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DEVELOPMENT STATUS AND INCENTIVES FOR THE HOT DIE SIZING PROCESS

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DEVELOPMENT STATUS AND
INCENTIVES FOR THE HOT DIE SIZING PROCESS

by:

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November 14, 1963

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ABSTRACT

The development status and incentives for the hot die sizing process for present reactor production fuels is reviewed and updated, and economic justification for the process for four different case studies is presented. Based on whether the end bonding step can be eliminated (development in progress) payout periods of 1.2 to 1.7 years can be realized if the present AlSi process (two-shift, five-day week) is converted to hot die sizing for all reactors. For K-Reactor operation only, payouts of 1.5 to 2.2 years can be realized by converting to hot die sizing. Of special interest is that with a capital investment sufficient to produce hot die size fuel elements for the K-Reactors only on a two-shift, five-day week, hot die size fuel elements to satisfy all eight reactors can be produced by operating on a three-shift, seven-day work week, with a payout of 0.8 to 1.2 years.

Should incentives exist for converting the present six-inch and eight-inch length fuel to longer models (10 inch and/or 12 inch), costs would be increased in the AlSi process by about \$320,000, which would not be incurred in hot die sizing. This provides additional incentives for hot die sizing and reduces all payout periods by about 0.2 years.

INTRODUCTION

The technology and incentives for the hot die sizing process were previously studied and documented in "Technology, Economics, and Incentives for a Solid State Diffusion Bonding Process--Hot Die Sizing."⁽¹⁾ Information for that study was largely based on Savannah River experience with diffusion bonded fuel elements, including their conception and initial laboratory demonstration of the hot die sizing process. Since that time, development facilities for the hot die sizing process have been installed at HAP0, process parameters have been optimized, and test quantities of fuel elements have been prepared and charged in C-Reactor. Total engineering effort to date indicates that this process offers sufficient technical and economical advantages over the existing AlSi process to justify conversion of fuel manufacturing facilities.

This document presents a review of the current development status, incentives, and programs planned to demonstrate more fully the recognized advantages of the hot die sizing process.

SUMMARY

Development Status

Laboratory facilities installed or activated at HAP0 for the development of the hot die process, starting in June 1962, are shown in Figures 1 and 2. Initial studies made to analyze process variables were followed by extensive tests to optimize process parameters and establish process specifications. By June 1963, sufficient progress had been made to prepare test quantities of both natural and enriched self-supported fuel elements for irradiation in the C-Reactor smooth-bore zirconium tube facility. An initial in-reactor test consisting of 20 columns of natural hot die sized fuel elements with

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AlSi controls will be discharged above goal exposure (800 MWD/T) in December. The second test consisting of 19 columns of enriched hot die sized fuel elements with AlSi controls was charged in September and October for exposure to 1000 MWD/T. A third test consisting of about 24 columns of natural hot die sized fuel is awaiting reactor space, which is expected to be available by year end. Irradiation of the test pieces charged to date has progressed without incident.

The basic flow sheet for the hot die sizing process is shown in Figure 3. Parameters have been optimized for all operations to produce high integrity lateral diffusion bonds and end closures. Average external tensile bond strength (26,000 psi) is about a factor of two higher than that of AlSi bonded fuel. Since the hot die sizing process produces essentially void-free bonds, uniform cladding thickness (± 5 mils) and homogeneous end closures, more consistent, higher quality fuel elements than can be produced by the AlSi process will result. In addition, statistical nondestructive testing of the finished hot die sized fuel elements should ultimately suffice.

Recent demonstrations of the feasibility of using tubular components (Figure 4) in the hot die sizing process, and the ability to extrude integral ribs (Figure 5) on projection fuel in the hot die sizing step, have resulted in substantial economic incentives over the AlSi process. In addition, it appears technically feasible to combine end bonding with the die sizing step. This will further simplify the process (Figure 6), as well as reduce equipment and operating costs.

Economic Incentives

The estimated economic incentives for converting fuel manufacturing facilities from the existing AlSi process to the hot die sizing process are based on the FY 1966 forecast of reactor requirements. Four specific operating cases, covering three levels of reactor operation, are included in this study. Estimated HDS process incentives and capital conversion costs for each case are based on the following fuel manufacturing schedules:

- Case I - Two-shift, five-day work week to meet production requirements for all (eight) operating reactors.
- Case II - Two-shift, five-day work week to meet production requirements for the C and K-Reactors.
- Case III - Two-shift, five-day work week to meet production requirements for the K-Reactors.
- Case IV - Three-shift, seven-day work week to meet production requirements for all (eight) operating reactors.

Capital Conversion Costs and Payout

Detailed capital costs for converting fuel manufacturing facilities are shown in Tables V and VI. Cost estimates are based on semi-mechanized equipment. A summary of these costs with economic payout is as follows:

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<u>Production Fuel Savings-- Basic Process</u>	<u>Estimated NDS Process Incentives</u>			
	<u>Case I (All Reactors)</u>	<u>Case II (K&C-Reactors)</u>	<u>Case III (K-Reactors)</u>	<u>Case IV (All Reactors)</u>
<u>Direct Materials</u>				
Aluminum Components	\$1,109,000	\$ 611,000	\$484,000	\$1,109,000
Other Direct Materials	*	*	*	*
<u>Direct Labor</u>				
Reduced Operating Labor	166,000	74,000	62,000	79,000
Associated Incremental IME	50,000	25,000	18,000	(29,000)
Other Added IME (Increased supervision, shift and holiday premium for supporting services)	---	---	---	(33,000)
Total Incentive - Basic Process	\$1,325,000	\$ 710,000	\$564,000	\$1,126,000
Total Production (Pieces)	2,235,000	1,210,000	946,000	2,235,000
Incentive/Fuel Element	0.59	0.59	0.60	0.50
Elimination of Projection Welding (Material, Labor, and IME)	74,000	64,000	65,000	74,000
Reduced Nondestructive Tester Maintenance (IME)	100,000	55,000	55,000	100,000
Combine End Bonding with Die Sizing (Labor and IME)	112,000	64,000	56,000	96,000
Total Production Fuels Incen- tive	\$1,611,000	\$ 893,000	\$740,000	\$1,396,000
Incentive/Fuel Element	0.72	0.74	0.78	0.62
Minimum Added Capital Cost to Convert ALSi Process to Long Fuel Production	320,000	320,000	320,000	320,000
Irradiation Incentive (No Increase in Production)	580,000	342,000	248,000	580,000

*Other direct material costs are essentially the same for the NDS and ALSi processes.

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	<u>Case I</u> <u>(All Reactors)</u>	<u>Case II</u> <u>(K&C Reactors)</u>	<u>Case III</u> <u>(K-Reactors)</u>	<u>Case IV</u> <u>(All Reactors)</u>
1) <u>End Bonding as Separate</u> <u>Process Step</u>				
Est. Capital Conversion Cost	\$2,611,000	\$1,535,000	\$1,535,000	\$1,535,000
Est. Annual Prod. Fuels Incen- tive	1,499,000	829,000	684,000	1,300,000
Payout (Years)	1.7	1.9	2.2	1.2
2) <u>End Bonding Combined With Die</u> <u>Sizing</u>				
Est. Capital Conversion Cost	\$1,995,000	\$1,145,000	\$1,145,000	\$1,145,000
Est. Annual Prod. Fuels Incen- tive	1,611,000	893,000	740,000	1,396,000
Payout (Years)	1.2	1.3	1.5	0.8
3) <u>Adjustment of Payout for Added</u> <u>Capital Cost to Convert ALSi</u> <u>Process to Long Fuel Pro-</u> <u>duction (\$320,000)</u>				
a) <u>End Bonding as Separate</u> <u>Step</u>				
Payout (Years)	1.6	1.7	2.0	0.9
b) <u>End Bonding Combined with</u> <u>Die Sizing</u>				
Payout (Years)	1.1	1.0	1.3	0.6

Major Process Advantages

1. Flexibility in terms of component design, fuel geometry and length is a strong attribute of the hot die sizing process.
2. The process has fewer and more easily controlled variables. It is relatively free of many of the variables experienced in the ALSi process, which adversely effect uniformity, quality, and irradiation performance of the finished product.
3. Process parameters produce a uniform cladding thickness and thin diffusion zones with high ductile strength.
4. Fuel element dimensional control is excellent.
5. The process is more amenable to mechanization, which leads to better control and reduced labor costs.

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6. Tungsten carbide dies for hot die sizing and end bonding are easily changed, relatively inexpensive and are expected to yield infinite service.

Testing and Evaluation Program

Programs underway or scheduled to test and evaluate further hot die sized fuel elements are shown in Figure 7. As indicated, effort will be concentrated on the following programs.

1. Optimization and in-reactor testing of integral ribbed projection fuel.
2. Preparation and irradiation of test quantities of fuel elements assembled in tubular components.
3. Evaluation and testing of high silicon cladding alloys, which offer certain process advantages and potentially improved corrosion resistance over 8001 alloy for either present or more severe reactor operating conditions.
4. Upon installation and beneficial use of nickel plating facility early in CY 1964, prepare pilot scale quantities of "O"-size and "K"-size fuel elements for irradiation.
5. Demonstrate process feasibility of combining end bonding with die sizing.
6. Pilot plant production transition early in CY 1965.

Considering the over-all technical and economic advantages, coupled with short-term payout of invested capital, conversion of fuel manufacturing facilities from the present ALSi process to the hot die sizing process appears to be amply justified for immediate budget and project action. The inherent flexibility and control aspects of the hot die sizing process for producing a more uniform high quality product at lower cost makes this process very attractive and highly competitive. This is not only true for present reactor production programs, but for future product diversification programs that may demand fuel elements capable of withstanding more severe irradiation conditions.

Case IV is particularly attractive because it shows that with a capital investment sufficient to produce hot die size fuel elements for the K-Reactors only on a two-shift, five-day work week, hot die size fuel elements to satisfy all eight reactors can be produced by operating on a three-shift, seven-day work week.

DISCUSSION

I. Process Development Status

Development of the hot die sizing process at Hanford has been carried out using laboratory scale electro-nickel plating facilities and prototype

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vacuum drying, preheating, die sizing and end bonding equipment. Figure 1 shows the plating facility. Figure 2 shows the layout of fuel assembly equipment. This equipment was installed for beneficial use in June 1962. Initial studies were made to analyze process variables, followed by a series of tests to optimize process parameters. Process specifications for the complete process were defined by May 1963.⁽²⁾

Techniques for electroplating uranium cores with nickel were developed initially using a modified Thompson plating process. By August 1962, it became evident that while this process produced a good plate, the adherence and quality of the plate was inferior to that of the Watt's process used by Sylcor and Savannah River for hot press fuel elements. Conversion to the Watt's process at that time, coupled with subsequent refinements in uranium core surface pretreatment, has provided plate with excellent adhesion properties, thickness control, and relatively free of oxides, porosity and other defects.

Process parameters for the hot die sizing step have been optimized to produce thin lateral fuel element bonds of high strength and integrity.⁽³⁾ Average external tensile bond strength is about 26,000 psi or a factor of two greater than AlSi bonded fuel. In the area of end bonding, some difficulty was experienced in developing process conditions that would consistently produce complete diffusion bonds over the cladding interface. Based on a series of tests to optimize end bonding temperature, pressure, and cycle time, the initial containment die concept was replaced with differential expansion dies to alleviate upset of the lateral cladding near the ends of the fuel elements and damage to the underlying bond areas. Lack of nickel diffusion through the aluminum cladding oxide film proved to be the cause of incomplete end bonding. Lateral bonding is facilitated by upsetting the cladding surface oxide film during the sizing step, which does not occur in end bonding. This problem has been resolved by inserting thin (10 mil) AlSi brazing wafers between the ends of the fuel cores and cladding to couple liquid diffusion with solid state diffusion.⁽⁴⁾ Other promising techniques for obtaining high integrity end bonding are being investigated.

Sufficient progress was made in the over-all development of the hot die sizing process by June 1963 to prepare test quantities of fuel elements for irradiation. Twenty columns of natural self-supported, hot die sized fuel elements and AlSi control pieces were charged in the C-Reactor smooth-bore zirconium 69-tube test facility during July.^(5,6) Two columns have been discharged at 400 MWD/T goal, and the remaining columns will be discharged at about the 800 MWD/T goal in December. Examination of the discharged material shows no unusual corrosion or differences in the behavior of the test and control pieces. A second irradiation test,⁽⁶⁾ consisting of nineteen columns of enriched self-supported, hot die sized and AlSi control pieces to be exposed to 1000 MWD/T in C-Reactor, was charged in September and October. This material will reach goal exposure in January 1964. Twenty-four (24) additional columns of natural self-supported fuel elements have been prepared for charging as reactor space becomes available in December. Other irradiation tests will follow to evaluate hot die sized fuel elements prepared with 1) integral ribs, 2) tubular

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components, and 3) a new high silicon cladding alloy. These tests will be discussed in more detail under development and testing programs. Pilot scale evaluation of hot die sized fuel elements in quantities of 5000 pieces or more is awaiting beneficial use of a nickel plating facility scheduled for installation early in CY 1964.

Based on present technology, the basic flow sheet for the hot die sizing process is shown in Figure 3. A brief description of this flow sheet follows. For further information, refer to the provisional process specifications.(2)

1. Components

a. Uranium Cores

Because of the sensitivity of the electro-nickel plating process to small uranium surface defects, it was thought originally that uranium core utilization for the hot die sizing process would be less favorable than for the AlSi process. Since that time, however, considerable development work has been accomplished (at HAPO, SRP, and NLO) to improve uranium core surface quality, and to improve nickel plating techniques. Considering 1) SRP hot press process experience in which over-all uranium utilization is above 98 per cent, as compared to about 96 per cent for HAPO AlSi process, 2) current and impending feed site (NLO) improvements in uranium quality resulting from oil quench after beta heat treatment and metal impurity control, and 3) significant advances in nickel plating technology, no difference is predicted between hot die size and AlSi process uranium utilization factors by the time the hot die size process could be established for fuel production.

b. Aluminum Components

Aluminum components used to date consist of a relatively thick wall (55 mil) spire-can and cap wafer. Conversion to a more economical inner and outer tube and cap wafer component design (Figure 4) is in progress. Process feasibility for using this component design has been demonstrated.

c. Projection Rails

Projection rails used on fuel elements produced to date have been of the conventional collapsible-bridge type, ultrasonically welded to the fuel cladding. Recently it has been determined that integral ribs or supports can be extruded on projection fuel in the die sizing operation, using thick-wall (~ 85 mil) external cladding components and a slotted sizing die. Since this technique is more economical than the former method, the assembly of fuel elements with various integral rail configurations (Figure 5) is being accelerated for testing and evaluation.

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2. Aluminum Component Preparation

Techniques used to clean and deoxidize aluminum components for the hot die sizing process differ slightly from that for the AlSi process. An inhibited caustic etchant is used to chemically mill less than one mil from the component surfaces. This not only provides a superior surface for bonding, but produces a surface that retains the lubricant required for die sizing.

Tubular components must be cut to length either prior to component cleaning or before fuel assembly. Eight-inch and six-inch fuel elements require nominal inner and outer tube lengths of about eleven inches and nine inches, respectively.

AlSi wafers, used between the ends of the uranium cores and cladding to facilitate end bonding, are cleaned in a detergent caustic and etched in acid prior to deoxidizing.

3. Uranium Core Preparation

The as-received uranium cores receive the same statistical quality inspection as for the AlSi process.

4. Uranium Grain Size and Surface Test

Existing UT-2 testing equipment is used to determine if the uranium cores are completely transformed, have the proper grain size, and to check for surface imperfections.

5. Nickel Plating

The former modified Thompson plating process has been replaced with the Watt's process to improve adhesion and quality of the plate. Although the Watt's plating bath contains some boron, no significant amounts are carried out in the nickel deposited on the uranium cores.

Nominal thickness of the plate currently produced is 0.8 mils. Use of thinner plate may be possible through further process refinement and control.

6. Visual Inspection and Nickel Thickness Test

After plating, each uranium core is visually examined for defects in the nickel. Statistical samples are subjected to a nondestructive eddy current test developed to measure plate thickness. Cores rejected for inadequate nickel thickness can be replated.

7. Fuel Assembly

This operation may be performed manually or mechanically, providing the bonding surfaces of the prepared aluminum components and nickel plated uranium cores are kept clean and free of contaminants.

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Use of tubes and end caps for fuel cladding require that the base end cap be crimped in position during the fuel assembly operation. Magnaforming equipment has been recommended for this purpose.

8. Lubricate Assembly

Lubricant is applied by dipping or swabbing the fuel assembly in a four parts Aqua-dag, one part water solution to within two to two and one-half inches of the top end. Excess lubricant is allowed to drain and the surface to dry.

9. Vacuum Dry

Vacuum drying equipment is used to remove any residual moisture from the fuel assemblies, and to extend the holding time between nickel plating and die sizing to longer periods than could be tolerated without incurring excessive oxidation if stored in air. The assemblies are placed under a vacuum of 1000 microns, minimum, for at least 30 minutes at 38 ± 5 C (100 ± 10 F) and backfilled with argon prior to removal for preheat.

10. Preheat Assembly

Fuel assemblies are preheated to an average external lateral core surface temperature of 525 to 575 C (977 to 1066 F). Preheat time ranges from 11-1/2 to 14 minutes in a resistance furnace set at 680 C (1256 F). Future plans are to evaluate induction preheating as an economic means of reducing cycle time.

11. Hot Die Size

Each fuel assembly is forced through an external die and over an internal die simultaneously at a hydraulic press ram speed of about 70 inches per minute to produce high-integrity lateral solid-state diffusion bonds. Reductions in aluminum component wall thickness range from about 45 per cent for non-projection fuel up to 65 per cent for integral ribbed fuel. Pressures required on the top and bottom press rams (about four tons and 1/4 ton, respectively) are low enough to consider multiple die sizing for fuel production.

12. Remove Lubricant

Die sized assemblies are washed in Stoddard's solvent to remove lubricant.

13. Trim Metal Flash

Metal flash is trimmed off the upper end of the fuel element, and a preliminary facing cut (.010 inch $\pm$.005 inch) is made on both the cap and base ends.

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14. Clip Integral Rails

If integral rails are produced during the die sizing step, equipment may be necessary to clip these rails to the prescribed length. The amount of clipping, if any, will depend on the testing and evaluation of various integral rail configurations.

15. End Bonding

Differential thermal expansion dies are placed on the end of each fuel element. The assembly is preheated to an end aluminum-nickel interface temperature of 375 to 388 C (705 to 725 F) in about six minutes in a resistance furnace set at 680 C (1256 F). The preheated assembly is then transferred to the end bonding press, and a longitudinal compressive load of $4 \pm 1/4$ tons per square inch is applied to the ends of the fuel element until the "end interface" temperature reaches 575 to 595 C (1067 to 1103 F) in the press resistance heater heads. A time cycle of 4-1/2 minutes is required at a heater setting of 655 C (1211 F). In order to reduce the over-all preheat and press cycle time to about two minutes, induction heating is being adapted to the press heads.

Based on present process technology, it is planned to develop techniques for incorporating end bonding in the die sizing step. This will not only simplify the process, but will result in a substantial reduction in direct labor. A modified flow sheet for this process revision is shown in Figure 6.

16. Stamp Identification

Stamp fuel element lot and bonding identification on each piece.

17. UT-4 Closure Test

Statistical measurement of fuel end closure quality with UT-4 tester is proposed. Homogeneity of the end closures should not warrant 100 per cent screening on a production basis.

18. Fuel Element Etch

All fuel elements are chemically etched in nitric acid and inhibited caustic-detergent solutions to remove surface contaminants.

19. Finish Face Ends

Face fuel elements to length, conforming with the specified cap and base thickness and end contours. An automatic end milling and weld closure machine is being developed to combine these operations. Ultimately, such a machine can be designed to clip integral ribs if required. This will be particularly advantageous after end bonding is incorporated in the die sizing step.

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20. Length Gage

Check fuel element length for conformance.

21. Weld Closures

A double pass end closure weld is produced using DC current. Spire can and cap components require an inner and outer weld on the cap end. Tubing components require corresponding weld closures on both the cap and base ends.

22. UE-3 Clad Thickness and Bond Test

Since the hot die sizing process produces essentially a void-free bond and uniform clad thickness (± 5 mils), statistical testing for bond quality and clad thickness should suffice.

23. Weld Closure Inspection

Visually inspect weld closures for defects.

24. Ultrasonic Projection Rail Welding, Sizing and Measuring

Process for projection rail attachment is the same as for the ALSi process unless integral ribs are formed in the die sizing step.

25. Autoclave Test

The normal steam autoclave test carried out at 165-185 C (329-365 F) for 20 hours is sufficient.

26. Final Inspection

Fuel elements are visually inspected for weld and cladding defects. Dimensions are checked with gages and mandrils.

II. Economic Incentives for the Hot Die Sizing Process

Assumptions

Basic assumptions used to compare the economics of the hot die sizing and ALSi processes are as follows:

1. Production

Fuel production is based on the FY 1966 forecast of reactor requirements.⁽⁸⁾ Allowing for possible curtailment of production, three levels of reactor operation are included in this study.

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Fuel Element Type	Fuel Production (Pieces/Year)			
	Case I (All Reactors)	Case II (C&K Reactors)	Case III (K-Reactors)	Case IV (All Reactors)
Eight-Inch Regular	1,045,000	349,000	179,000	1,045,000
Six-Inch Regular	333,000	96,000	9,000	333,000
Eight-Inch Bumper	0	0	0	0
Six-Inch Bumper	* 92,000	0	0	* 92,000
Eight-Inch Self-Support	561,000	561,000	554,000	561,000
Six-Inch Self-Support	<u>204,000</u>	<u>204,000</u>	<u>204,000</u>	<u>204,000</u>
TOTAL	2,235,000	1,210,000	946,000	2,235,000

*Bumper fuel loadings reduced to partial use in enriched fringes of old reactors and supporting water mixers.

2. Fuel Element Yields

Assumed yields represent best estimates of process capability. Current and anticipated improvements in ALSi process yields are expected to limit the potential hot die sizing process yield gain to approximately four per cent.

	Yield (Per Cent)	
	HDS Process	ALSi Process
Regular Fuel	95	91
Bumper Fuel (Welded Projections)	90	86
Self-Supported Fuel (Welded Projections)	88	84
Integral Self-Support & Bumper Fuel	92	--

3. Operating Schedule

Two-shift, five-day week, for both processes, except under Case IV. For this case study, it is assumed the HDS process will operate on a three-shift (A, B, C, and D) schedule, seven days per week, to meet Case I production requirements (all reactors).

4. Operating Efficiency

Ninety six per cent for both processes, except for assuming a HDS process efficiency of ninety-one per cent in Case IV.

Direct Material

1. Aluminum Components (8001 Alloy)

Cost estimates made prior to March 1962 in the previous study⁽¹⁾ indicated a cost differential of \$0.40 per set in favor of HDS

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spire-can and cap components over AlSi can and cap-spire components. Since that time, competition has forced the cost (\$1.10/set) of AlSi components down to approximately \$0.83 per set. Considering current competitive price trends, the cost of these components is expected to level out at about \$0.80 per set. An engineering analysis of component fabrication processes now indicates a cost differential of \$0.15 per set in favor of the HDS components is reasonable. Therefore, the following cost estimates were used in this study:

	<u>Cost/Set</u>
AlSi Can & Cap-Spire	\$0.80
HDS Spire-Can & Cap	<u>0.65</u>
Difference	\$0.15

Utilization of the tubing and end cap component concept will result in a substantially higher component cost differential in favor of the HDS process. As discussed under process development status, the feasibility of using this component design has been demonstrated and test quantities of tubing are on order for pilot scale evaluation. Based on initial vendor quotations and quoted prices for aluminum tubing, thin wall (55 mil) 8001 alloy outer and inner tubing for the assembly of regular fuel elements (without projections) is estimated at \$0.18 and \$0.05 per foot, respectively. End caps fabricated from extruded stock are estimated at \$0.085 each. Allowing eleven inches each of outer and inner tubing for the assembly of eight-inch fuel elements and nine inches of each type for the assembly of six-inch fuel elements, the estimated cost per component set is as follows:

<u>HDS Process</u>	<u>Estimated Cost/Component Set</u>	
	<u>Eight-Inch Fuel</u>	<u>Six-Inch Fuel</u>
Outer Tube	\$0.17	\$0.14
Inner Tube	0.05	0.04
End Caps	<u>0.17</u>	<u>0.17</u>
TOTAL	\$0.39	\$0.35

A comparison of the calculated total costs of AlSi and HDS 8001 aluminum alloy components (exclusive of projection fuel considerations) for the four cases under study are shown in Table I. These costs are summarized below.

	<u>Estimated Aluminum Component Costs</u>			
	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
A. AlSi Can & Cap-Spire	\$2,025,000	\$1,118,000	\$886,000	\$2,025,000
B. HDS Spire-Can & Cap	<u>1,569,000</u>	<u>868,000</u>	<u>689,000</u>	<u>1,569,000</u>
Net Savings over AlSi	\$ 465,000	\$ 250,000	\$197,000	\$ 456,000
/Good Piece	0.20	0.20	0.21	0.20

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	Estimated Aluminum Component Costs			
	Case I	Case II	Case III	Case IV
C. HDS Thin-Wall Tubes & Caps	\$ 916,000	\$ 507,000	\$402,000	\$ 916,000
Net Savings over ALSi /Good Piece	\$1,109,000 0.49	\$ 611,000 0.50	\$484,000 0.51	\$1,109,000 0.49

It will be noted from the above estimates that the incentive for using tubing and end caps in the HDS process for regular fuel production is about a factor of 2.4 higher than for spire-can cap components.

2. Other Direct Materials

Other direct material costs are incurred for chemicals, compressed gasses and other essential items for fuel assembly. In the previous study, (1) these costs were considered to be equal for the HDS and ALSi processes. Current cost analyses confirm this conclusion. Other direct material costs on a fuel element throughput basis will average \$0.11 per piece for the ALSi process, and are estimated at \$.0112 per piece for the HDS process. Correcting for process yield differences, other material costs for the four cases under study (exclusive of projection rails) are as follows:

<u>ALSi Process</u>	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
Total Cost	\$276,000	\$153,000	\$121,000	\$276,000
Cost/Good Piece	0.123	0.126	0.127	0.123
<u>HDS Process</u>				
Total Cost	271,000	150,000	118,500	271,000
Cost/Good Piece	0.121	0.124	0.125	0.121
<u>Difference</u>				
Total Cost	5,000	3,000	2,500	5,000
Cost/Good Piece	0.002	0.002	0.002	0.002

The above differences are well within the accuracy of present estimates for the HDS process and are discounted from any further consideration in this study.

Uranium Utilization

As stated earlier in this report, no difference is expected in the uranium utilization factors for the HDS and ALSi processes by the time the HDS process can be established for fuel production. This conclusion is based on Savannah River hot press process experience, current and

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impending improvements in uranium quality, and advances in nickel plating technology.

Direct Labor

The estimated manpower requirements for the ALSi and HDS processes, exclusive of manpower required for projection rail welding, sizing and measuring, are shown below.

	<u>Estimated Manpower (Exclusive of Projections)</u>			
	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
ALSi Process	154	90	79	154
HDS Process	<u>127</u>	<u>77</u>	<u>69</u>	<u>136</u>
Difference	27	13	10	18

Refer to Tables II and III for a breakdown of the above manpower requirements.

Allowing for an increase of five per cent in average hourly rates by FY 1966, direct labor costs are based on the following: (9)

1. Cases I, II, and III (Two Shift Operation-Five-Day Week)

Average direct labor cost/man year = 1872 hours x \$3.30/hour
 Associated incremental IME = 30 per cent x average direct labor
 (Vacation, Absence, Cont. cost/man year of Service & Supplies)

2. Case IV (HDS Process - A, B, C. & D Shift Operation-Seven-Day Week)

ALSi Process -

Average direct labor cost/man year and associated incremental IME is the same as in part 1.

HDS Process -

Average direct labor cost/man year = 1944 hours x \$3.30/hour
 Associated incremental IME = 36 per cent x average direct labor
 (Adjusted for increased cost/man year shift and holiday premium pay)

<u>ALSi Process</u>	<u>Estimated Direct Labor and Associated Incremental IME Cost</u>			
	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
Direct Labor	\$ 951,000	\$550,000	\$488,000	\$ 951,000
Associated Incremental IME	<u>285,000</u>	<u>167,000</u>	<u>146,000</u>	<u>285,000</u>
Total Cost	\$1,236,000	\$717,000	\$634,000	\$1,236,000
Cost/Good Piece	0.55	0.59	0.67	0.55

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<u>HDS Process</u>	<u>Estimated Direct Labor and Associated Incremental IME Cost</u>			
	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
Direct Labor	\$ 785,000	\$476,000	\$428,000	\$ 872,000
Associated Incremental IME	<u>235,000</u>	<u>142,000</u>	<u>128,000</u>	<u>314,000</u>
Total Cost	\$1,020,000	\$618,000	\$554,000	\$1,186,000
Cost/Good Piece	0.46	0.51	0.59	0.53

Difference

Total Cost	\$ 216,000	\$ 99,000	\$ 80,000	\$ 50,000
Cost/Good Piece	0.09	0.08	0.08	0.02

Added HDS Process IME Costs for Case IV

Under Case IV, it is assumed that the proposed HDS process facilities be operated on a four-shift (A, B, C, and D) schedule, seven days per week, to meet Case I fuel production requirements. This will require two additional supervisors to provide adequate coverage on all shifts, and it will increase shift and holiday premium pay for process control technicians and supporting maintenance craft personnel over and above Case I by the amounts shown below.

	<u>Estimate of Increased IME Case IV over Case I</u>
Salaries (Two Supervisors)	\$(20,000)
Shift & Holiday Premium (Eight Technicians)	(3,000)
Shift & Holiday Premium (Twenty- four Craftsmen)	(10,000)
TOTAL INCREASE	<u>\$(33,000)</u>

Elimination of Projection Rail Welding

Through the use of thick wall external cladding or tubing, the feasibility of forming integral ribs on projection fuel elements in the die sizing step of the HDS process has been demonstrated. This technique will eliminate the less economical conventional method of attaching projection rails by ultrasonic welding. Potential savings resulting from deleting this operation are outlined below.

1. Added Thick-Wall Tubing Cost

Assuming the cost of external thick-wall (~ 85 mil) tubing at \$0.27 per foot, and allowing eleven inches of tubing for an

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eight-inch fuel element and nine inches of tubing for a six-inch fuel element, the incremental cost difference between the thick-wall tubing and thin-wall tubing used to produce non-projection fuel is as follows:

	Tubing Cost	
	8-Inch Fuel Element	6-Inch Fuel Element
Thick-Wall Tubing	\$0.25	\$0.20
Thin-Wall Tubing	<u>0.17</u>	<u>0.14</u>
	\$0.08	\$0.06
Cost/Good Pc. @ 92% Yield	\$0.087	\$0.065

	Estimated Thick-Wall Tubing Cost			
	Case I	Case II	Case III	Case IV
Eight-Inch Projection Fuel	\$49,000	\$49,000	\$48,000	\$49,000
Six-Inch Projection Fuel	19,000	13,000	13,000	19,000
Total Added Cost	68,000	62,000	61,000	68,000

2. Projection Rail Savings

Assuming the current price of self-support and elliptical bumper rails can be reduced from about \$0.006 each to \$0.005, the cost of rails per fuel element is as follows:

- a) Cost/Self-Supported Piece = 8 Rails x \$0.005/93%
Yield = \$0.043
- b) Cost/Bumpered Piece = 6 Rails x \$0.005/95% Yield =
\$0.032

	Estimated Projection Rail Cost Savings			
	Case I	Case II	Case III	Case IV
Self-Supported Fuel	\$33,000	\$33,000	\$33,000	\$33,000
Bumper Fuel	<u>3,000</u>	<u>0</u>	<u>0</u>	<u>3,000</u>
TOTAL	\$36,000	\$33,000	\$33,000	\$36,000

3. Direct Labor Savings

Estimated reductions in direct labor requirements (see Table III) and costs are shown below:

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	Estimated Direct Labor Reduction			
	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
No. of Operators	7	6	6	7
Direct Labor Savings	\$43,000	\$37,000	\$37,000	\$43,000
Assoc. Incremental IME	13,000	11,000	11,000	13,000
TOTAL SAVINGS	\$56,000	\$48,000	\$48,000	\$56,000

Average direct labor and incremental IME rates used in calculating these savings are the same as used to compute labor savings independent of projection rail attachment.

4. Associated Maintenance and Shop Overhead Savings

A conservative estimate of associated ultrasonic welding equipment maintenance and shop overhead savings is as follows:

	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
Assoc. Maint. & Shop Overhead Savings	\$50,000	\$45,000	\$45,000	\$50,000

Based on the above estimates, the potential over-all savings that can be realized from the elimination of projection rail welding is summarized below:

	Total Potential Savings for Elimination of Projection Rail Welding			
	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
Added Thick-Wall Tubing Cost	\$(68,000)	\$(62,000)	\$(61,000)	\$(68,000)
Projection Rails	36,000	33,000	33,000	36,000
Direct Labor & Inc. IME	56,000	48,000	48,000	56,000
Associated Maintenance & Overhead	50,000	45,000	45,000	50,000
TOTAL SAVINGS	\$74,000	\$64,000	\$65,000	\$74,000

Reduced Maintenance of Nondestructive Testing Equipment

Since diffusion bonded fuel elements produced by the HDS process are essentially free of voids, pinholes, thin walls and other defects found in AlSi bonded fuel, statistical nondestructive testing should suffice

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for process control. This will reduce the number of bond and penetration (UE-1) testers and braze closure integrity (UT-4) testers by about 75 per cent, with a corresponding reduction in equipment maintenance costs. Assuming efforts of the present Nondestructive Testing Task Force are successful in reducing current maintenance costs for this equipment from \$14,500 to \$11,000 per month, the estimated annual maintenance savings to be realized from statistically testing HDS bonded fuel is shown below.

	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
Reduced Nondestructive Testing Equipment Maintenance	\$100,000	\$55,000	\$55,000	\$100,000

End Bonding Combined with Die Sizing

Incorporation of end bonding in the die sizing step of the HDS process now appears technically feasible. Although process feasibility has not been demonstrated, this change is being given high priority in the development program. Such a change will not only simplify the process, but will result in the following estimated direct labor savings (see Table IV).

	<u>Estimated Annual Savings</u>			
	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
No. of Operators	14	8	7	12
Direct Labor Savings (1872 hrs. @ \$3.30/hr.)	\$86,000	\$49,000	\$43,000	\$74,000
Associated Incremental IME @ 30%	26,000	15,000	13,000	22,000
TOTAL SAVINGS	\$112,000	\$64,000	\$56,000	\$96,000

Increased Fuel Element Length

Incentives exist for using longer enriched and natural fuel elements in the existing reactors.⁽¹⁰⁾ For the three possible conditions being considered (1) 14 per cent of enriched fuel 10-inch, (2) 69.8 per cent of natural fuel 10-inch or (3) 14 per cent of enriched fuel 10-inch and 69.8 per cent of natural fuel 12-inch, a minimum capital expenditure of \$320,000 will be required to convert existing ALSi process facilities to longer fuel over and above the capital costs required to obtain HDS process capability for producing both standard and long fuel elements.⁽¹¹⁾

Irradiation Incentives

Both the reactivity and conversion ratio of diffusion bonded fuel produced by the HDS process are higher than that for ALSi bonded fuel of similar geometry. This improvement is attributed to the replacement of

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the thicker AlSi braze layer with a thin (0.8 mil) nickel coating and uranium. Clad thickness is also controlled to 30 ± 5 mils. In addition, the use of thinner end closures permits an increase of approximately 200 mils in uranium core length. On this basis, irradiation incentives have been estimated, (12) and fall into two possible categories:

1. Unit product cost savings derived from lower U-235 burnout and fuel throughput costs with no change in production.
2. Production increases corresponding to higher conversion ratio.

The estimated annual savings and potential production gains for the four cases under study are as follows:

	Case I (All Reactors)	Case II (K&C-Reactors)	Case III (K-Reactors)	Case IV (All Reactors)
1) Unit Product Cost Savings (Dollars)	\$580,000	\$342,000	\$248,000	\$580,000
2) Potential Product Gain (kg)	81.4	46.5	37.7	81.4

In addition to the above incentives, fuel elements produced by the HDS process would be expected to be less susceptible to manufacturing oriented failures and thus improve reactor operating efficiency.

Summation of Economic Incentives

Based on the over-all study, the combined estimated incentives for converting fuel manufacturing facilities to the HDS process are as follows:

	HDS Process Economic Incentives			
	Case I (All Reactors)	Case II (K&C-Reactors)	Case III (K-Reactors)	Case IV (All Reactors)
<u>Assumed Fuel Mfg. Schedule</u>	2-Shifts 5-Day Week	2-Shifts 5-Day Week	2-Shifts 5-Day Week	3-Shifts 7-Day Week
<u>Production Fuel Savings -- Basic Process</u>				
<u>Direct Materials</u>				
Aluminum Components	\$1,109,000	\$ 611,000	\$484,000	\$1,109,000
Other Direct Materials	0	0	0	0
<u>Direct Labor</u>				
Reduced Operating Labor	166,000	74,000	62,000	79,000
Associated Incr. IME	50,000	25,000	18,000	(29,000)

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	HDS Process Economic Incentives			
	Case I (All Reactors)	Case II (K&C-Reactors)	Case III (K-Reactors)	Case IV (All Reactors)
Other Added IME (Increased supervision, shift differential & holiday pay for support- ing services)	-----	-----	-----	\$ (33,000)
TOTAL INCENTIVE-- Basic Process	\$1,325,000	\$ 710,000	\$564,000	\$1,126,000
Total Production (Pieces)	2,235,000	1,210,000	946,000	2,235,000
Incentive/Fuel Element	0.59	0.59	0.60	0.50
Elimination of Pro- jection Welding (Matls. Labor, IME)	74,000	64,000	65,000	74,000
Reduced Nondestructive Tester Maintenance (IME)	100,000	55,000	55,000	100,000
Combine End Bonding with Die Sizing (Labor & IME)	112,000	64,000	56,000	96,000
TOTAL PRODUCTION Fuels Incentive	\$1,611,000	\$ 893,000	\$740,000	\$1,396,000
Incentive/Fuel Element	0.72	0.74	0.78	0.62
Minimum Added Capital Cost to Convert ALSi Process to Long Fuel	320,000	320,000	320,000	320,000
Irradiation Incentive (No Increase in Pro- duction)	580,000	342,000	248,000	580,000

Capital Conversion Costs

Capital cost estimates⁽¹³⁾ used in this study to convert fuel production facilities to the HDS process are based on the following assumptions:

1. Use of tubing and end cap type cladding components.
2. Integral ribs will be formed on projection (self-supported and bumper) fuel in the die sizing step.

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3. Consider two schemes for end bonding; one as a separate process step and the other as being incorporated in the die sizing step.
4. Two-shifts, five day week minimum operation for Cases I, II, and III, and three-shifts, seven day week operation for Case IV.
5. Equipment will be semi-mechanized.

Guided by the above assumptions, a breakdown of the capital cost estimates are shown in Table V and VI. A summary of these estimates, including economic payout based on fuel production cost incentives for the HDS process, are shown below.

1) <u>End Bonding as Separate Process Step</u>	<u>Case I</u>	<u>Case II</u>	<u>Case III</u>	<u>Case IV</u>
Estimated Capital Conversion Cost	\$2,611,000	\$1,535,000	\$1,535,000	\$1,535,000
Production Fuels Incentive/Year	1,499,000	829,000	684,000	1,300,000
Payout (Years)	1.7	1.9	2.2	1.2
2) <u>End Bonding Incorporated with Die Sizing</u>				
Estimated Capital Conversion Cost	\$1,995,000	\$1,145,000	\$1,145,000	\$1,145,000
Production Fuels Incentive/Year	1,611,000	893,000	740,000	1,396,000
Payout (Years)	1.2	1.3	1.5	0.8
3) Assuming a minimum capital expenditure of \$320,000 for converting existing ALSi process facilities to longer fuel over and above costs required to establish HDS capability, the above payout periods are reduced as follows:				
a) <u>End Bonding as Separate Step</u>				
Payout (Years)	1.6	1.7	2.0	0.9
b) <u>End Bonding Incorporated with Die Sizing</u>				
Payout (Years)	1.1	1.0	1.3	0.6

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HDS Process Advantages

The hot die sizing process offers many advantages over the AlSi process other than the aforementioned economic incentives. Some of these advantages are unique as compared to other diffusion bonding processes.

1. Flexibility

Flexibility in terms of component design, fuel geometry and length is one of the major attributes of the HDS process. Since the fuel assemblies are preheated in an air atmosphere to the required temperature for bonding, only simple die replacements are necessary to accommodate changes in component or fuel geometry. Aluminum component designs and dimensions are less critical since the parameters imposed by process techniques and conditions are relatively small as compared to other processes. This not only provides a larger degree of flexibility, but the process is readily adaptable to more economical or new component designs.

HDS process capability for extruding ribs (Figure 5) on projection fuel during die sizing, using thick wall external cladding components, will eliminate the necessity of attaching projection rails by ultrasonic welding and associated operations. Because of higher strength under small deflection loads (up to 400 psi), integral rails will be more resistant to handling and reactor charging damage than the present collapsible-bridge rail design for K-Reactor self-supported fuel.

Incentives exist for using longer fuel elements (10-inch enriched and 12-inch natural) in the "K" and older reactors.⁽¹⁰⁾ Since longer fuel elements can be fabricated at significantly lower unit costs, fuel manufacturing capability is not only desirable for this reason, but the use of longer fuel may ultimately prove to be a factor in maintaining a strong competitive position. Existing AlSi process equipment will require extensive modifications and capital expenditures to produce longer fuel elements. Even with these modifications, the AlSi process will not offer the inherent flexibility of the HDS process for assembling both standard (4, 6, and 8-inch) and long fuel models.

2. Process Variables and Control

The HDS process is free of many of the inherent variables experienced in the AlSi process, which adversely effect the uniformity, quality, and irradiation performance of the finished product. Since there is no solution with or penetration of the bonding media, the cladding thickness of HDS fuel elements is controlled within close tolerances (± 0.005 inch). Cladding thickness is a function of:

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- a) Original die diameter and coefficient of expansion at operating temperature.
- b) Original diameter tolerance of fuel core and effect of fuel assembly temperature on the coefficient of expansion of uranium.
- c) Alignment of the uranium core with the die during the sizing operation.

Because of better cladding thickness control, and since the space occupied by the braze in AlSi bonded fuel is not required in diffusion bonded fuel, more uranium can be used per fuel element. This results in both increased reactivity and conversion ratio, providing the irradiation incentives previously discussed.

Process parameters⁽²⁾ for the HDS process produce extremely thin nickel-uranium-aluminum diffusion zones of high strength, thus minimizing the nickel plate thickness (0.8 mils) required on the as-plated uranium cores. Diffusion bonded fuel is essentially free of porosity, brittle fractures, and aluminum non-bonding, characteristic of the thicker AlSi brazed fuel. In addition, the closure areas are more homogeneous, further reducing the probability of critical defects that may not be detected and permit coolant entry during irradiation. These improved quality attributes should assure HDS fuel elements with significantly greater rupture resistance than AlSi bonded fuel, particularly with respect to those failures caused by fuel manufacturing oriented defects and non-uniform heat transfer through the braze. This would not only be expected to benefit reactor operating efficiencies for present plutonium and tritium production, but for the more highly enriched uranium "driver" fuel elements that may be required to compete favorably for future product diversification programs. Use of higher uranium enrichments, coupled with significant increases in fuel irradiation severity (power, temperature, and exposure) may exceed the capability of AlSi fuel. All comparative measurements of fuel quality attributes to date indicate HDS fuel performance should be superior to AlSi fuel under more stringent conditions.

Dimensional control of HDS fuel elements is significantly better than that of AlSi bonded fuel.⁽⁶⁾ Variance in O.D. from end to end of the finished pieces is less than five mils, as compared to about ten mils for AlSi bonded fuel. Ellipticity problems are nonexistent.

3. Other Advantages

Other advantages of the HDS process are as follows:

- a) The process is completely amenable to mechanization. This should lead to better control and lower unit costs.

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- b) Process tooling is easily changed and relatively inexpensive. The dies are made of tungsten-titanium carbide and should last indefinitely.
- c) No upsetting or deformation of the uranium cores occur during fuel element bonding, characteristic of the Sylcor hot press. Thus, the reject recovery cycle is similar to that for AlSi brazed fuel, except for the substitution of an acid solution for the caustic solution to remove the nickel-uranium compound layer.

HDS Testing and Evaluation Program

The status of programs in progress, and target dates for those programs scheduled to further test and evaluate hot die sized fuel elements, is shown in Figure 7.

1. Integral Ribbed Fuel

Process feasibility has been demonstrated for extruding either four or eight equally spaced, longitudinal ribs on the surface of projection fuel in the die sizing step, using thick-wall external cladding components (Figure 5). Necessary sizing equipment modifications are currently being made to demonstrate the feasibility of producing a spiral integral ribbed fuel concept. This concept not only offers the advantage of eliminating the need for attaching projection rails by existing ultrasonic welding and sizing techniques, but offers a potential added advantage for intermixing the annular coolant flow in reactor smooth-bore process tubes between the top and bottom of the annulus. Thus, the self-centering of projection fuel in these tubes will probably not be as critical as it would be in the absence of this feature. Examination of fuel elements produced with four and eight integral ribs have shown excellent control of rib height and width, with no detrimental effects on the underlying bond structure.

Extensive ex-reactor testing is underway to optimize integral rib designs with respect to configuration, dimensions, deflection load resistance, collapsibility features, flow and thermal hydraulic characteristics. Sufficient progress is expected to permit the fabrication of test quantities for irradiation by the second quarter of CY 1964.

2. Tube Cladding

In order to implement the testing and evaluation of HDS fuel elements assembled with 8001 alloy tubing components, tubing is being procured to initiate in-reactor testing early next year. Interim ex-reactor tests are being carried out using external and internal tubes cut from inventories of spire-can components. Experience to date indicates the use of tubing is

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both technically and economically justified, even though additional process operations such as tube cut-off, crimping the base end cap in position for fuel assembly, and double end facing and closure welding will be required. Ultimately, it is conceivable that the integrity of diffusion bonded fuel element end closures will not warrant secondary welding of the closures.

3. High Silicon Cladding Alloys

Dynamic corrosion test data for high silicon alloys developed by Norwegian(14,15) and Swedish(16) sources, and from samples exposed in treated river water in the Hanford 1706-KE single-pass facility, (17) indicate that aluminum alloys containing in the order of ten per cent silicon offer the greatest potential for improving fuel cladding resistance under present or future reactor operating conditions. At flow rates of 65 feet per second in 270 C, 4.5 pH distilled water, the Norwegian data showed corrosion rates of 7.9 mils and 2.4 mils per year, respectively, for pickled and autoclave prefilled high silicon alloy samples, containing nominally 1.0 per cent Ni, 0.15 to 0.31 per cent Fe, and 10.0 to 11.5 per cent silicon. Up to 0.8 per cent magnesium was added to some of the samples to increase mechanical strength with no detrimental corrosion effects. Comparative corrosion rates for polished and autoclave prefilled 8001 alloy samples subjected to the same corrosion environment were 15.7 mils and 15.7 mils per year, respectively. Etched high silicon alloy samples tested in the 1706-KE single-pass facility in treated river (1.8 ppm sodium dichromate and 6.6 pH), at 100 C under flow rates of 20 feet per second showed calculated equilibrium corrosion rates of 0.02 mils per month after 1000 hours exposure, as compared to 0.21 mils per month for 8001 alloy samples. Although the above results cannot be extrapolated to in-reactor corrosion conditions, corrosion resistance of the high-silicon alloys would be expected to be significantly better than 8001 alloy. The observed improvement in dynamic corrosion tests is largely attributed to the more tenacious oxide films formed on high silicon alloys, and the ability of these films to self-heal or develop in a corrosion environment.

Because the high silicon alloys closely approach the melting temperatures and compositions of the AlSi canning baths, these alloys cannot be used readily in the AlSi process. Considering the lower fuel assembly temperature parameters for the hot die sizing process, certain benefits may be derived from the use of high silicon alloys in terms of bond quality and reduced nickel plate thickness. Since uranium-aluminum diffusion would not be a problem, the nickel thickness on the as-plated uranium cores could probably be reduced at least fifty per cent. This would increase both the reactivity and irradiation incentives for HDS fuel. Cladding costs would not be expected to change appreciably,

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except for slightly higher costs that may result from high silicon alloys being more difficult to fabricate into component shapes.

Test quantities of tubing extruded from four different high silicon alloys, ranging from six to ten per cent in silicon content, are being procured. Assuming successful demonstration of one or more of these cladding alloys in the HDS process, test quantities of enriched fuel elements will be fabricated to compare in-reactor corrosion resistance with 8001 alloy clad fuel elements by the third quarter of CY 1964. If the in-reactor corrosion resistance of high silicon alloy fuel cladding is significantly improved as expected, its use may eliminate ledge and groove corrosion failures which have accounted for about 40 per cent or 33 of the ruptures incurred in the reactors during the past year. Also improved corrosion resistance will make HDS fuel elements more attractive for either present reactor production programs or future diversification programs demanding fuel elements capable of withstanding more severe operating conditions. In-reactor testing of HDS fuel elements will be extended to higher enrichments (up to 1.25 per cent U-235) as warranted to confirm this capability.

4. Pilot Scale Demonstration

Upon installation and beneficial use of the nickel plating facility early in CY 1964, pilot scale quantities of HDS fuel elements will be produced for irradiation. In conjunction with other scheduled production tests during CY 1964, at least 5,000 "O"-size and 5,000 "K"-size fuel elements will be prepared for exposure to 800 MWD/T or above. This will be followed by pilot plant production transition in CY 1965, producing HDS fuel elements at the nominal capacity (2,500 to 5,000 pieces per month) of this facility.

Concurrent with the above programs, development will be carried out to demonstrate the feasibility of combining the die sizing and end bonding operations.

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TABLE I
COMPARISON OF 8001 ALUMINUM ALLOY COMPONENT COSTS
HDS AND ALSI PROCESSES

	Cost/ Comp. Set	Yield (%)	Cost/ Piece	*Case I (All Reactors)		Case II (K&C Reactors)		Case III (K-Reactors)	
				No. of Pcs.	Cost	No. of Pcs.	Cost	No. of Pcs.	Cost
A. <u>ALSI CAN & CAP-SPIRE</u>									
Regular	\$0.80	91	\$0.88	1,378,000	\$1,212,640	445,000	\$ 391,600	188,000	\$165,440
Bumper	0.80	86	0.93	92,000	85,560	0	0	0	0
Self-Support	0.80	84	0.95	765,000	726,750	765,000	726,750	758,000	720,100
TOTAL COST					\$2,024,950		\$1,118,350		\$885,540
B. <u>HDS SPIRE-CAN & CAP</u>									
Regular	\$0.65	95	\$0.68	1,378,000	\$ 937,040	445,000	\$ 302,600	188,000	\$127,840
Bumper	0.65	90	0.72	92,000	66,240	0	0	0	0
Self-Support	0.65	88	0.74	765,000	566,100	765,000	566,100	758,000	560,920
TOTAL COST					\$1,569,380		\$ 868,700		\$688,760
Net Gain over ALSI (Part A)					455,570		249,650		196,780
C. <u>HDS THIN WALL TUBES & END CAPS</u>									
8" Regular	\$0.39	95	\$0.41	1,045,000	\$ 428,450	349,000	\$ 143,090	179,000	\$ 73,390
6" Regular	0.35	95	0.37	333,000	123,210	96,000	35,520	9,000	3,330
8" Bumper	0.39	90	0.43	0	0	0	0	0	0
6" Bumper	0.35	90	0.39	92,000	35,880	0	0	0	0
8" Self-Support	0.39	88	0.44	561,000	246,840	561,000	246,840	554,000	243,760
6" Self-Support	0.35	88	0.40	204,000	81,600	204,000	81,600	204,000	81,600
TOTAL COST					\$ 915,980		\$ 507,050		\$402,080
Net Gain Over ALSI (Part A)					1,108,970		611,300		483,460

*Case IV component costs are the same as for Case I.

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TABLE II
ESTIMATED DIRECT LABOR REQUIREMENTS
ALSI PROCESS

<u>FUEL MANUFACTURING SCHEDULE</u>	<u>*Case I</u> <u>(All Reactors)</u> <u>2-Shifts, 5-Day</u> <u>Week</u>	<u>Case II</u> <u>(K&C Reactors)</u> <u>2-Shifts, 5-Day</u> <u>Week</u>	<u>Case III</u> <u>(K-Reactors)</u> <u>2-Shifts, 5-</u> <u>Day Week</u>
<u>Estimated Direct Labor by Operation</u>			
Hanford Test Reactor	2	1	1
Material Handling	10	7	5
Coverage	8	8	8
Core Recovery	2	1	1
Pre-Irradiation Measurements	1	1	1
Aluminum Component Inspection	1	1/2	1/2
Steel Sleeve Evaluation	1	1/2	1/2
Component Preparation Lead Men	2	1	1
Aluminum Component Cleaning	4	2	2
Steel Sleeve Cleaning	2	1	1
Steel Sleeve Control	1	1	1/2
UT-2 Core Grain Size Test	6	3	3
Spire Etch	4	2	1
Component Distribution	2	1	1
Core Pickle Inspection	2	1	1
Canning Lead Men	2	1	1
Canning	38	23	20
Quench	10	5	4
Finishing Lead Men	2	1	1
Facing	6	3	3
Closure Welding	6	3	3
UE-1 Bond & Penetration Test	6	3	3
UT-4 Closure Test	2	1	1
Fuel Element Etch	2	1	1
Closure Weld Inspection	6	3	2
Mandrel & Misc.	2	1	1
Water-Mix Spool Welding	2	1	1/2
Projection Rail Weld & Test	7	6	6
Autoclave Basket Load	2	1	1
Autoclave Test	2	1	1
Final Inspection Lead Man	1	1	1
Final Inspection	5	3	2
Projection Rail Sizing & Measuring	3	3	3
Vacation & Absentee Relief	<u>12</u>	<u>7</u>	<u>6</u>
TOTAL	164	99	88

*Case IV direct labor requirements are the same as for Case I.

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TABLE III
ESTIMATED DIRECT LABOR REQUIREMENTS
HOT DIE SIZING PROCESS
(Tubing Components, Without & With Integral Rails)

<u>FUEL MANUFACTURING SCHEDULE</u>	<u>Case I</u> <u>(All Reactors)</u> <u>2-Shifts,</u> <u>5-Day Week</u>	<u>Case II</u> <u>(K&C Reactors)</u> <u>2-Shifts,</u> <u>5-Day Week</u>	<u>Case III</u> <u>(K-Reactors)</u> <u>2-Shifts,</u> <u>5-Day Week</u>	<u>Case IV</u> <u>(All Reactors)</u> <u>3-Shifts,</u> <u>7-Day Week</u>
<u>Estimated Direct Labor by Operation</u>				
Hanford Test Reactor	2	1	1	2
Material Handling	10	7	5	12
Coverage	8	8	8	4
Core Recovery	2	1	1	2
Pre-Irradiation Measurements	1	1	1	1
Tubing Cut-Off	4	2	2	4
Aluminum Component Inspection	1	1/2	1/2	1
Component Preparation Lead Men	2	1	1	4
Aluminum Component Cleaning	4	2	2	4
UT-2 Core Grain Size Test	6	3	3	6
Core Nickel Plate	6	4	3	8
Nickel Plate Visual Inspection	2	1	1	2
Nickel Plate Thickness Test	2	1	1	2
Fuel Assembly, Comp. Crimp & Lubricate	4	2-1/2	2	4
Vacuum Dry & Preheat	2	1	1	2
Sizing (O.D. & I.D.)	6	4	3	8
Remove Lubricant	2	1	1	2
Flash Trim	2	1	1	2
End Bonding	8	5	4	8
UT-4 Closure Test	1	1	1	2
Fuel Element Etch	2	1	1	2
Facing	7	4	4	7
Closure Welding	7	4	4	7
Finishing Lead Men	2	1	1	4
UE-3 Bond & Penetration Test	2	1	1	2
Closure Weld Inspection	8	4	4	8
Mandrel & Misc.	2	1	1	2
Water-Mix Spool Welding	2	1	1/2	2
Projection Rail Weld & Test	7	6	6	7
Autoclave Basket Load	2	1	1	2
Autoclave Test	2	1	1	2
Final Inspection Lead Man	1	1	1	2
Final Inspection	5	3	3	5
Projection Rail Sizing & Measuring	3	3	3	3
Vacation & Absentee Relief	<u>10</u>	<u>6</u>	<u>5</u>	<u>11</u>
TOTAL	137	86	78	146

With Integral Rails

Delete Projection Rail Welding,, Sizing & Measuring	(10)	(9)	(9)	(10)
Add Rail Clipping	<u>3</u>	<u>3</u>	<u>3</u>	<u>3</u>
	130	89	75	139

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TABLE IV
ESTIMATED DIRECT LABOR REQUIREMENTS
HOT DIE SIZING PROCESS

(Tubing Components, Sizing & End Bonding Combined, and Integral Rails)

<u>FUEL MANUFACTURING SCHEDULE</u>	<u>Case I</u> <u>(All Reactors)</u> <u>2-Shifts,</u> <u>5-Day Week</u>	<u>Case II</u> <u>(K&C Reactors)</u> <u>2-Shifts,</u> <u>5-Day Week</u>	<u>Case III</u> <u>(K-Reactors)</u> <u>2-Shifts</u> <u>5-Day Week</u>	<u>Case IV</u> <u>(All Reactors)</u> <u>3-Shifts</u> <u>7-Day Week</u>
<u>Estimated Direct Labor by Operation</u>				
Hanford Test Reactor	2	1	1	2
Material Handling	10	7	5	12
Coverage	8	8	8	4
Core Recovery	2	1	1	2
Pre-Irradiation Measurements	1	1	1	1
Tubing Cut-Off	4	2	2	4
Aluminum Component Inspection	1	1/2	1/2	1
Component Preparation Lead Men	2	1	1	4
Aluminum Component Cleaning	4	2	2	4
UT-2 Core Grain Size Test	6	3	3	6
Core Nickel Plate	6	4	3	8
Nickel Plate Visual Inspection	2	1	1	2
Nickel Plate Thickness Test	2	1	1	2
Fuel Assembly, Comp. Crimp & Lubricate	4	2-1/2	2	4
Vacuum Dry & Preheat	2	1	1	2
Size & End Bond	6	4	3	8
Finishing Lead Men	2	1	1	4
Fuel Element Etch	2	1	1	2
Facing & Rail Clipping	10	7	7	10
Closure Welding	7	4	4	7
Closure Weld Inspection	8	4	4	8
Mandril & Misc.	2	1	1	2
UE-3 Bond & Penetration Test	2	1	1	2
UT-4 Closure Test	1	1	1	2
Water-Mix Spool Welding	2	1	1/2	2
Autoclave Basket Load	2	1	1	2
Autoclave Test	2	1	1	2
Final Inspection Lead Man	1	1	1	2
Final Inspection	5	3	2	5
Vacation & Absentee Relief	8	5	4	10
	<u>116</u>	<u>72</u>	<u>65</u>	<u>126</u>
TOTAL	116	72	65	126

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TABLE V
ESTIMATED CAPITAL COSTS FOR CONVERSION
TO THE HOT DIE SIZING PROCESS
(END BONDING AS A SEPARATE STEP)

	Case I		Cases II, III, & IV	
	<u>Units</u>	<u>Cost</u>	<u>Units</u>	<u>Cost</u>
1. Tubing Preparation		\$ 186,000		\$ 104,000
2. Electroplating Machine w/Controls	2	251,000	1	151,000
3. Component and Fuel Assembly		60,000		35,000
4. Preheat Furnace	2	84,000	1	48,000
5. Die Sizing Press	7	315,000	4	180,000
6. Flash Trimming Machine	2	40,000	1	25,000
7. End Bonding Press	7	385,000	4	220,000
8. Cleaning & Quenching Equipment		25,000		13,000
9. Miscellaneous Equipment		50,000		30,000
10. Ventilation		10,000		7,000
11. Electrical		15,000		9,000
12. Piping		20,000		12,000
13. Foundation Work		10,000		6,000
14. Equipment Removal		140,000		60,000
15. Equipment Relocation & Modification		180,000		100,000
TOTAL Construction & Equipment		\$1,771,000		\$1,000,000
Supervision of Construction		50,000		30,000
Project Startup		50,000		30,000
Contingency		415,000		250,000
Escalation		60,000		35,000
General Overhead		65,000		40,000
Design Services		200,000		150,000
TOTAL Project Cost		\$2,611,000		\$1,535,000

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TABLE VI
ESTIMATED CAPITAL COSTS FOR CONVERSION
TO THE HOT DIE SIZING PROCESS
(END BONDING INCORPORATED IN DIE SIZING)

<u>Project Cost Breakdown</u>	<u>Case I</u>		<u>Cases II, III, & IV</u>	
	<u>Units</u>	<u>Cost</u>	<u>Units</u>	<u>Cost</u>
1. Tubing Preparation		\$ 186,000		\$ 104,000
2. Electroplating Machine w/Controls	2	251,000	1	151,000
3. Component & Fuel Assembly Equipment		60,000		35,000
4. Preheat Furnace	2	84,000	2	48,000
5. Sizing & End Bonding Press	7	315,000	4	180,000
6. Cleaning & Quenching Equipment		25,000		13,000
7. Miscellaneous Equipment		50,000		30,000
8. Ventilation		10,000		7,000
9. Electrical		12,000		7,000
10. Piping		18,000		10,000
11. Foundation Work		9,000		5,000
12. Equipment Removal		140,000		60,000
13. Equipment Relocation & Modification		180,000		100,000
 TOTAL Construction & Equipment		 \$1,340,000		 \$ 750,000
Supervision of Construction		40,000		25,000
Project Startup		40,000		25,000
Contingency		300,000		180,000
Escalation		45,000		30,000
General Overhead		50,000		35,000
Design Services		180,000		100,000
 TOTAL Project Cost		 \$1,995,000		 \$1,145,000

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FIGURE 1

NICKEL PLATING LINE

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HW - 79706

FIGURE 2

HOT DIE SIZE PROCESS DEVELOPMENT LABORATORY

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FIGURE 3
BASIC FLOW SHEET
HOT DIE SIZING PROCESS

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PROPOSED TUBULAR CLADDING
SYSTEM

BEFORE SIZING

AFTER SIZING

FIGURE 4

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PROPOSED HDS
INTEGRAL RIB CONCEPTS

4 RIB

8 RIB

SPIRAL 4 RIB

FIGURE 5

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FIGURE 6
MODIFIED FLOW SHEET
HOT DIE SIZING PROCESS
END BONDING INCORPORATED IN DIE SIZING OPERATION

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FIGURE 7
HOT DIE SIZED FUEL ELEMENT
EVALUATION SCHEDULE

P.T. & Doc. No.	Test Description	CY 1963												CY 1964												CY 1965																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
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IP-546-A HW-75465	Compare dimensional stability and corrosion behavior of HDS self-supported natural fuel elements with AlSi bonded control pieces. (Twenty columns-C-Reactor-800 MWD/T)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																

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