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PROPOSED SOLID STATE DIFFUSION BONDING
(SSDB) PROCESS - GAS PRESSURE BONDING

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PROPOSED SOLID STATE DIFFUSION BONDING (SSDB) PROCESS -

GAS PRESSURE BONDING

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June 22, 1960

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PROPOSED SOLID STATE DIFFUSION BONDING (SSDB) PROCESS-

GAS PRESSURE BONDING

INTRODUCTION

The ability of the present lead-dip canned fuel elements to withstand the proposed reactor requirements four to five years from now is unknown. Evidence that is available casts some doubt on the ability of Al-Si bonded fuel elements to withstand specific powers in the range of 120-140 percent higher than present.⁽¹⁾ However, the data are very limited because of limited experience in irradiating quantities of HAP0 fuel elements at high specific power. Also, there is no indication that any other process would perform any better.

In four to five years, specific power levels are expected to be 120-140 percent higher^(1a) and the exposure levels some 200-300 MWD/T higher than present. These proposed specific power levels for the HAP0 reactors are in the operating range of the Savannah River Plant reactors. SRP uses both I & E brazed (triple-dip canned) fuel elements and I & E solid state diffusion bonded (hot-press die) fuel elements. The failure rate of the brazed pieces is four times greater than for the SSDB pieces.⁽²⁾ Consequently, SRP is using SSDB fuel elements bonded by Sylvania in the hottest zones of the reactors. SRP installed a hot-press bonding fabrication plant in June 1960, for fabrication of I & E SSDB fuel elements and expects to convert to 100 percent use of SSDB elements as soon as possible.

HAP0 reactor experience with I & E SSDB fuel elements is very limited. Four tubes were charged alternately with SSDB (hot-press) and lead-dip canned I & E elements in 1957. There were no significant differences found between SSDB and lead-dip canned elements in this limited test⁽³⁾ which was not designed to determine reactor failure rates. Eight SSDB (hot-press) I & E wafered 1.6 percent enriched uranium KER size fuel elements were irradiated in the KER loops at high specific powers (72 and 150 KW/ft), exposures of 725 and 400 MWD/T, and at high surface temperatures (about 250 C) without incident.^(3a) In addition, two SSDB I & E elements are currently being irradiated in the MIR⁽⁴⁾ with no apparent difficulties with specific powers up to 200 percent higher than those in the HAP0 reactors. Three charges of SSDB I & E elements are awaiting irradiation in a HAP0 reactor based on the outcome of the MIR results. However, these elements are now an obsolete design and it is uncertain if they will be irradiated.

SUMMARY

This report presents a technological and economic study of the lead-dip canning process as compared to two types of solid state diffusion bonding

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processes (hot-press die and gas pressure bonding) for Hanford production fuel elements (exclusive of NPR). It is concluded that either type of solid state diffusion bonding process has potential technological advantages over the present lead-dip process. Some of these advantages are: (1) elimination of braze layer permits use of a larger uranium core with increased reactor conversion ratios of about 2 percent, (2) better control of aluminum cladding thickness, (3) elimination of porous braze layer, (4) sounder closures, (5) no welding or radiography required, and (6) stronger and tougher bonds. In addition, an annual saving of approximately \$2,700,000 would be realized by changing to a solid state diffusion gas pressure bonding process. Of the two types of diffusion bonding processes, the gas pressure bonding process is considered to have advantages over the hot-press die process. Some of these are: (1) all cladding surfaces are subjected to uniform pressure during assembly, (2) the process is readily adaptable to any size or shape of fuel element without the need to maintain a large inventory of dies and punches for the various HAPO sizes, (3) the process is self-testing for cladding leaks, and (4) bonding is accomplished without core deformation. The annual cost of operating a gas pressure bonding plant is about three million dollars less than the cost of a hot-press die plant based on equal production rates at the present level. The additional cost of a hot-press die plant is mostly attributable to the more expensive aluminum components required for the hot-press die process and the added cost of dies. The capital cost of the two types of diffusion bonding plants is essentially the same.

Based on Savannah River experience plus other isolated irradiation experience, it can be postulated that solid state diffusion bonded fuel elements will perform at least as good as and possibly better than lead-dip canned fuel elements, particularly at higher specific powers and exposures. In order to demonstrate this, irradiation of significant quantities of test pieces both at present and future specific power is required. As an initial step toward an alternate and improved process, some 2000 each of gas pressure bonded and Sylcor hot-press die fuel elements, as well as a quantity of HAPO hot-press die pieces will be obtained and/or prepared for rigorous out-of-reactor evaluation and possible irradiation. For a meaningful evaluation of the gas pressure bonding process and the performance of gas pressure bonded fuel elements, pilot plant quantities will be required. The FY 61 plant acquisition and construction budget submission includes \$480,000 for a gas pressure bonding process pilot plant. Completion is scheduled for March 1962.

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DISCUSSION

The use of a solid state diffusion bonding process has several potential advantages over the present lead-dip process. These advantages are:

1. The SSDB process does not require a braze layer. Therefore, a larger diameter uranium core can be used. This larger core would increase reactor conversion ratios about two percent, resulting in a net gain in the order of 3.7 million per year, by converting from lead-dip canned fuel elements to SSDB fuel elements for all the present reactors.
2. The aluminum cladding thickness can be controlled within more precise limits, since there is no dissolution or penetration of the cladding by the bonding media.
3. There is no porous brazing layer.
4. The closure on the proposed SSDB gas pressure bonding process is bonded metallurgically cold then hot diffusion bonded, which should be more structurally sound than the present fusion welded closures. No welding or radiographing is necessary with this SSDB process.
5. The SSDB nickel bonding layers are stronger, tougher, and more uniform than the lead-dip bonding layers.
6. The nickel bonding layer should be more resistant to corrosive attack in the event of water penetrating the aluminum cladding.
7. The proposed SSDB gas pressure bonding process uses a cheaper aluminum component than the lead-dip process.

There are two basic processes for solid state diffusion bonding of aluminum clad nickel-plated fuel elements. The first process is the use of mechanical pressing devices such as a hot-press die, and the second basic process uses fluid pressure bonding. Fluid pressure can be applied using pressurized molten salts or liquid metals or inert gases at high pressure.

Most of the experience at Hanford is with the use of a hot-press die process.⁽⁵⁾ However, IPD reactor experience with I & E hot press fuel elements is very limited.⁽³⁾ SRP, on the other hand, uses large quantities of hot-press die bonded I & E fuel elements and is converting

to 100 percent hot-press die bonded fuel elements.⁽⁶⁾ The use of a molten salt or liquid metal as a media for bonding has not been developed at any site in the United States. However, it does appear feasible⁽⁷⁾ but would require considerable development. The use of gas pressure as a bonding media for aluminum clad fuel elements has been demonstrated at Savannah River Laboratories,⁽⁸⁻⁹⁾ Atomics International,⁽¹⁰⁻¹¹⁻¹²⁾ and Battelle Memorial Institute.⁽¹³⁾ The Savannah River Laboratory has been bonding both plate elements and tubular elements using gas pressure bonding and has proven its feasibility. The Battelle Memorial Institute has done small quantities of gas pressure bonding for Hanford as well as for other sites. Atomics International is using gas pressure bonding for producing reactor loads of fuel elements.⁽¹⁴⁾ For example, Piqua OMRE reactor is being entirely loaded with this type of fuel element. Also, they are using gas pressure bonded fuel elements in the OMRE reactor at Arco.

The gas pressure bonding method has several advantages over the hot-press die method which makes it worthy of investigation. Some of the advantages are:

1. Uniform pressurizing of all cladding surfaces.
2. The method is adaptable to any shape.
3. The process is self testing for any leaks in the cladding since a large blister forms if there is a leak.
4. Bonding is accomplished without core deformation.
5. A high production rate is possible and is only limited by the size and number of autoclaves.
6. No large inventories of different sizes of expensive dies, punches, and mandrels are necessary.

Some of the disadvantages of gas pressure bonding are:

1. High pressure autoclaves are moderately expensive and require higher than normal building costs for safety reasons.
2. Argon or helium gas must be used which is expensive and/or difficult to obtain.
3. Operators and maintenance personnel must be highly trained and competent to handle high pressure equipment safely.

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By considering the experience at HAP0 and other sites, a proposed SSDB gas pressure bonding process has been outlined as shown in the flow sheet in Fig. 1. A breakdown of each step of the flow sheet follows:

1. Components

a. Uranium Cores

The I & E uranium cores for SSDB fuel elements must be of a better quality than those now obtained for lead-dip canning. As a comparison, Sylcor rejects 12 to 20 percent of the uranium cores for surface imperfections. This includes all rejects after core machining. HAP0 core rejection rates at National Lead and HAP0 are between 10 and 12 percent for the lead-dip canning process. The bare core surface must be better for an SSDB process than for the lead-dip canning process since a good nickel plate will not be obtained over cracks, seams, and striations resulting in poor bonding, if not rejected before bonding. The core geometry is essentially the same as the present I & E core used for lead-dip canning with the exception that an end groove is machined on the closure end of the core as shown in Fig. 3.

b. Aluminum Components

The aluminum component used for this proposed process is a thick-wall impact extruded cup as shown in Fig. 3. This cup is cheaper to produce than a separate can and spire as used in the lead-dip process. It can be produced in either C-64 or X-8001 alloy.

c. Self Supports

The aluminum self supports used will be the design currently being used at the time these fuel elements are being fabricated.

2. Aluminum Component Preparation

a. Quality Control Inspection

The as-received aluminum cups and self-supports will be subjected to a statistical inspection to assure an acceptable quality level.

b. Degrease

The aluminum cups must be degreased prior to the annealing step in either trichloroethylene or perchloroethylene. A submerge-vapor degreaser is recommended.

c. Anneal

The aluminum cups must be annealed in a muffle furnace to soften the aluminum for subsequent sizing operations. Conditions of the anneal are: 575 C for 15-30 minutes.

d. Aluminum Cleaning and Deoxidizing

The same process now used in the lead-dip canning process can be used for cleaning aluminum cups and self-supports for an SSDB process and the same type of equipment can also be used. (15-16)

3. Uranium Core Preparation

a. Quality Control Inspection

The as-received uranium cores will be subjected to the same type statistical inspection now being given to lead-dip uranium cores. (16)

b. Core Etch and Vacuum Outgas

It is not definitely known if these two steps are necessary for obtaining good bonding by the SSDB process. HLO has specified that these two steps are necessary in the hot-press die process to prevent blistering due to outgassing of the core at bonding conditions. Atomics International and Sylcor outgas their core material after the core assembly. Atomics International does not size the jacket onto the core material and the air in the annular space must be removed, the assembly vacuum outgassed, and sealed prior to bonding. (12) Sylcor has a

loose fit between the core and cladding and the assembly is inserted into the hot-press chamber and outgassed before pressure is applied to the assembly. (17-18) On the other hand, SRL has developed a gas pressure bonding method which uses no core outgassing but does size the aluminum jacket onto the core, thus removing the air from the assembly before bonding. (8)

If this core etch and vacuum outgassing step are found to be unessential, it will eliminate costly vacuum outgassing equipment and a time-consuming step. If it is necessary to etch and vacuum outgas, conditions and equipment are:

(1) Core Etch

Same as the process now used for etching lead-dip process cores. That is: degrease; 50 percent nitric acid etch at 55 to 65 C for approximately three minutes; two water rinses; and forced air dry. Equipment used is the present type cleaning equipment.

(2) Vacuum Outgassing

Conditions are: 600 C, 1×10^{-3} mm Hg, for two hours minimum. Equipment for vacuum outgassing includes: heating chamber; cooling chamber; rough, booster, diffusion and holder pumps; heaters; controls and hoist. A pit area about 12 feet deep is needed to contain the heating and cooling chambers.

4. Grain Size and Surface Test

The present UT-2 type test equipment will be used to determine if the uranium cores have been completely transformed, have the proper grain size, and check for surface imperfections.

5. Nickel Plating

Most of the experience on nickel plating of uranium cores has been done using a Watts plating bath. This method is presently used at Sylcor, (17) Atomics International, (12) and SRP. (19) HAPCO's experience has been with a modified Thompson plating bath. (5-20) Fig. 2 compares the two types of plating methods. As noted, the modified Thompson bath uses a plating solution

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containing no boric acid. Sylcor, Atomics International, and SRP report that this boric acid does not contaminate the nickel plates. However, the French⁽²¹⁾ have reported that the nickel plate becomes highly contaminated by boron (400 to 500 ppm of boron) when using a boric acid plating bath. It is therefore recommended that HLO's present modified Thompson plating method be used at HAPO for any SSDB process.

Electroless plating has been tried on uranium cores, especially by Atomics International, but was discontinued when it was found that an electrolytic nickel strike on the uranium was necessary before the electroless nickel coating would adhere to the uranium core.⁽¹⁴⁾

The major equipment items needed for the modified Thompson nickel-plating method are outlined in Reference 5. The major equipment items are briefly:

- a. Eleven process tanks of which five are heated. The plating tank must be coated with a Unichrome 218X or similar coating.
- b. Nickel solution makeup tank with filter system.
- c. pH control system.
- d. Rectifier and electrical system for two tanks.
- e. Rocker system for the plating tank to agitate the plating racks.
- f. Nitric acid storage tanks, if none are available in the area.
- g. A circulating pump for nickel solutions.
- h. Nitric acid transfer pumps.
- i. Fume exhaust system.
- j. A de-ionizer system for a source of de-ionized water.
- k. All tanks should be installed over an acid brick area that slopes into a central drain or over an acid resistant pit with a central drain.

The amount of nickel plated on the uranium cores must be thick enough to prevent the formation of voluminous UAl_3 , which can expand and break the jacket, and to prevent the diffusion of uranium through the aluminum wall. On the other hand, the nickel layer must not be too thick or an unnecessary loss of neutrons will result. A nickel layer of 0.8 to 1 mil thick is recommended as suitable for SSDB fuel elements for our expected reactor condition.

6. Vacuum Drying

The need of a vacuum chamber at 30 inches of Hg to dry the cores after Ni plating is controversial. Sylcor and SRP both use a vacuum dryer for drying cores to prevent the formation of oxide films on the nickel which might prevent good bonding.

However, HLO(5) and SRL(8) have found that a hot water rinse after nickel plating followed by an air dry at room temperature is sufficient.

Development tests should be made to determine if vacuum drying produces better bonding. If there is no difference, a savings in equipment costs and processing time would be obtained. If, however, vacuum drying chambers are necessary, equipment must be obtained that will pump a vacuum chamber down to 30 inches of Hg. The cores are held for 30 minutes minimum in this chamber, and are held in the vacuum chamber until the cores are ready for assembly or nickel thickness testing.

7. Nickel Thickness Test and Visual Examination

A nickel thickness test must be developed by Testing Methods or elsewhere to assure that the nickel plate is thick enough to prevent the formation of undesirable UAl_3 compound. Cores with a thin nickel layer can be returned to the nickel plating line and replated.

If the non-destructive test has to be made under water, the test will be done before drying the cores. Tank equipment similar to the present bond tester could be used. If the test can be done in air, the equipment will be simplified and the test can be done after drying.

A visual examination must also be made, especially on the ends and I.D. of the cores, to determine that no cracks, seams, or other imperfections are present that have not been completely covered with nickel.

8. Core-Can Assembly

After the core is nickel plated and the cans cleaned, all handling of the components that involve contact with the bonding surfaces must be done with clean, lint-free cotton gloves or with clean process equipment. Grease or fingerprints on bonding surfaces results in unbonded areas on the finished fuel elements.

A cold closure core-can assembly method was selected over the usual method using a spire and can that is sized onto the core because:

- a. The cold closure technique with its deep drawing operation should break up the oxide film on the aluminum cup and nickel plate to permit a better and faster bond to occur.
- b. All of the air in the assembly should be removed.
- c. No welding is required in the assembly before or after bonding. Cold closure forms a cold metallurgical bond between the O.D. and I.D. of the aluminum cladding which should be improved further during the bonding operation. No radiographing is needed.
- d. Core and aluminum component tolerances are not critical to the finished fuel element O.D. and I.D. The finished diameters are dependent on the I.D. mandrel and O.D. die used during the cold closure operation and can be closely controlled. With self-supported fuel elements, this control of the finished O.D. should be more important than with cores for use in ribbed process tubes.
- e. Aluminum cups are considerably cheaper than using a can and spire.

P. A. Ard, HLO, has done the initial work on the I & E cold closure technique.(22-23) However, the feasibility studies were not completed and further development work must be done on this technique. The steps of the proposed cold closure are as follows:

- a. Core-Can Assembly Lubrication

The core is inserted into the cup and the cup O.D. and tube I.D. are lubricated to prepare the assembly for the sizing operation.

b. Sizing O.D. and I.D.

The aluminum jacket is sized onto the core by: (1) pushing the assembly through the appropriate die; and (2) by pushing a mandrel through the tube, as shown in Fig. 3. Back pressure must be applied to the aluminum metal as it extrudes past the end of the core to prevent the cup and tube wall from shearing off at the core radii.

c. Brushing and Lubrication

It is necessary to wire brush the interface on the aluminum metal extruded over the end of the core just prior to the cold closure operation. Lubricant is also applied to the assembly O.D. and I.D. before the cold closure operation.

d. Cold Closure

In the cold closure operation, the fuel element assembly is placed in a die with a slightly tapered mandrel inserted through the I.D., as shown in Fig. 4. When pressure is applied, the excess tube and cup wall metal above the core forms a cap and extrudes up into the spacing between the the top punches forming a metallurgically bonded closure. The recess in the top end of the core provides backflow of extruded metal that breaks up the oxide film and promotes a better closure.

e. To disassemble the fuel element from the cold closure die the fuel element assembly is pushed out and the mandrel removed with a hydraulic pin puller.

f. Equipment necessary for assembling a fuel element by the cold closure technique are:

- (1) Assembly area with brushes and a warm air dryer.
- (2) Two twenty-ton double acting presses or one 40-ton press if both sizing operations can be done at once.
- (3) Wire brush and lubrication area.
- (4) One 200-ton press for cold closure.
- (5) Hydraulic pin-puller.

9. Gas Pressure Bonding

Basically, the gas pressure bonding utilizes a hot inert gas at high pressure to obtain intimate contact between the core and cladding resulting in a diffusion bond between the nickel layer, aluminum cladding, and uranium core. However, the gas bonding conditions and equipment that have been used for cladding uranium or 3-1/2 weight percent Mo-U cores with aluminum jackets varies between the different sites. For comparison, the bonding conditions and autoclaves that have been used for three sites are described briefly as follows:

a. Atomics International Gas Bonding Experience (12-14)

(1) Bonding Conditions

Argon or helium gas pressure at 8,000 psi and 537 C for 10 to 20 minutes at temperature and pressure. It takes approximately one hour to obtain operating temperature and pressure and approximately 15 minutes to decrease the pressure after bonding. AI has bonded large numbers of plate type elements and are now bonding Piqua OMR tubular fuel elements.

(2) Autoclave Equipment

The autoclave is a hot wall high alloy steel pressure vessel heated by forced hot air. The autoclave I.D. is just large enough to permit bonding of 5" O.D. tubular fuel elements for the Piqua OMR reactor. The bonding chamber is long enough to permit bonding of four of the 12" long Piqua fuel elements at one time. The autoclave is rated to withstand 15,000 psi at 537 C.

(3) Radiation Exposure Conditions

Full-size fuel element plates have been irradiated in the OMRE to 3,000 MWD/T with no significant damage to the bond. Estimated bond temperatures are 315 C with hot spots to 400 C.

(4) Present Program

AI is planning to fabricate two complete core loadings of aluminum clad 3-1/2 percent Mo-U cores by gas

pressure bonding. One core loading is for the Piqua OMR reactor and the other core loading is for the OMRE reactor at Arco.

b. Savannah River Laboratory Gas Bonding Experience(8)

(1) Bonding Conditions

Helium gas at 5,000 to 6,000 psi at either 525 C for two minutes or 30 minutes at 460 C are used in bonding. Ten minutes is needed to pressurize the autoclave and another ten minutes to reduce the pressure. An additional 30 minutes is necessary to load and unload the autoclave. SRL has bonded 15-foot plate and four-foot tubular fuel elements. An average bond strength of 15,400 psi was obtained.

(2) Autoclave Equipment

A hot wall high alloy steel pressure vessel heated by resistant heaters is used. Vessel O.D. is 15 inches, I.D. is five inches, and the vessel is 21 feet long with a bonding area of 12 feet in length in the center of the vessel. Temperature control over the 12-foot length is within ± 10 C. The present bonding basket can handle 98 Mark VII-A fuel elements (1.21" O.D. and 8.42" long) or tubes and rods up to 15 feet long.

(3) Exposure Conditions

One 15-foot plate element and three 4-foot long tubular elements were irradiated to 600 MWD/T and were discharged when a failure occurred in one of the elements. The failure is believed due to a faulty end closure.(24)

(4) Present Program

The program on gas pressure bonding is essentially completed but some additional work is necessary to bring the studies to an orderly conclusion.

c. Battelle Memorial Institute Gas Bonding Experience(13)

(1) Bonding Conditions

Helium gas at 10,000 psi and 510 C for either five minutes or one hour at temperature and pressure have

been used to bond HAP0 samples. These samples were three 20-inch long tubular and one 20-inch long rod fuel elements. One hour is required for heat-up and pressurization and another hour for reducing pressure and temperature. An additional 30 minutes to 40 minutes is necessary for loading and unloading.

(2) Autoclave Equipment

A cold wall 4340 steel pressure vessel with a 410 stainless steel liner is used. The elements are heated by resistance heaters inside the vessel. The vessel O.D. is 25 inches, I.D. is 14 inches and is six feet long with an active bonding zone of five inches I.D. by four feet long.

(3) Exposure Conditions

None of the samples were irradiated at HAP0.

(4) Present Program

BMI is not presently working on any aluminum cladding of uranium fuel elements by gas pressure bonding. They are, however, working on Zircaloy cladding of uranium and uranium alloy cores.

Other sites besides AI, SRL, and BMI have gas bonding autoclaves, but they are being used for work other than bonding aluminum-clad fuel elements. For example, Westinghouse at Bettis is bonding Zircaloy-2 to uranium cores using gas pressure bonding.⁽²⁵⁾ Their conditions are more severe than those necessary for aluminum bonding. Argon gas at 815 to 1650C, 10,000 psi, and with a four hour bonding cycle at temperature and pressure are used for Zircaloy-2 bonding. Their autoclave is a cold-wall steel pressure vessel, 24 inches O.D., 14-inch I.D., and 11 feet long with a working area of 6-1/2 inches I.D. by five feet in length. The heat is supplied by three resistant heaters within the autoclave.

It is recommended by Autoclave Engineers, Inc., that the proposed autoclaves for gas pressure bonding at HAP0 be of a cold-wall construction. A cold-wall autoclave is considerably cheaper than a hot-wall autoclave with equivalent bonding volume since the hot-wall autoclave requires the use of high Cr-Ni alloy steels, whereas the cold-wall autoclaves use 4340 steel with a thin 410 stainless liner. A schematic drawing of the proposed autoclave is shown in Fig. 5. This proposed autoclave has a bonding volume ten-inch I.D. by ten feet long. The dimensions of the autoclave vessel would be approximately 18-inch I.D.,

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30-inch O.D. by 18 feet long. The resistance furnace which surrounds the bonding zone of the autoclave is separated from the autoclave shell by insulation, such as bubble aluminum oxide. The wall of the autoclave is cooled by cold water flowing through cooling grooves between the stainless steel liner and the autoclave wall. This water must be free of sand and other insolubles to prevent plugging of this cooling channel. The bottom cover on the autoclave is approximately two feet thick, is fabricated of 410 stainless steel and is sealed with neoprene gaskets. The 410 stainless steel autoclave lid is composed of two parts, the outer cover is sealed in permanently unless maintenance is required inside the furnace. The thermocouple and electrical leads, gas inlets, and rupture disc outlets pass through this outer cover. The inner cover on the lid is removed each time the autoclave is loaded and unloaded, and the I.D. of the outer cover is the same I.D. as the working area within the autoclave furnace. The outer cover is sealed in with neoprene packing and the inner cover is sealed with neoprene "O" rings. The inner cover has a thermocouple connection through the lid to permit up to three thermocouples to be located on each basket. The basket is attached to the inner cover and the basket and inner cover are lowered into place simultaneously.

With a bonding zone of ten-inch I.D. by ten feet long, between 190 and 220 OIVN-size fuel elements (1.692-inch O.D.) or 310 to 370 CVN-size fuel elements (1.494-inch O.D.) can be loaded in each basket. Bonding conditions have not been established for HAPO cores, but it is estimated that a complete cycle could be made in less than one hour. This means that a minimum of five autoclaves would be necessary for production bonding.

The major pieces of auxiliary equipment used for supporting a bonding autoclave are shown in the diagram in Fig. 6. The diagram does not include pressure-reducing valves, blow-off valves, and other minor control mechanisms.

The steps in the proposed bonding cycle are as follows:

- a. Basket loading.
- b. Attaching basket to inner cover of autoclave.
- c. Load basket into autoclave.
- d. Seal autoclave.
- e. Pump out air with vacuum pump.

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- f. Pressurize autoclave by bleeding gas from the accumulators to the required pressure. The furnace is maintained at operating temperature between bonding cycles. The gas is partially preheated as it enters to reduce heat-up time.
- g. Maintain autoclave at the specified time at the required temperature and pressure.
- h. Decrease pressure through the gas cooler by expanding into the gas storage vessels.
- i. Pump remainder of the gas from the autoclave to about atmospheric pressure with gas transfer pump.
- j. Open autoclave exhaust line to the atmosphere.
- k. Unseal autoclave.
- l. Remove basket and inner cover.
- m. Disconnect basket from autoclave cover.
- n. Quench basket in water or let the basket air cool.

While the bonding cycle is being carried out, the six-stage compressor is continually pumping gas, either from the gas cylinder manifold or from the gas storage vessel into the accumulators. Enough accumulators should be supplied to permit the autoclave to be pressurized without using the compressor to pump gas into the autoclave.

For safety reasons, the high pressure equipment over 2,000 psi should be behind reinforced concrete walls. The autoclave itself is usually retained in a pit area within a concrete enclosure. The control room is outside of this concrete enclosure and remote viewing of the pit area is necessary. Heavy steel shields with large bolts to absorb the impact if the autoclave cover comes loose can be supplied if necessary. The autoclaves at Bettis were equipped with large cumbersome steel shields which increased the cycle time by at least one-third. At BMI and SRL, however, the concrete walls and pit area were primarily used for personnel protection.

10. Finishing

Finishing of gas pressure bonded fuel elements is very similar to finishing fuel elements fabricated by lead-dip canning. In

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fact, the finishing is simpler since welding and radiograph inspection are not necessary. The process steps are:

a. Machining

The ends of the fuel elements must be machined to remove aluminum flashing and to obtain the desired end contours.

b. Inspection and Stamping

The normal length inspection and stamping is necessary.

c. Bond Test and Aluminum Thickness Test

The normal ultrasonic bond testing equipment can be used for testing for unbonded areas on SSDB fuel elements.⁽¹⁶⁾ An aluminum thickness tester, however, must be developed for SSDB fuel elements.

d. All subsequent processing steps are the same as the steps used for lead-dip process fuel elements.⁽¹⁵⁻¹⁶⁾ These include:

- (1) Warp and dimensional inspection.
- (2) Fuel element cleaning for self-support welding.
- (3) Self-support welding.
- (4) Attachment and alignment tests.
- (5) Fuel element etch.
- (6) Autoclave.
- (7) Final inspection.
- (8) Storage.

11. Core Recovery

Cores from fuel element rejected after bonding can be recovered at least once and rebonded. The process used by SRP and Sylcor is:⁽¹⁷⁻¹⁹⁾

- a. Remove the aluminum cladding in a caustic solution, such as a 15 percent NaOH - 13 percent NaNO₃ solution at 65-100 C.

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- b. Rinse in cold flowing water.
- c. Remove the nickel plate in a 15-25 percent HNO_3 solution at 60-70 C.
- d. Rinse in cold flowing water.
- e. Forced air dry.
- f. Machine the core ends, centerless grind the O.D., and ream the I.D. to the desired dimensions if necessary. With hot press die bonded cores, approximately 0.005 inch is removed from the core surfaces during this operation.⁽²⁶⁾ With the proposed SSDB process there should not be as much up-setting of the core during cold closure as there is during bonding by the hot-press die process. Therefore, this machining, reaming, and grinding operation may not be necessary.

ECONOMICS

Table I compares the economics of the lead-dip process with the proposed SSDB processes. The equipment and building depreciation and overhead costs were assumed equal for all processes, therefore, were not shown. A detailed description of the cost breakdown is given in Appendix I. Not shown under irradiation economics are the expected gains due to the decreased failure rate of the SSDB fuel elements. (The SRP failure rate for brazed fuel elements is four times greater than for their SSDB hot-press die fuel elements).⁽²⁾

The basic assumptions for the fabrication costs are:

- 1. Number of good fuel elements per year - 2,350,000 (20 percent enriched, 80 percent normal uranium).
- 2. Bonding yield - 90 percent. Yield is based on the number of cores to canning lines or to assembly in the case of the lead-dip and SSDB processes, respectively.
- 3. Bare core reject rate at HAP0
 - a. Lead Dip - 2 percent (assuming all pieces are rejected after core pickles).
 - b. SSDB - 12 percent (assuming all pieces are rejected after nickel plating).
- 4. Nickel plate thickness - 0.001 inch.
- 5. Core size for plating and pickling - OIVN (1.591" O.D., 0.513" I.D., 8.325" long).

TABLE I
ECONOMICS OF THE LEAD-DIP AND PROPOSED SSDB PROCESSES

	<u>Lead-Dip Process</u>	<u>Proposed SSDB Processes</u>	
		<u>Gas Bonding</u>	<u>Hot-Press Die</u>
<u>Direct Material & Labor Costs/Yr.</u>			
Bonding Costs (90% Yield)	\$5,823,000	\$3,603,000	\$6,031,000
Recovery Costs	26,000	31,000	31,000
Bare Core Reject Costs	3,000	39,000	39,000
	<u>\$5,852,000</u>	<u>\$3,673,000</u>	<u>\$6,101,000</u>
<u>Uranium Depreciation Costs/Yr.</u>			
Normal Processing (90% Yield)	\$ 26,000	\$ 209,000	\$ 209,000
Recovery	406,000	632,000	632,000
Bare Core Rejects	470,000	3,161,000	3,788,000
	<u>\$ 902,000</u>	<u>\$4,002,000</u>	<u>\$4,629,000</u>
Total Yearly Costs	\$6,754,000	\$7,675,000	\$10,730,000
<u>Irradiation Economics</u>			
Ni Layer Costs			
(Reactivity Loss & Enrichment)		\$ 900,000	\$ 900,000
Improved Conversion Ratio			
(Increased Production)		(4,560,000)	(4,560,000)
		<u>(\$3,660,000)</u>	<u>(\$3,660,000)</u>
Overall Total Yearly Costs	\$6,754,000	\$4,015,000	\$7,070,000
Yearly Saving by Using Gas Bonding Process		\$2,739,000	\$3,055,000

6. Average core weight - 8 lbs. (OIVN of 8.61 lbs. to KIIE of 5.20 lbs.).

7. Loss of uranium on all surfaces when recovering nickel-plated cores - 0.005 inch.

8. Direct labor cost - \$0.00239/man/fuel element (based on 3rd Q FY 60 value of \$.43/pc., 85 percent yield, and 159 men as direct labor).

As noted in Table I, the largest cost figure for the SSDB processes occurs in uranium depreciation by reprocessing bare reject cores back to the producer sites for remelting, casting, rolling, heat treating, and machining. This high value is due to core surface defects such as cracks, seams, and striations which prevent a good nickel plate from being formed. Hot-press cores must also have

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closer diameter and eccentricity tolerances than lead-dip or gas bonded cores which increases the bare reject core rate at the producer sites. If the producer sites can increase their metal quality level, substantial savings can be made since reprocessing costs of reject cores are \$1.10 per pound or about \$8.80 per reject core. The difference in direct material and labor costs of the gas pressure bonding process is due mainly to the use of a cheaper aluminum component. If this cheaper aluminum component cannot be used, the direct material and labor costs will be essentially the same, if not slightly higher, for the gas pressure bonding process.

The estimated project costs for an SSDB gas pressure bonding pilot plant and production facility are shown in Table II. The pilot plant is planned to be installed in the 306 Bldg. with a small heavy-walled addition to house the autoclave equipment. It is expected that the production facility would be installed in the 313 Bldg. with the installation of gas pressure bonding equipment and removal of lead-dip equipment to be done in stages so that production of fuel elements will not be interrupted. Thus, the gas pressure bonding process would replace the lead-dip process gradually over a period of several months.

TABLE II

ESTIMATED PROJECT COSTS FOR SOLID STATE DIFFUSION GAS PRESSURE BONDING

PILOT PLANT AND PRODUCTION FACILITY

	<u>Pilot Plant</u> ⁽²⁷⁾	<u>Production Facility</u> ⁽²⁸⁾
<u>Construction Costs</u>		
Equipment	\$297,000	\$2,180,000
Structural Modifications	30,000	400,000
	<u>\$327,000</u>	<u>\$2,580,000</u>
		(\$2,880,000)*
<u>Project Overhead</u>		
(Contingency, escalation, design services, management services, supervision of construction, general overhead)	\$153,000	\$1,290,000
Total Project Costs	<u>\$480,000</u>	<u>\$3,870,000</u>
		(\$4,320,000)*
Starting Date (Design)	Nov. 1960	CY 1962
Completion Date (Construction)	Mar. 1962	CY 1964

* Project cost if bare core vacuum outgassing equipment is needed.

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RECOMMENDATIONS

It is recommended that a small-scale production test (about 2000 pieces) be made as soon as possible comparing SSDB gas pressure bonded fuel elements with lead-dip and Sylcor and HAPC SSDB hot-press bonded fuel elements. The gas pressure bonded elements could be fabricated as follows:

1. Have HLO complete the feasibility and development work on the cold closure technique on I & E fuel elements.
2. Procure the necessary aluminum and uranium components for the P.T.
3. Have HLO and FPD personnel prepare the fuel elements for gas pressure bonding by the cold closure technique.
4. Ship the assembled cores to SRL or other site that has a gas pressure bonding facility for gas bonding.
5. Return the bonded pieces to HAPC for finishing by FPD and irradiation by LPD.

The large-scale testing of SSDB gas pressure bonded fuel elements would be made after the completion of the SSDB gas pressure bonding pilot plant in the 306 Bldg. in 1962. The pilot plant nickel-plating equipment should be installed first, since it usually takes about two months to "shake down" this type of equipment.

The design of the SSDB gas pressure bonding production facility must be started before the completion of the SSDB gas pressure bonding pilot plant if the project is to be completed in CY 1964.

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FIGURE 1 - PROPOSED FLOWSHEET OF SOLID STATE DIFFUSION BONDING (SSDB) PROCESS - GAS PRESSURE BONDING

FIGURE 2 - COMPARISON OF SRP AND HAPO
NICKEL PLATING PROCESS FOR URANIUM CORES

FIGURE 3 - SIZING OF ALUMINUM CUP ONTO THE URANIUM CORE

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FIGURE 4 - COLD CLOSURE METHOD ON AN ISE FUEL ELEMENT

**FIGURE 5 - SKETCH OF PROPOSED
AUTOCLAVE FOR GAS PRESSURE BONDING**

FIGURE 6. SCHEMATIC DIAGRAM OF
HIGH PRESSURE AUTOCLAVE SYSTEM

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APPENDIX I

ECONOMICS OF LEAD-DIP AND SSDB PROCESSES

All of the values used for calculating fabrication costs are those used in Reference No. 29, unless otherwise noted.

Basic assumptions used throughout this study are as follows:

Production, 10 line shifts/day	2,350,000 good pieces/yr.
Bonding Yield	90%
Operating Efficiency	93%
Direct Labor Cost	\$0.00239/man-pc.
Nickel Plate Thickness	0.001"
Core Size for Plating & Pickling	OIVN
Average Core Weight	8.0 lbs.
Work Days/Yr.	253

A. Direct Material and Labor

1. Bonding Costs	<u>Lead Dip</u>	<u>Gas Bonding</u>
Aluminum Cladding Components	\$1.40/pc.	\$0.57/pc.
Self-Support Rails	0.23	0.23
Other Direct Materials	0.16	0.16
Direct Labor at \$.00239/man-pc.	<u>0.44</u>	<u>0.42</u>
	\$2.23/pc.	\$1.38/pc.

Cost/Year (90% Yield):

• • • • • \$/pc. x 2,350,000/.90 • • • • • \$5,823,000. • • • • • \$3,603,000 • • • • •

The aluminum cladding component for the lead-dip process is based on the average cost of \$1.40 now being paid for an X-8001 can and spire, and for the gas pressure bonding process is based on Reference 29, p.59, for an I & E cup.

The present price for self-support rails is \$0.029 each. With eight rails per element, this makes \$0.23/pc.

The "other" direct materials costs include such items as: argon, chemicals, sleeves, and make-up metal. The "other" direct costs for lead-dip canning have been increased from the \$0.14/pc. in Reference 29, p.48, to \$0.16/pc. to

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reflect increases in material costs and use of more materials as a result of self-support welding. Likewise, the "other" material costs for the gas pressure bonding process were increased over the value for the point closure of \$0.13/pc. in Reference 29, p.59, to \$0.16/pc. to reflect use of materials in gas bonding, self-supports, and increased material costs.

Direct labor costs per man per fuel element were determined from the third quarter FY 60 direct labor costs of \$0.45/pc. at an 85 percent yield and assuming 159 men assigned to direct labor as shown in Table A-I:

$$\$0.45/\text{pc.} \times .85/159 = \$0.00239/\text{man-pc.}$$

For the lead-dip process with self-supports and with the gas pressure bonding process, this gives \$0.44 and \$0.42 per piece, respectively.

From a previous study⁽³³⁾ it was determined that the hot-press combined direct labor and material costs were \$0.01/lb (or \$0.08/pc.) greater than for the lead-dip process. This then gives a total cost of \$2.31/pc. for the hot-press process or \$2.31/pc. $\times$ 2,350,000/.90 = \$6,031,000/Yr.

2. Recovery Costs

	<u>Lead Dip</u>	<u>SSDB</u>
Direct Material	\$0.06/pc.	\$0.07/pc.
Direct Labor	0.04	0.05
	<u>\$0.10/pc.</u>	<u>\$0.12/pc.</u>

Assuming 2,350,000 good pieces per year at a 10% reject rate the direct recovery costs are:

$$\$/\text{pc.} \times 2,350,000 \times .10/(1-.10) = \quad \$26,000 \quad \quad \$31,000$$

Direct material costs are estimated at \$0.06 pc. in Reference 29, p.24, for the lead-dip process and direct labor at \$0.04/pc. The direct material cost for the SSDB processes was increased to \$0.07/pc., and the labor to \$0.05/pc. due to the machining operation needed for recovering these cores.

3. Bare Core Reject Costs

	<u>Lead Dip</u>	<u>SSDB</u>
Direct Material	\$0.035/pc.	\$0.049/pc.
Direct Labor	0.026	0.060
	<u>\$0.061/pc.</u>	<u>\$0.109/pc.</u>

Number Bare Rejects/Yr. 53,300 356,000

Total Cost:

$$\$/\text{pc.} \times \text{No. Bare Rejects/Yr.} \quad \quad \$3,000 \quad \quad \$39,000$$

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The present bare core reject rate at HAP0 is about 2% of the ingot metal cores received and for this study it is assumed that all rejects have been pickled. The estimated bare core reject rate at HAP0 for the SSDB processes is 12%. This is based on experience at Sylcor with bare reject rates of 20% (2-30). This rate includes cores that normally would be rejected at NLO or MCW (an average of about 9%), since Sylcor machines their own cores from core blanks heat treated elsewhere. Thus, an 11% reject rate for surface defects plus a 1% reject rate for UT-2 testing gives a 12% overall reject rate. If NLO or MCW can increase their metal quality level, substantial savings can be made in uranium depreciation costs.

With the above bare core reject rates, the number of bare reject cores per year is estimated at 53,300 and 356,000 for the lead dip and SSDB processes, respectively.

The only material costs on bare core rejects are:

- a. Pickling in the lead-dip process.
- b. Nickel plating in the SSDB processes.

The cost of materials for core pickle from Reference 29, p. 18, was \$0.01636/pc. By multiplying this by the area ratio between a CIIN (used in Reference 29) and an OIVN core, this value becomes \$0.035/pc.

The Ni plating material costs for 0.001" of Ni plate can be obtained from the following equation:

$$$/pc. = A(.031)/37 = \$0.049/pc.$$

$$A = \text{Area of Core in Sq. In.} = 58.58 \text{ Sq. In.}$$

The number of men handling bare reject cores through the process for the lead-dip and SSDB processes are 11 and 25, respectively, which at \$0.00239/man-pc. gives \$0.026 and \$0.060 for the two processes.

B. Uranium Depreciation

1. Normal Processing (90% Yield)	<u>Lead Dip</u>	<u>SSDB</u>
Cost of Reprocessing U Lost During Pickling of Plating	\$0.01/pc.	\$0.08/pc.
Total Cost:		
2,350,000/.90 x \$/pc.	\$26,000	\$209,000

During normal processing the only source of uranium depreciation is at pickle or Ni plating. These costs can be calculated from the following equations from Reference 29, pp. 23 and 25:

- a. U depreciation at pickle - $\$.005 \times A/37 = \$.0079/\text{pc.}$
- b. U depreciation Ni plate - $\$.050 \times A/37 = \$.079/\text{pc.}$

A - Area - 58.58 Sq. In.

2. Recovery	<u>Lead Dip</u>	<u>SSDB</u>
U Scrap Reprocessing	\$345,000	\$511,000
U Sludge	61,000	121,000
	<u>\$406,000</u>	<u>\$632,000</u>

In the lead dip, about 15 percent of the recovered cores are rejected for underweight or surface defects and it is expected that SSDB recovered pieces will be just as high, if not higher. Thus, about 39,200 recovered cores will be rejected per year. It is also doubtful that an SSDB fuel element can be recovered more than once (which is the case with SRP hot-press cores). Therefore, approximately 18,900 additional SSDB recovered cores will be rejected per year.

The difference between the cost for good cores and the value received for uranium scrap is \$1.75/lb. and \$0.96/lb. for enriched and normal uranium, respectively.⁽³⁴⁾ With 20 percent of the cores enriched and 80 percent normal, this gives an overall cost of \$1.10/lb. for reprocessing reject cores. Assuming an average weight of a core as 8 lbs., this gives:

- a. Lead Dip - $39,200 \times 8 \times \$1.10 = \$345,000.$
- b. SSDB - $(39,200 / 18,900) \times 8 \times \$1.10 = \$511,000.$

The uranium loss during recovery for a CIIN lead-dip core averages 0.047 lbs./pc. (Reference 29, p. 27). By multiplying this value by the area ratio between a CIIN and an OIVN core, this value becomes 0.102 lbs./pc. Sylcor has stated⁽²⁶⁾ that about 0.005" of uranium is removed from the surface during recovery of a nickel-plated core. This amounts to 0.201 lbs./pc. for an SSDB core.

The cost of reprocessing the sludge is \$2.30 per pound (Reference 29, p. 27). This gives:

- a. Lead Dip - $261,000 \times 0.102 \times \$2.30 = \$61,000.$
- b. SSDB - $261,000 \times 0.201 \times \$2.30 = \$121,000$

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3. Bare Core Rejects	<u>Lead-Dip</u>	<u>SSDB</u>
Reprocessing U Lost at Pickle or Plating	\$ 0.01/pc.	\$ 0.08/pc.
U Scrap Reprocessing (8 lbs. x \$1.10/lb.)	$\frac{8.80}{\text{pc.}}$ \$ 8.81/pc.	$\frac{8.80}{\text{pc.}}$ \$ 8.88/pc.
Number of Bare Core Rejects/Yr.	53,300	356,000
Total Cost	\$470,000	\$3,161,000

The bases for the bare reject reprocessing costs are given in part A, 3 and B, 1.

The producer site costs for producing SSDB hot-press die cores are expected to be higher than for lead-dip or SSDB gas bonding cores because of the closer diameter and eccentricity tolerances that must be maintained on the I.D. of I & E cores. This added cost, due to higher reject rates at the producer sites, has been estimated at \$0.03/lb.⁽³³⁾ This gives an additional cost for hot-press reject cores of:

$$\$0.03/\text{lb.} \times 8 \text{ lb.} \times 2,350,000/.90 = \$627,000/\text{Yr.}$$

Total bare core reject costs for the hot-press process is therefore:

$$\$627,000 / \$3,161,000 = \$3,788,000/\text{Yr.}$$

C. Irradiation Economics

The economic values determined previously by L. W. Lang,⁽³¹⁾ should be multiplied by a factor of 1.2⁽³²⁾ to obtain the expected values at a rate of 2,350,000 fuel elements per year. Thus, the value of the 2 percent increase in reactor conversion ratios becomes \$3,800,000 x 1.2 = \$4,560,000, and the loss in reactivity and cost of enrichment due to the Ni layer becomes \$750,000 x 1.2 = \$900,000.

The direct material and labor costs and uranium depreciation costs are summarized in Table A-II as \$/good piece and \$/year. For this study the building and equipment depreciation and overhead costs were assumed equal for all processes, therefore, were not shown.

The estimated project costs for the SSDB gas pressure bonding production facility in the 313 Bldg. are shown in Table A-III. The total project cost for a hot-press die bonding production facility in the 313 Bldg. is estimated as approximately \$100,000 less than for the gas pressure bonding facility.⁽²⁸⁾ The project costs for the SSDB gas pressure bonding pilot plant are given in Reference 27.

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TABLE A-I

APPROXIMATE DIRECT LABOR REQUIREMENTS FOR LEAD DIP

AND SSDB GAS PRESSURE BONDING PROCESSES

Ten-Line Shift Operation

(Does not include vacation relief, sick relief, tool room, supervision, etc.)

Operation	Lead Dip as of June 1960	Lead Dip with Self-Support Welding	Operation	SSDB Process - Gas Pressure Bonding
Material Handling	9	9		9
Coverage	8	8		8
Core Recovery	4	5		7
305 Test Pile	3	3		3
Core Receiving Insp.	1	1		1
Pre-irradiation Meas.	1	1		1
Component Insp.	1	1		1
Sleeve Evaluation	1	1		0
Component Cleaning	4	4		4
UT-2 Test	6	6		6
Component Prep. Leadman	2	2		2
Distribution	2	2		2
Spire Etch	3	3	Ni Plating	8
Sleeve Cleaning	3	3	Ni Thick. Test	6
Pickle Insp.	2	2	Ni Surface Insp.	2
Canning Operators	48	48	Cup Degrease & Anneal	4
Canning Leadman - .	2	2	Assembly & Lub.	6
Lathe Operators	8	8	Sizing	12
Braze & Length Insp.	2	2	Brush & Lub.	6
Welders	12	12	Cold Closure	10
Weld Insp.	8	8	Assembly Leadmen	2
Bond & Pen. Test	8	8	Basket Loaders	4
F.E. Etch	4	6	Autoclave Operators	16
Finishing Leadmen	2	2	Basket Unload & Insp.	6
Radiograph	7	8	Bonding Leadmen	2
Final Insp.	3	3	Lathe Operators	8
Final Insp. Leadman	1	1	Bond & Can Wall Test	8
Weld Recovery	2	2	F.E. Etch	6
Dimensional Insp.	0	2		2
Support Weld & Testing	0	12		12
Support Weld Insp.	0	4		4
Autoclave	2	4		4
			Finishing Leadmen	2
			Final Insp.	3
Total	159	183		177

TABLE A-II

DIRECT MATERIAL AND LABOR COSTS AND URANIUM DEPRECIATION COSTS FOR
LEAD-DIP AND SSDB PROCESSES

	<u>Lead-Dip Process</u>		<u>Proposed SSDB Processes</u>			
	<u>\$/Yr.</u>	<u>\$/Good Pc.</u>	<u>Gas Bonding</u>		<u>Hot-Press Die</u>	
			<u>\$/Yr.</u>	<u>\$/Good Pc.</u>	<u>\$/Yr.</u>	<u>\$/Good Pc.</u>
<u>Direct Material & Labor Costs</u>						
Bonding Costs (90% Yield)	\$5,823,000	\$2.48	\$3,603,000	\$1.53	\$6,031,000	\$2.57
Recovery Costs	26,000	0.01	31,000	0.01	31,000	0.01
Bare Core Reject Costs	3,000	0.00	39,000	0.02	39,000	0.02
	<u>\$5,852,000</u>	<u>\$2.49</u>	<u>\$3,673,000</u>	<u>\$1.56</u>	<u>\$6,101,000</u>	<u>\$2.60</u>
<u>Uranium Depreciation Costs</u>						
Normal Processing (90% Yield)	\$ 26,000	\$.01	\$ 209,000	\$0.09	\$ 209,000	\$0.09
Recovery Costs	406,000	.17	632,000	0.27	632,000	0.27
Bare Core Reject Costs	470,000	.20	3,161,000	1.34	3,788,000	1.61
	<u>\$ 902,000</u>	<u>\$0.38</u>	<u>\$4,002,000</u>	<u>\$1.70</u>	<u>\$4,629,000</u>	<u>\$1.97</u>
 Total	 <u>\$6,754,000</u>	 <u>\$2.87</u>	 <u>\$7,675,000</u>	 <u>\$3.26</u>	 <u>\$10,730,000</u>	 <u>\$4.57</u>

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HW-65759

TABLE A-II I

ESTIMATED PROJECT COSTS FOR AN SSDB GAS PRESSURE BONDING

PRODUCTION FACILITY IN THE 313 BLDG. (28)

Item	Cost	Remarks
Core Pickle	(-0-)*	Use Present Equip.
Bare Core Vacuum Outgas	(\$ 300,000)*	
UT-2 Testers	-0-	Use Present Testers
Ni Plating Lines	500,000	
Ni Thickness Testers	100,000	
Al Cleaning Lines	-0-	Use Present Equip.
Degreasers	20,000	
Annealing Furnaces	100,000	
Sizing Presses	40,000	
Cold Closure Presses	100,000	
Bonding Autoclaves (6)	840,000	
Quench Tanks	70,000	
Lathes	-0-	Use Present Lathes
Length Insp.	-0-	Use Present Equip.
Bond & Al Thickness Test	50,000	Modification of Present Equip.
Fuel Element Cleaning	-0-	Use Present Equip.
Self-Support Welders	-0-	Use Present Equip.
Attachment & Alignment Test	-0-	Use Present Equip.
Fuel Element Etch	-0-	Use Present Equip.
Autoclave	-0-	Use Present Equip.
Final Inspection	-0-	Use Present Equip.
Recovery Equip.	100,000	
Gages, Baskets, Conveyors, Etc.	260,000	
Bldg. Modifications	400,000	
	\$2,580,000	
	(\$2,880,000)*	

Project Overhead (Contingency,
Escalation, Design Services,
Management Services, Supervision \$1,290,000
of Construction, General Overhead) (\$1,440,000)*

Total Project Cost \$3,870,000
(\$4,320,000)*

*Cost if bare core vacuum outgassing equipment is needed.

**DATE
FILMED**

7/13/94

END