranium on the recess sidewall and excess machine removal of zircaloy sidewall.

CX-508 - End Closure Brazing - This standard applies with the following exceptions:

1. Item 2 under Limits is deleted.
2. Replace Item 9 under Limits with, "The height of coil measured from the top of the fuel to the bottom of the coil shall be 1-3/4 inches."
3. Item 2 under Techniques is deleted.

CX-509 - Beta Heat Treatment - Modifications to the present heat treat cycle will be determined by Quality Control.

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CX-510 - Straightening - This standard applies with the addition of 26" length.

Straightening range = 0.031 to 0.100 inch inclusive.

Reject limit = 0.100 inch.

CX-511 - End Machining - This standard applies with the exception that the facing depth will be $0.120 \pm .005$ inch instead of present $0.090 \pm .005$ inch. The shoulder width is equal to the present outer tube width.

CX-514 - Preweld Inspection - This standard applies with the exception that the visual inspection for cap thickness should reject those caps which are obviously less than 0.180 inch.

CX-515 - End Closure Welding - This standard applies with the following exceptions:

1. Item 4 under Limits shall read: "Any welds which blow out or show other abnormalities shall be rejected and held for rewelding."
2. Include spindle speeds for driver fuel:
Outer weld - 3.5 RPM
Inner weld - 4.5 RPM
3. Item 4 under Techniques shall read: "Any change in the arc appearance within a welding cycle shall be identified and classified as to disposition at weld inspection."

CX-518 - Clad Thickness Test - This standard applies with the following exceptions:

1. OD minimum clad thickness = 0.028 inch.
2. ID minimum clad thickness = 0.018 inch.
3. OD maximum circumferential variation = 0.010 inch.
4. ID maximum circumferential variation = 0.014 inch.

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Material with ID clad variation in excess of 0.010 inch shall be segregated for special charging.

CX-519 - Cap-Core Bond Test - Development work is not complete on this test to date and suitable standards cannot, as yet, be recommended.

CX-523 - Autoradiography - This standard applies with the clad thickness exceptions detailed in CX-518.

CX-525 - Support and Locking Clip Welding - This standard applies with the following exceptions under Techniques:

1. Change to $2.570" \pm 0.010"$
2. Change to $0.930" \pm 0.015"$
3. Change to $2.570" \pm 0.010"$
4. b. Change to 45 psi.
c. Change to $19/32"$

CX-529 - Post-Autoclave Inspection - This standard applies with the following exceptions:

1. Outside diameter = 2.287 - 2.307 inches.
2. Inside diameter = 1.426 - 1.446 inches.
3. Wall thickness variation = 0.035 inch.
4. Length = 26.040 - 26.160 inches.

CX-530 - Shoe Attachment and Final Assembly - This standard applies with the following exceptions for co-product assembly:

Limits

1. Change to 1.465" and add, "the lowest support shall be sized-up where the support circle diameter is less than 1.450".
3. Delete.
4. Delete first sentence. Data is not now available to complete this limit.

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5. Substitute: "After mating the locking device and its companion support, inspect to insure that the inner support welds have not been sheared."

Techniques

1. Change to 1.465".
3. Delete.
4. Delete
9. a. More data must be developed for establishing the limits for this technique.

CX-531 - No change.

C. Standards Unchanged

The following standards as issued apply, without change, to driver fuel fabrication.

- CX-403 Pre-Extrusion Lubrication.
- 404 Tooling Preheat and Lubrication.
- 405 Cut-off Preheat.
- 406 Billet Preheat.
- 407 Extrusion.
- 503 Copper Removal.
- 504 Fuel Section Marking
- 507 Pre-Braze Cleanup.
- 512 Abrasive Cleaning.
- 513 Preweld Bright Etch.
- 516 End Weld Inspection.
- 520 Cap Clad Bond Test.
- 522 Fuel Section Stamping.

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- CX-523 Pre-Support Welding Degreasing.
- 526 Support and Locking Clip Weld Inspection.
- 527 Final Etch.

D. Standard Sample Identification and Measurement Requirements

The standard sample shall include:

1. All even numbered pieces in extrusions ending in "zero".
2. All odd numbered pieces in extrusions ending in "five".
3. One random fuel element from each of the remaining extrusions.

The measurements required on the co-product driver fuels are:

1. The standard variation data throughout the process for each standard sample.
2. Measure a minimum of 25 per cent of the fuel elements on the PIM gauge. The 25% shall include the standard sample.
3. Weigh in air and water all fuel elements measured on the PIM gauge.

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APPENDIX

Table 1

| Extrusion
Number | Sleeved
Billet | U-to-U
Bond
Results | Zircaloy
Subassembly | Enrichment
U-235 | U-to-Zr
Bond
Results | Comments |
|---------------------|-------------------|---------------------------|-------------------------|---------------------|----------------------------|-------------------------------------|
| X-109 | Yes | Good | Yes | .947 | Poor | Unbonded on OD |
| X-110 | Yes | Good | Yes | .947 | Good | |
| X-111 | No | -- | Yes | 1.25 | Good | |
| X-112 | No | -- | Yes | 1.25 | Good | |
| X-113 | No | -- | Yes | 1.25 | Poor | Unbonded on ID
middle & front |
| X-114 | No | -- | Yes | 1.25 | Good | |
| X-122 | No | -- | No | .947 | Good | Tipped mandrel NOE
OD, Driver ID |
| X-123 | No | -- | No | .947 | Good | " " " |
| X-124 | Yes | Good | No | .947 | Poor | Complete unbonds
OD and ID |
| X-125 | Yes | Good | No | .947 | Poor | " " " |
| X-129 | Yes | Good | Yes | .947 | Poor | Unbond OD front |
| X-130 | Yes | Good | Yes | .947 | Good | |
| X-131 | Yes | Good | Yes | .947 | Good | |
| X-132 | Yes | Good | Yes | .947 | Good | |
| X-133 | Yes | Good | Yes | .947 | Good | |
| X-134 | No | -- | Yes | .947 | Good | |
| X-135 | No | -- | Yes | .947 | Good | |
| X-136 | No | -- | Yes | .947 | Good | |
| X-137 | No | -- | Yes | .947 | Good | |
| X-138 | No | -- | No | .947 | Good | QC clad standard
N.D. testers |
| X-139 | No | -- | No | .947 | Good | " " " |

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Table 2

Outer Diameter As Extruded

2.342

Bimodal Distribution due to Differences
Between Extrusions

Maximum Outer Diameter - End Closure Region

Outer Diameter After Heat Treat

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Table 3

Inner Diameter

	As Extruded	As Heat Treated
1.420		
1		
2		
3		
4	####	
5	####	
6	####	
7	####	
8	####	
9		
30		
1		
2		
3		
4		
5		
6		
7		
8		
9		
40		

Table 4

Total Wall Thickness

As Extruded

$\bullet .425$ $n = 216$
 30 $\bar{x} = \bullet .4356$
 35 $s = .00490$
 40
 45
 $\bullet .450$

As Heat Treated

.420 n = 204
 5
 30 $\bar{X} = .4294$
 35
 40 S = .00502
 45
 50

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Table 5

Maximum Circumferential Wall Thickness Range

Range	As Extruded	As Heat Treated
.001		
2		
3	/	
4		
5	//	//
6	//	///
7	////	
8	/	///
9	///	///
10	/	////
11	///	/
12	/	//
13	/	//
14	////	/
15	////	///
16	//	/
17	/	///
18	//	/
19	/	/
20	/	/
1	/	/
2		
3	/	
4		
5		

n = 36

$\bar{X} = .01222$

S = .00497

n = 34

$\bar{X} = .01182$

S = .00462

Table 6

End Recess Depth as Chem-Milled

Cladding Core Interface

	Outer		Inner
.310			
15		/	
20	////	////	////
25	////	////	////
30	////	////	////
35	////	////	////
.340	////	////	////
45	////	////	////
.350	////	////	////

n = 108

$\bar{X} = .3335$

S = .0064

n = 108

$\bar{X} = .331$

S = .006

Maximum Depth at Bottom of Chevron

.480	//
5	////
90	////
.495	////
.500	/

n = 108
 $\bar{X} = .4910$
S = .0031

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Table 7

Warp Double Throw

	Magnitude	
	As Machined	As Heat Treated
.000	///	
5	//// // / n = 36	/// / n = 34
10	//// //	/// //
15	//// //	/// /// $\bar{X} = .0135$
.020		///
.025	$S = .0045$	/// $S = .0056$

Degrees	Direction	
	As Machined	As Heat Treated
0-44°	///	///
45-89	////	/// n = 33
90-134	/// / n = 36	///
135-179	////	///
180-224	//// ///	///
225-269	//// ///	///
270-314	///	///
315-359	/	///

Table 8

External Cladding Thickness

Maximum		Minimum	
30		Sleeves	///
1		/	/
2			/// n = 52
3		n = 50	
4		///	/// /// $\bar{X} = 34.58$
5	Sleeves	/// /// $\bar{X} = 40.0$	/// /// $S = 1.66$
6		/// /	///
7	/	///	///
8	///	///	/
9	///	/// /	
40	///	///	
1	///	/// /	
2	///	///	
3	///		

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Table 8 (Continued)

External Variation

	129-33 Sleeves		134-37 Drivers	
0				
1				
2	//			
3	//// //	n = 26	////	n = 25
4	//// //	$\bar{X} = 4.26$	//// ///	$\bar{X} = 5.12$
5	////		////	
6	////	S = 1.53	////	S = 1.45
7			/	
8	//	/	/	
9				
10				
11				
12				

Table 9

Internal Cladding Thickness

	Maximum		Minimum	
20			Sleeves	/
1				///
2	Sleeves		//	////
3		n = 51	//// ///	$\bar{X} = 23.86$
4		$\bar{X} = 31.50$	//// /	//// ///
5		S = 2.36	//// /	//// /
6	/		////	////
7	/			
8	////			
9	/			
30	//// /			
1	//// //			
2			//// /	
3	///		/	
4	/		//// /	
5			////	
6	/		/	

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Table 9 (Continued)

Internal Variation

	<u>129-33 Sleeves</u>		<u>134-37 Drivers</u>	
0				
1				
2				
3				
4	###	////		
5	///		/	
6	###	////	###	/
7	/		///	
8	///	$n = 26$	###	$n = 25$
9	/	$\bar{X} = 4.424^*$	###	$\bar{X} = 6.00^*$
10	/	$S = 2.16$	###	$S = 2.22$
11			/	
12	/		/	
13				
14				
15				

*Significant difference.

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Table 10

Support Height (After Welding)

	As Welded	As Shod
170	/	
1	/	
2	////	
3	####	
4	####	
5	####	
6	####	
7	####	
8	####	
9	////	
180		
1	n = 183	n = 126
2	$\bar{X} = 0.1759$	$\bar{X} = 0.1888$
3		
4		
5	S = .00161	S = .00173
6		///
7		////
8		####
9		####
190		####
1		####
2		####
3		####
4		####
5		####

Support Height Eccentricity

	As Welded	As Autoclaved	As Shod
0			/
1	####	####	////
2	####	####	####
3	####	####	####
4	####	####	####
5	####	####	####
6	////	////	////
7	/		/
8			//
9	n = 45	/ n = 31	n = 31
10	$\bar{X} = .00286$	$\bar{X} = .00287$	$\bar{X} = .00277$
	S = .00142	S = .00162	S = .00164

Table 10 (Continued)

Support Circle Diameter (at Final)

2.670	////	////	///	
1	////	/		n = 62
2	////			
3	////	////	//	$\bar{X} = 2.6729$
4	////	////	/	
2.675	////	///		S = .00207
6	////			
7	///			
8				

Table 11

Target Element (at Final)

.563	////	////		n = 35
4	////	////	////	$\bar{X} = 0.5638$
5	///			
.566	/			S = .00069

Diameter + one Support

1.000				
1	/			
2				
3				
4	/			
5	//			
6	///			n = 153
7	////	////		
8	////	///		$\bar{X} = 1.0107$
9	////	////	/	
1.010	////	////	////	S = 0.0026
11	////	////	////	
12	////	////	////	////
13	////	////	////	
14	////	////	////	/
15	////	////	/	
16	/			
17	/			
1.018				

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Table 11 (Continued)

Co-Product Assembly - Annulus

.435					
6					
7	//				
8					
9					
.440	///				
1	////				n = 102
2	////				$\bar{X} = .4456$
3	////	////			S = .00310
4	////	////	////		
5	////	////	////		
6	////	////	////		
7	////	////	////		
8	////	////	////		
9	////	////	////		
.450	////				
1	///				
2	/				
3					
.454	/				

Maximum Annulus Range per End

0	////	//			n = 33
5	////	////	////	/	$\bar{X} = .00639$
10	////	///			S = .0036
15	///				

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