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EXPERIMENTAL ^{60}Co HEAT SOURCE CAPSULES

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EXPERIMENTAL ^{60}Co HEAT SOURCE CAPSULES

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ABSTRACT

Cobalt containing up to 280 curies of ^{60}Co per gram of metal was encapsulated in nickel- and cobalt-based superalloys. These experimental heat source capsules, producing up to 660 watts each, were prepared for testing at 850-1000°C for up to 10,000 hours.

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INTRODUCTION

Cobalt-60 is potentially useful in large isotopic power sources because it can be produced in large quantities at low cost. High-activity ^{60}Co is produced in the high neutron fluxes of the Savannah River Plant reactors.[1] Radioactive cobalt contains ^{60}Co, ^{60}Ni, and natural ^{59}Co.[1,2] ^{60}Co, with a half-life of 5.24 years, decays to nonradioactive ^{60}Ni by emitting beta particles and gamma rays (1.17 and 1.33 Mev); no gas is generated during radioactive decay.

The ^{60}Co heat source program at the Savannah River Laboratory is to provide the data required to design, fabricate, and operate ^{60}Co heat sources.[3] The initial objective is to establish operating limits for capsules containing ^{60}Co metal in various oxidation-resistant alloys such as nickel- or cobalt-based superalloys. Capsules are expected to operate at 850-1000°C for up to five years in inert gases or about one year in air.

This report describes design, fabrication, and performance of experimental capsules of various candidate cladding alloys; the capsules contain either unirradiated cobalt or ^{60}Co for long-term tests to determine cobalt-cladding compatibility and cladding oxidation resistance.

SUMMARY

Cobalt metal wafers containing 280 curies of ^{60}Co per gram have been encapsulated for experimental heat sources at the Savannah River Laboratory. The hot cell facility described in this report is designed to encapsulate 400-curie-per-gram ^{60}Co in six-inch-long capsules that produce 1500 watts (100,000 curies) per capsule.

Experimental capsules are assembled, tungsten-inert-gas welded, and leak tested before they are heated for performance tests at temperatures to 1000°C for up to 10,000 hours. ^{60}Co wafers have been encapsulated in "Inconel"* 600 and "Hastelloy"** C. Capsules for heating tests have also been made of "Hastelloy" X, "Haynes"** 25, "Incoloy"* 825, TD Nickel,*** and TD Nickel-Chromium*** using ^{59}Co wafers.

* Trademark of International Nickel Co.
** Trademark of Union Carbide Corp.
*** Product of Fansteel Co.

DISCUSSION

HOT CELL FACILITY

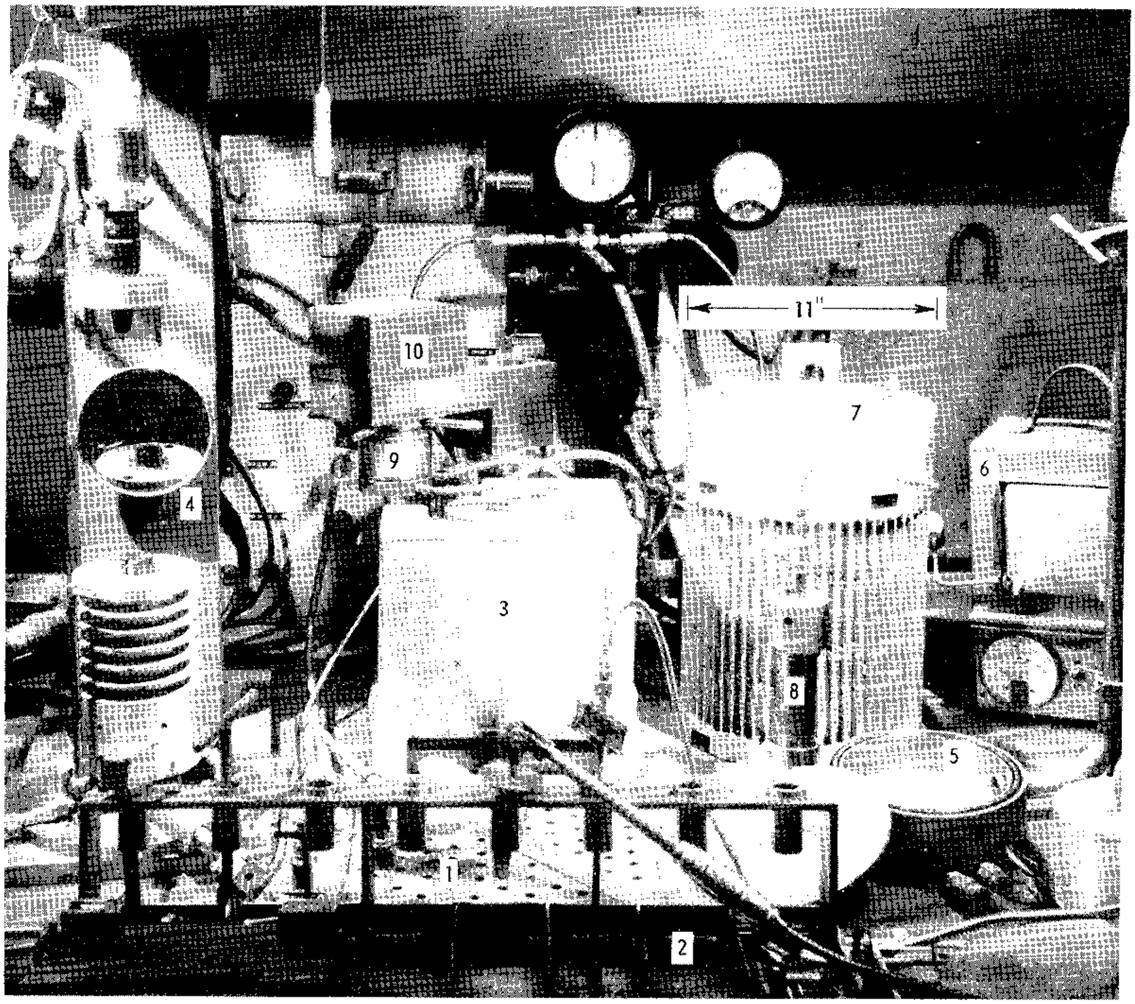
^{60}Co experimental capsules are fabricated in the Hot Cell Facility of the Savannah River Laboratory.[4] One cell module, six feet square and 16 feet high, was adapted and is used for all encapsulation steps.[5] A pair of master-slave manipulators and a one-ton bridge crane serve the cell, along with access plugs for services, utilities, and controls. Cell walls of three-foot-thick barytes concrete have a density of 3.5 grams per cubic centimeter. The cell window is of the all-glass, 3.2 density oil-filled type composed of four 9-inch-thick panes. With the cell liner, or equipment frame, in the cell, the usable work area is $5\frac{1}{2}$ feet square. Work tables are ~36 inches high.

The encapsulation facility, Figure 1, was designed to fabricate experimental capsules up to six inches long and one inch in diameter that would contain a maximum of 100,000 curies of ^{60}Co wafers. With minor changes, instrumented capsules or capsules up to nine inches long by two inches in diameter can be welded, cobalt slabs encapsulated, and end or girth welds made.

In-cell shielding was prescribed to reduce radiation exposure of personnel through the cell window and radiation damage to cell equipment by the hard gamma from ^{60}Co wafers and capsules. The primary shield for capsules in the cell is the air-cooled storage cask shown in Figure 2. It is fabricated from aluminum-covered lead, weighs 320 pounds, and is designed to attenuate 99% of the gamma radiation and to dissipate the heat generated to the cell air from capsules up to six inches long and containing 100,000 curies of ^{60}Co. Two casks are available, usually in a well beneath the work table.

Supplementary cooling systems such as fins and tubing for either gas or liquid coolant are incorporated in the shields, fixtures, and work areas as a supplement to cell convection for dissipating the heat generated in equipment by high radiation levels.

The cell module has been in operation since June 1966; ^{60}Co wafers with activities up to 280 curies per gram have been fabricated into capsules that contain as much as 40,000 curies of ^{60}Co. Radiation through the cell window during fabrication has proved tolerable. The dose rate from a three-inch-long capsule containing 40,000 curies held six inches from the inside of the cell window was 15 mr/hr three inches from the window. Particular care is taken to eliminate organic materials on or near the work area to lessen the chance of contamination of ^{60}Co wafers or capsule surfaces.



1. Wafer cleaning well
2. Wafer gaging and work tray
3. Shielded loading chuck
4. Welding station
5. Leak detection chamber
6. Furnace
7. Air-cooled storage cask
8. Vessel for pressurizing capsule
9. Platen
10. Shielded hydraulic press

FIG. 1 ^{60}Co ENCAPSULATION FACILITY

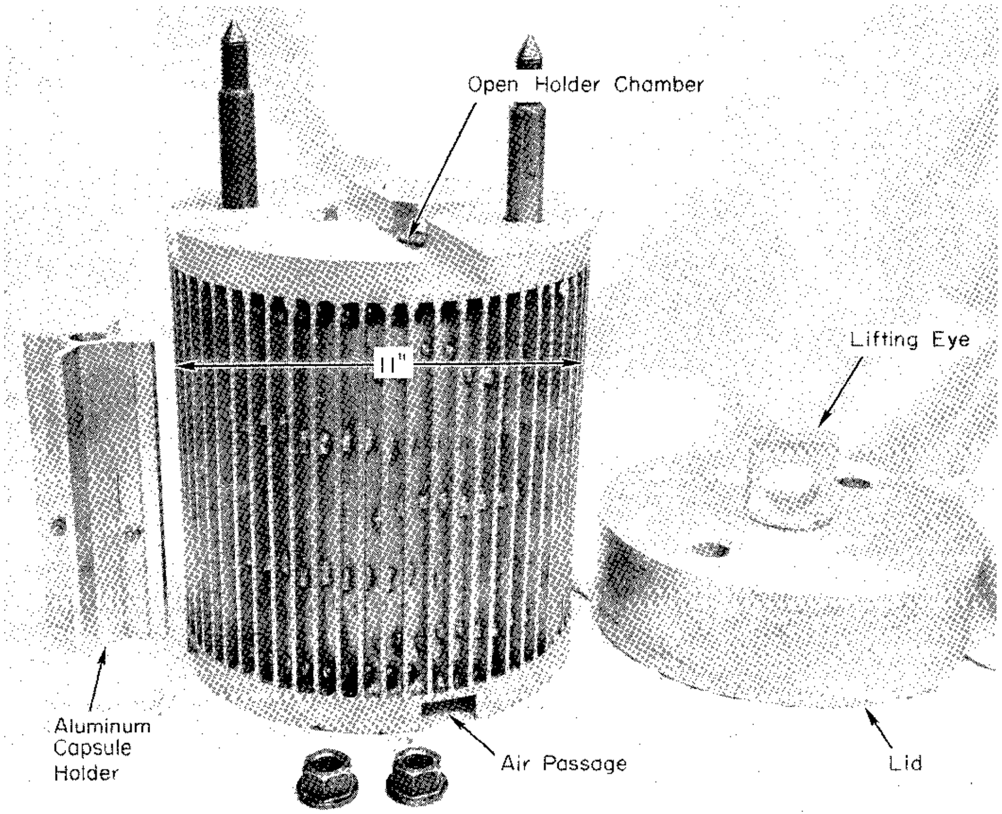


FIG. 2 AIR-COOLED STORAGE CASK

CAPSULE DESIGNS

The simple capsule designs shown in Figure 3 are used for encapsulating ^{60}Co heat sources of various oxidation-resistant alloys. Though capsules up to six inches long can be fabricated on existing cell equipment, capsules are generally one to three inches long to restrict the total gamma activity in the hot cell facility. Spacers are included at the top and bottom of a column of ^{60}Co wafers to prevent cutting into cobalt when cutting off the ends of the capsule after test. The spacers are beveled on one edge to clear the fillet in the capsule bottom and to ensure that the cobalt wafers are loaded with their faces parallel to the capsule bottom. A void volume of about 7% is left in the capsule to accommodate the small amount of gases entrapped in the capsule during cap pressing or released from the cobalt during testing, to provide for differential thermal expansion, and to provide loading clearance between the cobalt wafers and the capsule wall. A radial clearance of about 2.5 mils (~1½% void) is adequate for loading convenience and sufficient to accomodate differential thermal expansion between wafers and the capsule wall.

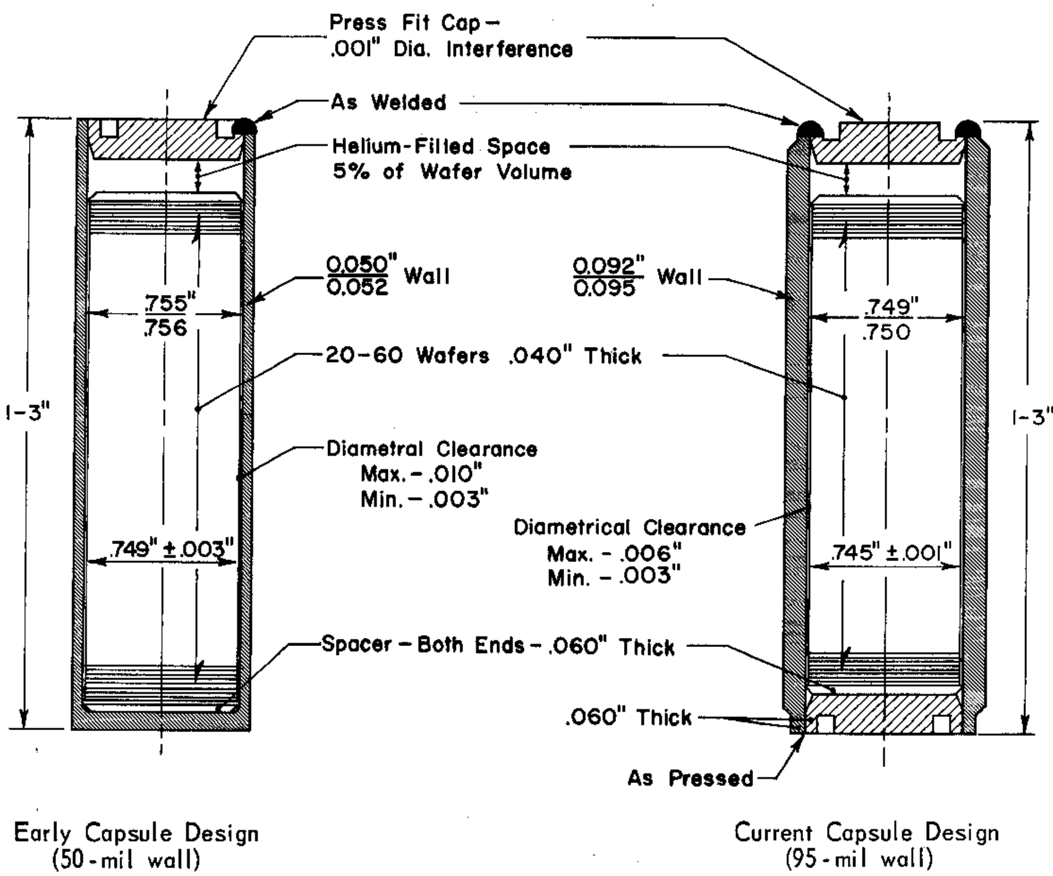


FIG. 3 EXPERIMENTAL CAPSULE DESIGNS

COBALT WAFERS

Cobalt wafers are commercially available. Changes in dimensions, density, hardness and microstructure of cobalt before and after irradiation showed that the effects of irradiation and decay were not significant except for the expected increase in hardness.[6] This indicates that the properties of ^{59}Co can be used confidently in the design of ^{60}Co heat sources. Wafers are

3/4 inch in diameter and 0.040 inch thick, and are electroplated with about 0.001 inch of nickel to minimize contamination during encapsulation.[3] The wafers are irradiated in aluminum target slugs designed to minimize flux depression in the cobalt caused by self-shielding (Figure 4).

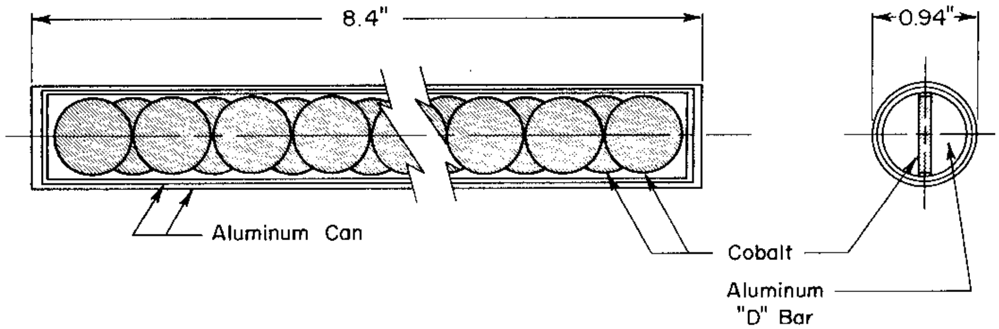


FIG. 4 TARGET DESIGN FOR 3/4-INCH COBALT WAFERS

Irradiated cobalt wafers are removed from the aluminum target slugs and prepared for encapsulation in the hot cell facility. Individual target slugs are suspended in a stainless steel basket and dissolved in caustic. The cobalt wafers remain in the basket and are emptied into an inspection tray for additional cleaning of corrosion products (Figure 5). The highly radioactive ^{60}Co

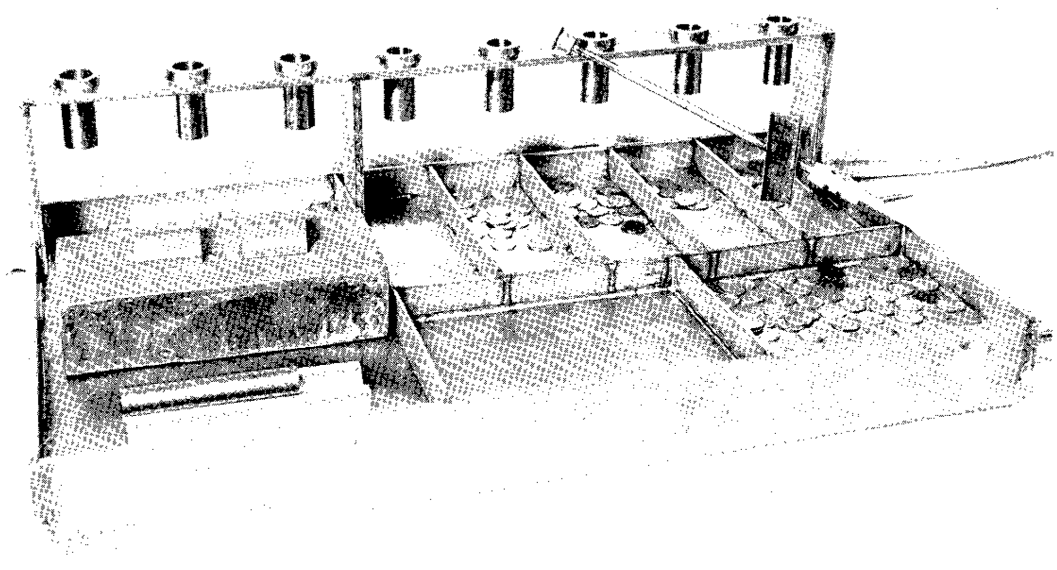


FIG. 5 INSPECTION TRAY AND VACUUM PICKUP DEVICE
Shown Out-of-cell (Wafers = 3/4 inch dia.)

wafers are spread out in the tray to keep them cool. Wafers are handled individually during transfers with an all-metal vacuum pickup device to decrease damage to the wafers and spread of contamination.

To remove residual dissolution products, the wafers are cleaned in 0.5N NaOH and 0.5M oxalic acid solution followed by rinsing. A small segmented stainless steel basket is used to separate wafers for effective cleaning of both sides, and to prevent heating that would result from wafer-to-wafer contact. After the final water rinse, wafers are dried in hot air and transferred to the inspection tray.

ENCAPSULATION

Capsules, caps, and spacers are machined from bar stock and inspected and degreased prior to entrance into the hot cell. Bottom caps are welded out-of-cell on equipment similar to that in the cell.

Capsule Loading

Wafers and spacers are individually gauged to ensure that they will load successfully. Sleeve-type ring gauges, three inches long and sized to simulate the inside diameter of the capsule, are mounted on the inspection tray about two inches above the tray surface (Figure 5). Using the vacuum pickup, each wafer is lowered through the smallest ring gauge possible.

Empty capsules are loaded in a shielded chuck assembly that contains a finned aluminum collet for removal of heat. The collet can be cooled by gas from a manifold shown in Figure 6.

The radiation shield (Item 3, Figure 1) consists of $1\frac{1}{2}$-inch-thick lead in an aluminum housing that is set on $1\frac{1}{2}$-inch legs to allow air to flow by convection up through the space between the chuck collet and the shield. Together, the shield, collet base, and a lead plug that rests on top of the collet attenuate about 90% of the ^{60}Co radiation from a capsule. The hydraulic unit used for pressing the top cap into the capsule, shown in Figure 6, is also shielded in a rectangular lead block (Item 10, Figure 1) to protect the piston O-rings from radiation damage.

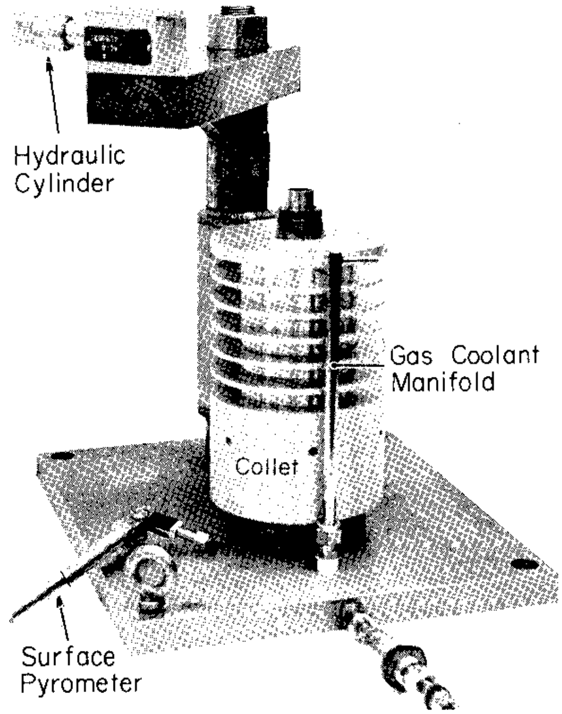


FIG. 6 LOADING CHUCK AND PRESS

The platen, shown in Figure 1 and explained in detail in Figure 7, is used to evacuate and backfill the capsule and to insert the cap. After the wafers and spacers are loaded into the open capsule, the platen, with cap in place and secured with the toggle clamp, is attached to the shielded hydraulic piston. By rotating the spoked wheel, the platen is lowered to seal against the top of the capsule. Before the cap is dropped on the capsule and pressed in, the capsule is evacuated and purged with helium several times. The cap is pressed into the capsule without breaking the platen-to-capsule seal. Ports in the platen for evacuating and backfilling the capsule are shown in section in Figure 7.

Capsule Welding

Capsule closures are made by TIG fusion welding. The automated equipment is inexpensive and simple to install and operate remotely (Figure 8). The torch and head are in the cell, while the power supply, weld-current controller, and automatic controller for arc voltage (which controls head position) are outside. Welds are started by a high frequency current initiated from a 24-volt dc touch-retract circuit. Once the touch-retract circuit is started, capsule rotation and the weld cycle proceed

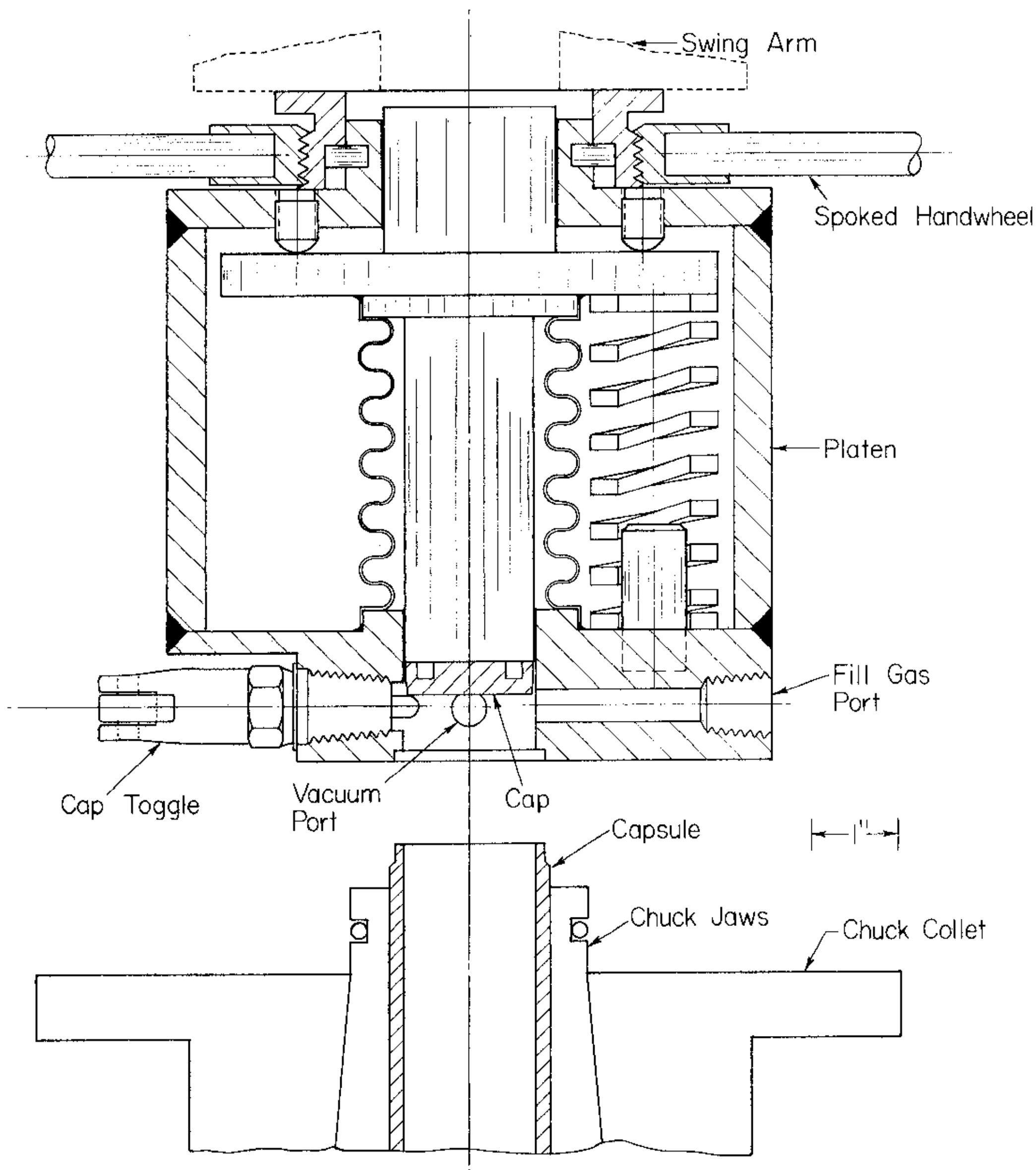


FIG. 7 SECTION THROUGH PLATEN AND CAP

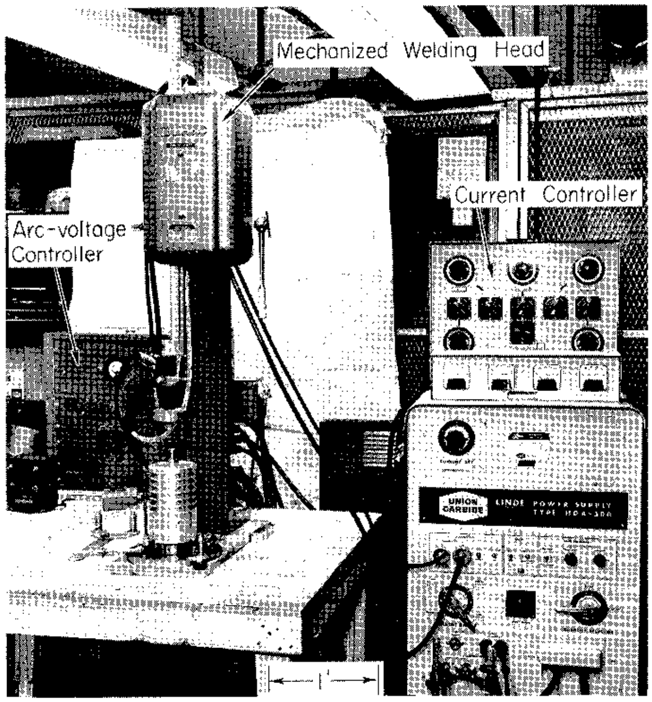
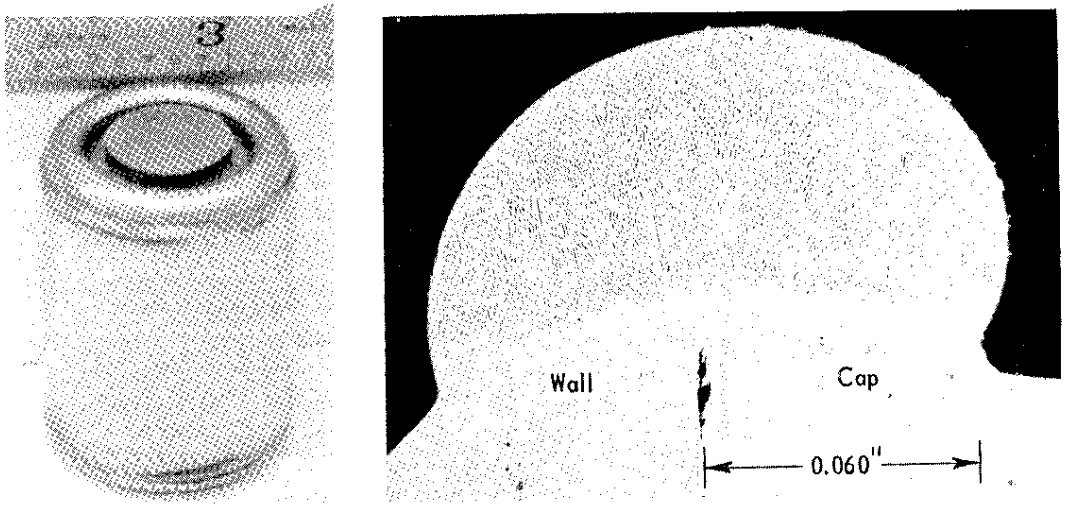


FIG. 8 AUTOMATIC TUNGSTEN-INERT-GAS (TIG) WELDING EQUIPMENT
(Shown out-of-cell)

automatically. Welding is done with a 2% thoriated tungsten electrode in helium shield gas. To simplify piping, this same helium is also used to cool the torch body. A glass shroud, attached to the torch, is also fed with helium to blanket the top of the capsule during welding and cooling. The welding chuck is similar in design to the capsule loading chuck, but is not shielded because capsules are in the welding chuck for less than five minutes, whereas they may be in the loading chuck from $\frac{1}{2}$ to 3 hours.

To ensure proper operation during welding of heat source capsules, welding trials are conducted immediately before capsule welding. Several welds are performed on bar stock to verify gas flow, amperage, arc voltage, and speed of chuck rotation. A dummy capsule is then welded using the heat source capsule welding conditions developed out of cell. If this test weld is found satisfactory on visual inspection, the heat source capsule is welded. An example of the welds produced on thick-walled capsules is shown in Figure 9.



Surface View Cross Section

FIG. 9 TYPICAL WELD CLOSURE ON "INCONEL" 600 CAPSULE

Inspection and Testing

Capsules are inspected and tested before beginning long-term heating tests.[7,8] Inspection and testing consists of visual examination, a four-hour heating at 850°C, and dimensional measurements and a helium leak test before and after the four-hour heating test.

Immediately after welding, capsules are helium leak tested using a mass spectrometer leak detector. Though the system can detect helium leaks as small as 2×10^{-10} atm cc/sec, the practical minimum is about 2×10^{-9} due to the high helium background in the cell and the outgassing characteristics of the capsule weld and wall surfaces. The detector, located out of cell, is connected through the cell wall to the leak-detection chamber shown in Figure 1. A labyrinth-type grease trap is located in the vacuum line to the detector to keep gross particulate contaminants from escaping the cell. After the four-hour heating test, capsules are externally pressured with 200 psi helium for one-half hour and again helium leak tested.

EXPERIMENTAL ENCAPSULATIONS

All ^{60}Co capsules made to date have passed helium leak test (less than 2×10^{-9} atm cc He/sec), visual examination, dimensional measurements, and the four-hour anneal at 850°C.

Seven capsules containing ^{60}Co listed in the following table were fabricated in the SRL hot cell facilities. The results of heating tests on these capsules are being reported in the quarterly progress reports.[8] Cobalt-60 wafers are now being encapsulated in "Hastelloy" X and "Haynes" 25.

^{60}Co CAPSULES FABRICATED THRU 12/15/67

Encapsulation Material	Wall Thickness, inch	Specific Activity, curies/g[a]	Total Activity, curies[a]	Total Power, watts[a]	Capsule Length, inch	No. of ^{60}Co Wafers
"Hastelloy" C	0.050	120	11,000	170	2.2	38
"Inconel" 600	0.050	120	17,000	260	2.9	57
"Inconel" 600	0.050	100	5,000	80	~2.0	21
"Inconel" 600	0.050	155	15,000	230	2.2	38
"Inconel" 600	0.050	155	15,000	230	2.2	38
"Inconel" 600	0.050	155	7,000	110	1.3	19
"Inconel" 600	0.095	280	41,000	650	2.9	57

(a) At encapsulation.

More than forty capsules have been fabricated containing unirradiated cobalt for testing in furnaces located out-of-cell. Some inactive capsules serve as controls for similar capsules containing ^{60}Co to assess the effects of radiation field and the nickel content of ^{60}Co on oxidation and diffusion in capsules. Others are tested to define limiting conditions of operation, and the effects of capsule defects. Figure 10 shows three ^{59}Co capsules before and after a 1000-hour heating test in air at 1000°C. Figure 11 shows a capsule, containing about 40,000 curies of ^{60}Co, during a heating test at 850°C.

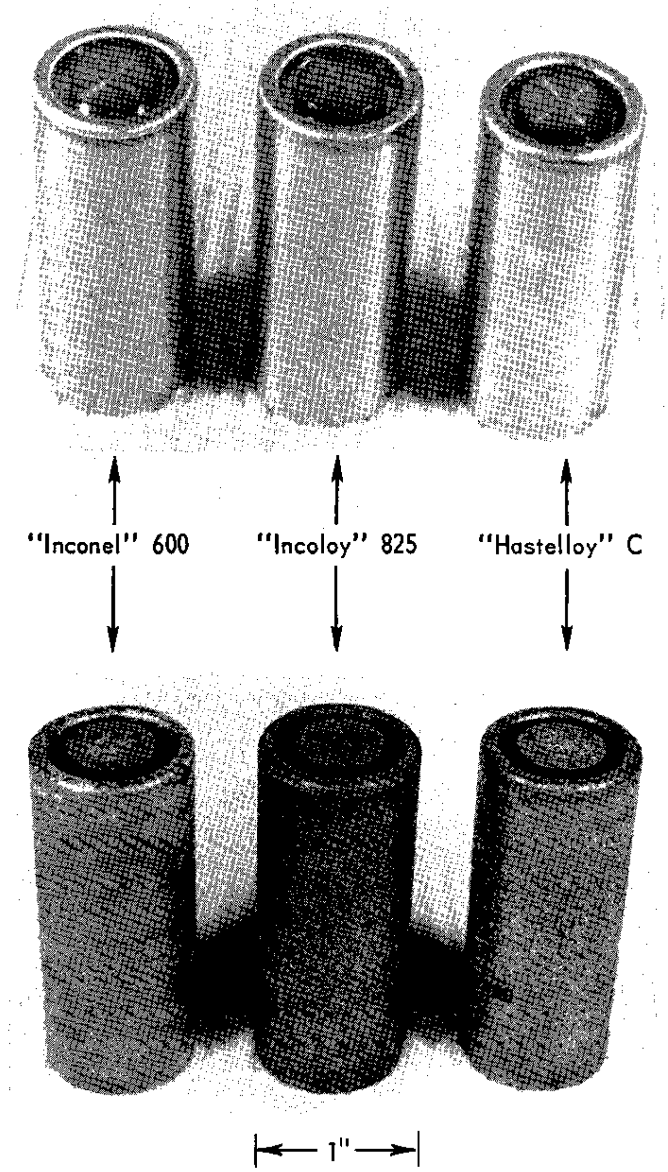


FIG. 10 ^{59}Co CAPSULES BEFORE AND AFTER 1000-HOUR HEATING TEST AT 1000°C

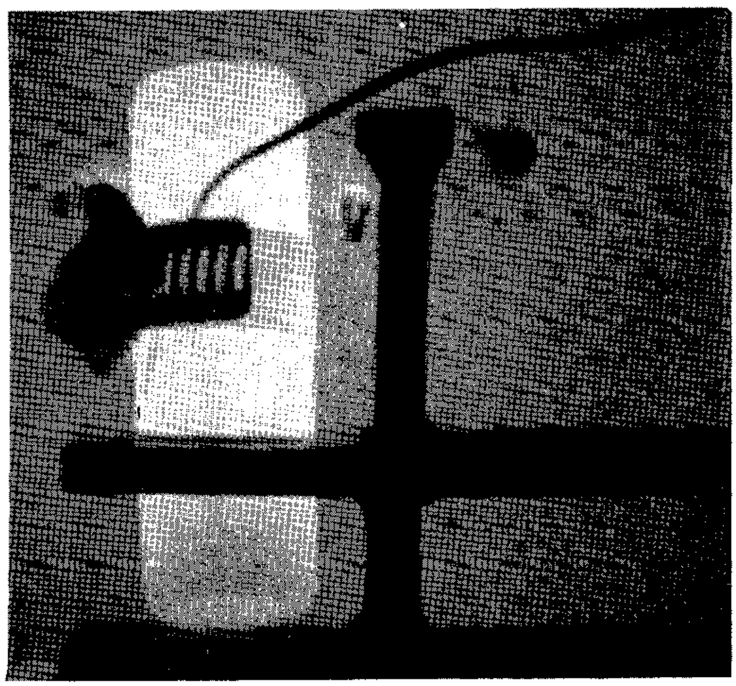


FIG. 11 ^{60}Co CAPSULE DURING HEATING TEST AT 850°C

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