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DP-1237

AEC RESEARCH AND DEVELOPMENT REPORT

SAVANNAH RIVER LABORATORY COBALT-60 POWER AND HEAT SOURCES

QUARTERLY PROGRESS REPORT

JANUARY – MARCH 1970

DU PONT
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Savannah River Laboratory

Aiken, South Carolina

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65

DP-1237

UC-23, Radioisotope and Radiation Applications
UC-33, Propulsion Systems and Energy Conversion
(TID-4500, 55th Ed.)

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January - March 1970

Compiled by

C. L. Angerman
C. P. Ross

May 1970

E. I. DU PONT DE NEMOURS & COMPANY
SAVANNAH RIVER LABORATORY
AIKEN, S. C. 29801

CONTRACT AT(07-2)-1 WITH THE UNITED STATES ATOMIC ENERGY COMMISSION

PREFACE

This report is one in a series on the applied aspects of ^{60}Co that are under study at the Savannah River Laboratory (SRL). These reports are intended to present data that are useful to system designers and also to potential or active user agencies. The reports thus deal with the following subject areas of SRL programs:

1. Properties and reactions of ^{60}Co fuel forms useful or potentially useful as heat sources.

2. Information on the irradiation and postirradiation processing of these materials, when the information is relevant to their use as heat sources and is not in a sensitive area of production technology.

3. Development of design data directed toward the use of and manufacturing capability for isotopic heat sources.

This report contains principally data from work performed during the report period. Previous reports are listed in the Publications section.

SUMMARY

Improved welds were made in arc-cast tungsten capsules by increasing weld speed and providing additional cooling to the cap being welded. (p 1)

Wafers of cobalt oxide (CoO) at 90% of theoretical density were fabricated by an improved sintering process. (p 9)

High-melting cobalt compounds were not compatible with tungsten and TZM at 1600°C. (p 9)

Radiation streaming from coolant ducts will not be limiting in the WANL 30 kw(t) ^{60}Co heat source. (p 12)

CONTENTS

PROGRAM

The purpose of the Savannah River Laboratory (SRL) program on ^{60}Co is to provide data that will be required for designing, fabricating, and operating ^{60}Co heat sources. Primary emphasis is on selecting materials for encapsulating cobalt fuel forms and establishing temperature limits for operation of capsules. Development of specific heat source concepts is not at present included in the scope of the SRL program.

MATERIALS TECHNOLOGY AND DEVELOPMENT

CAPSULE FABRICATION AND TESTING

Welding Techniques for Refractory Metal Capsules

Welding techniques for tungsten, rhenium and tungsten-25 wt % rhenium (W-25 Re) capsules are being developed. An inert atmosphere welding station for refractory metals has been completed with the exception of the station for continuous analysis of oxygen and water vapor.

The initial welds of an arc-cast tungsten capsule had intergranular cracks. A helium leak test of the capsule and visual inspection indicated that the cracks initially did not penetrate the wall of the capsule. Stresses induced or released during sectioning of the capsule for metallography apparently propagated the cracks to the outer surface of the weld. Large grains observed in the welds probably aided crack propagation. None of the voids that are typical of powder metallurgy tungsten were observed. Cracks penetrating through the welds in other arc-cast tungsten specimens were found only when the welds had been made at low welding speeds and when there had been no cooling of the cap with a jet of helium during welding. Other variables in this series were the stress relief the capsules receive before and after welding, the preheat of the capsules just prior to welding, and the height of the capsule in the chuck. Welds were examined extensively for cracks prior to destructive examination. Liquid nitrogen bubble tests, helium leak tests, and dye penetrant tests showed penetrating cracks in three of the eight welds. Two of the cracked welds were made at the lower welding speed and the third was in the cap for which no cooling was provided. No penetrating cracks were observed in the five welds made at the higher welding speed with cooling of the cap. Destructive examination of the welds is in progress.

Welds were also made in four caps of W-25 Re. This alloy is not as susceptible to cracking as tungsten but is susceptible to hot tearing. All welds were found to be leak tight by helium leak tests. Destructive examination showed cracks in some areas starting from the capsule to cap interface and extending in one case 80% of the way through the weld.

A facility for welding refractory metal capsules containing ^{60}Co was designed and ordered for the High Level Caves (HLC).

Heating Tests of Capsules Containing Unirradiated Cobalt Metal

Superalloy Capsules

Three capsules were removed from test after 10,000 hr at the following conditions:

Material	Temperature, °C	Special Conditions
"Inconel"* 600	900	-
"Inconel" 600	1000	Internal atmosphere air instead of helium
"Haynes"** 25	850	-

There were no significant dimensional changes. Sectioning of the samples was completed and metallographic examination was begun. Another Inconel 600 capsule achieved its goal exposure of 10,000 hr at 900°C but was left in test for an additional 10,000 hr.

* Trademark of International Nickel Co.

** Trademark of Union Carbide Corp.

Fourteen capsules remain under test, (Table I). One of these, an "Inconel" 600 capsule contaminated with caustic residue, will be removed from test during the next quarter after 10,000 hr at 900°C. Goal exposures of the remaining capsules are 20,000 and 50,000 hr.

Refractory Metal Capsules

Capsules of tungsten and W-25 Re were received from the vendor, Thermo Electron Corporation. Long-term heating tests will begin during the next quarter, Table II, as soon as the welding techniques for these materials are proven.

Reprocessing of rhenium into capsules was begun by Thermo Electron. Delivery of these capsules and adaptation of welding techniques to rhenium are scheduled during the next quarter.

Heating Tests of Capsules Containing Irradiated Cobalt Metal

Superalloy Capsules

Eleven capsules removed from test in 1969 after 5000 and 10,000 hr at up to 1000°C are being stored in the High Level Caves (HLC). The metallography facility in the HLC was returned to operation, and destructive examination of these capsules is scheduled to begin during the next quarter.

Nine capsules remain under test at 900 and 1000°C, Table III. Goal exposures are 20,000 and 50,000 hr.

Refractory Metal Capsules

Capsule tests with irradiated cobalt are scheduled to begin in 1971 in a new shielded cell in the Isotopes Process Development Laboratory (IPDL). The floor slab for this facility was poured and the cell walls were prefabricated. Construction is scheduled to be nearly complete during the next quarter, and process equipment will be ordered.

TABLE I

Summary of ^{59}Co Capsule Heating Tests
All Co wafers 0.745-in. diameter

Capsule Material	Heating Time, hr	Heating Temp, °C	Wall, mils	No. of Capsules	Approx. Starting Date	Approx. Completion Date	Remarks
"Inconel" 600 (m.p. 1370°C)	1,000	850	50	1	12-66	2-67	Capsule intact
	5,000	850	50	1	12-66	7-67	Capsule intact
	10,000	850	50	1	12-66	1-68	Capsule intact
	10,000	850	95	1	7-67	9-68	Capsule intact
	50,000	850	95	1	7-67	3-73	
	1,000	900	95	1	11-68	12-68	Capsule intact
	5,000	900	95	1	11-68	6-69	Capsule intact
	5,000[e]	900	95	1	3-69	10-69	Increased Co/capsule reaction
	→ 10,000	900	95	1	11-68	1-70	Examination in progress
	→ 20,000	900	95	1	11-68	3-71	
	10,000[e]	900	95	1	3-69	5-70	
	50,000	900	95	1	11-68	7-74	
	1,000	1,000	50	4	8-66	10-66	3 capsules intact; 1 capsule oxidized[b]
	5,000	1,000	50	1	4-67	11-67	Capsule intact
	1,000[a]	1,000	95	2	7-67	9-67	No severe oxidation of Co
	1,000[d]	1,000	95	1	2-68	4-68	No oxidation of Co or capsule
	5,000[d]	1,000	95	1	2-68	9-68	No oxidation of Co or capsule
	5,000	1,000	95	1	8-67	2-68	Capsule intact
	10,000	1,000	95	1	8-67	10-68	Capsule intact
	50,000	1,000	95	1	10-67	6-73	
	→ 10,000[d]	1,000	95	1	11-68	1-70	Examination in progress
"Hastelloy" C (m.p. 1270°C)	1,000	1,000	50	4	8-66	10-66	3 capsules intact; 1 capsule oxidized[b]
	5,000	1,000	95	1	10-67	5-68	Capsule intact
	10,000	1,000	95	1	10-67	12-68	Capsule intact
	50,000	1,000	95	1	10-67	6-73	
	20,000	1,000	95	1	5-68	9-70	
TD Nickel (m.p. 1450°C)	1,000	850[c]	95	1	10-67	12-67	Capsule intact
	5,000	850	95	1	10-67	5-68	Capsule intact
	10,000	850	95	1	10-67	12-68	Capsule intact
	50,000	850	95	1	10-67	6-73	
	1,000	1,000	95	1	12-66	2-67	Capsule intact
	1,000[a]	1,000	95	2	10-67	12-67	No severe oxidation of Co
TD Nickel Chromium (m.p. 1430°C)	1,000[a]	1,000	95	2	10-67	12-67	Co near pinhole oxidized
	1,000	1,000	95	1	10-67	12-67	Capsule intact
	5,000	1,000	95	1	10-67	5-68	Capsule intact
	10,000	1,000	95	1	10-67	12-68	Capsule intact
	50,000	1,000	95	1	10-67	6-73	
"Haynes" 25 (m.p. 1330°C)	→ 10,000	850	95	1	11-68	1-70	Examination in progress
	1,000	1,000	95	1	10-67	12-67	Capsule intact
	5,000	1,000	95	1	10-67	5-68	Capsule intact
	5,000	1,000	95	1	5-68	12-68	Capsule intact
	10,000	1,000	95	1	10-67	12-68	Capsule intact
	50,000	1,000	95	1	10-67	6-73	
	20,000	1,000	95	1	5-68	9-70	
"Hastelloy" X (m.p. 1260°C)	1,000	1,000	50	1	4-67	6-67	Capsule intact
	5,000	1,000	50	1	4-67	11-67	Capsule intact
	5,000	1,000	95	2	2-68	9-68	Capsules intact
	10,000	1,000	95	1	2-68	4-69	Capsule intact
	50,000	1,000	95	1	2-68	10-73	
	20,000	1,000	95	2	5-68	9-70	

a. Two capsules, one not welded and one with drilled hole in wall, to test effects of capsule defects.
b. Capsules reacted with fire-brick. See DP-1094, "SRL Isotopic Power and Heat Sources - Quarterly Progress Report," October-December 1966.
c. Tests of TD Nickel at 850°C in flowing argon.
d. Internal atmosphere air instead of helium.
e. Caustic residue on wafers.
→New information reported.

TABLE II

Summary of Planned ^{59}Co-Refractory Metal Capsule Heating Tests*

Capsule Material	Heating Time, hr	Heating Temp, °C	Approx. Starting Date	Approx. Completion Date	Wafer Diameter, inch	Welding Technique
Tungsten	1,000	1200	6-70	8-70	0.745	TIG
	1,000	1200	6-70	8-70	0.745	TIG
	5,000	1200	6-70	1-71	0.745	TIG
	5,000	1200	6-70	1-71	0.745	TIG
	5,000	1200	8-70	3-71	1.490	TIG
	5,000	1200	10-70	5-71	0.745	EB
	10,000	1200	6-70	8-71	0.745	TIG
	10,000†	1200	6-70	8-71†	0.745	TIG
	10,000	1200	8-70	10-71	1.490	TIG
	10,000†	1200	8-70	10-71†	1.490	TIG
	10,000	1200	10-70	12-71	0.745	EB
	50,000	1200	6-70	2-76	0.745	TIG
Rhenium	1,000	1200	8-70	10-70	0.745	TIG
	5,000	1200	8-70	3-71	0.745	TIG
	5,000	1200	10-70	5-71	0.745	EB
	10,000	1200	8-70	10-71	0.745	TIG
	10,000†	1200	8-70	10-71†	0.745	TIG
	10,000	1200	10-70	12-71	0.745	EB
	50,000	1200	8-70	4-76	0.745	TIG
	1,000	1400	8-70	10-70	0.745	TIG
	5,000	1400	8-70	3-71	0.745	TIG
	10,000	1400	8-70	10-71	0.745	TIG
W-25 wt % Re	1,000	1200	6-70	8-70	0.745	TIG
	5,000	1200	6-70	1-71	0.745	TIG
	5,000	1200	10-70	5-71	0.745	EB
	10,000	1200	6-70	8-71	0.745	TIG
	10,000†	1200	6-70	8-71†	0.745	TIG
	10,000	1200	10-70	12-71	0.745	EB
	50,000	1200	6-70	2-76	0.745	TIG
	1,000	1400	6-70	8-70	0.745	TIG
	5,000	1400	6-70	1-71	0.745	TIG
	10,000	1400	6-70	8-71	0.745	TIG

* One capsule containing ~10 Co wafers 0.073-in.-thick and one 0.060-in.-thick spacer will be heated at each listed condition.

† Test time may be extended to 20,000 hr, or more, depending on results of other 10,000-hr tests.

TABLE III

Summary of ^{60}Co Capsule Heating Tests

Capsule Material	Heating Time, hr	Heating Temp, °C	Wall, mils	No. of Capsules	Activity Spec, Ci/g	Activity Total, Ci	Approx. Starting Date	Approx. Completion Date	Remarks
"Inconel" 600	130	850[a]	50	1	120	16,000	2-67	2-67	Swelled due to overheating
(m.p. 1370°)	1,000	∿900	50	1	100	5,000	4-67	6-67	Capsule intact
	5,000	∿900	50	1	150[b]	15,000	4-67	10-67	Capsule intact
	10,000	∿900	50	1	150[b]	15,000	4-67	6-68	Increased Co/capsule reaction
	10,000	∿900	50	1	150[b]	9,000	5-67	10-68	Increased Co/capsule reaction
	10,000	900	95	1	255[c]	36,500	2-68	8-69	Begin destructive examination 5-70
	20,000	900	95	1	288[c]	13,700	7-68	10-70	
	50,000	900	95	1	282[c]	13,400	7-68	3-74	
	5,000	1,000	95	1	295[c]	14,000	9-68	4-69	Begin destructive examination 5-70
	10,000	1,000	95	1	288[c]	13,700	9-68	11-69	Begin destructive examination 5-70
	20,000	1,000	95	1	263[c]	12,500	9-68	1-71	
	50,000	1,000	95	1	255[c]	12,100	9-68	5-74	
	10,000	850	95	1	(d)	-	9-68	11-69	Begin destructive examination 5-70
"Hastelloy" C	100	850	50	1	120	9,000	1-67	1-67	Capsule intact
(m.p. 1270°C)	10,000	900	95	1	276[c]	13,100	7-68	8-69	Begin destructive examination 5-70
	10,000	1,000	95	1	282[c]	13,400	9-68	11-69	Begin destructive examination 5-70
	50,000	1,000	95	1	270[c]	12,800	9-68	5-74	
"Haynes" 25	5,000	1,000	95	1	263[c]	12,500	9-68	4-69	Begin destructive examination 5-70
(m.p. 1330°C)	10,000	1,000	95	1	288[c]	13,700	9-68	11-69	Begin destructive examination 5-70
	20,000	1,000	95	1	282[c]	13,400	9-68	1-71	
	50,000	1,000	95	1	295[c]	14,000	9-68	5-74	
	10,000	850	95	1	(d)	-	9-68	11-69	Begin destructive examination 5-70
"Hastelloy" X	5,000	1,000	95	1	250[c]	11,900	9-68	4-69	Begin destructive examination 5-70
(m.p. 1260°C)	10,000	1,000	95	1	263[c]	12,500	9-68	11-69	Begin destructive examination 5-70
	20,000	1,000	95	1	263[c]	12,500	9-68	1-71	
	50,000	1,000	95	1	301[c]	14,300	9-68	5-74	

[a] Excursion to >1100°C for 3-6 hr.
[b] Activity as of 2-67.
[c] Activity as of 6-68.
[d] Capsule contains ^{59}Co but was heated along with ^{60}Co capsules.

Heating Tests of Capsules Containing Unirradiated Cobalt Compounds

Rhenium capsules were machined and wafers of CoO, $Co_{0.5}Mg_{0.5}O$, and $CoAl_2O_4$ were prepared for 1000- and 5000-hr tests at 1500, 1700, and 1850°C. These tests are scheduled to begin during the next quarter, Table IV.

TABLE IV

^{59}Co High Temperature Fuels Compatibility Program

Capsule Material (and Temp)	Fuel Material	Heating Time, hr	Heating Startup	Heating Terminated	Remarks
		Preliminary Tests			
"Inconel" 600 Foils of Ir, Rh, Re, Pt (1200°C)	$Co_{0.5}Mg_{0.5}O$	200	5/69	6/69	Oxide reduced by "Inconel" 600
"Inconel" 600 Foils of Ir, Rh, Re, Pt (1200°C)	$Co_{0.5}Mg_{0.5}O$	500	6/69	7/69	Oxide reduced by "Inconel" 600
Rhenium (1525°C)	CoO	200	7/69	7/69	No detectable interaction
Rhenium (1525°C)	$Co_{0.5}Mg_{0.5}O$	200	7/69	7/69	No gross interaction
Rhenium (1525°C)	$CoAl_2O_4$	200	7/69	7/69	No gross interaction
Tungsten(1620°C)	CoO	260	12/69	12/69	Reaction
Tungsten(1620°C)	$CoAl_2O_4$	260	12/69	12/69	Reaction
TZM (1620°C)	CoO	260	12/69	12/69	Reaction
TZM (1620°C)	$Co_{0.5}Mg_{0.5}O$	260	12/69	12/69	Reaction
TZM (1620°C)	$CoAl_2O_4$	260	12/69	12/69	Reaction
		1500°C Tests			
Rhenium; foils of Ir, Rh	CoO	1,000	6/70	8/70	Capsule machined
Rhenium; foils of Ir, Rh	$Co_{0.5}Mg_{0.5}O$	1,000	5/70	7/70	Capsule machined
Rhenium; foils of Ir, Rh	$CoAl_2O_4$	1,000	5/70	7/70	Capsule machined
W-25 Re	CoO	1,000	6/70	8/70	Capsule machined
W-25 Re	$Co_{0.5}Mg_{0.5}O$	1,000	6/70	8/70	Capsule machined
W-25 Re	$CoAl_2O_4$	1,000	6/70	8/70	Capsule machined
Rhenium	CoO	1,000	6/70	8/70	Capsule machined
Rhenium	$Co_{0.5}Mg_{0.5}O$	1,000	5/70	7/70	Capsule machined
Rhenium	$CoAl_2O_4$	1,000	5/70	7/70	Capsule machined
Rhenium	CoO	5,000	6/70	1/71	Capsule machined
Rhenium	$Co_{0.5}Mg_{0.5}O$	5,000	5/70	12/70	Capsule machined
Rhenium	$CoAl_2O_4$	5,000	5/70	12/70	Capsule machined
Rhenium	Best Oxide	10,000	6/70	8/71	Capsule ordered
Rhenium	Best Oxide	50,000	6/70	2/76	Capsule ordered
Iridium	CoO	1,000	10/70	12/70	Capsule machined
Iridium	$Co_{0.5}Mg_{0.5}O$	1,000	10/70	12/70	Capsule machined
Iridium	$CoAl_2O_4$	1,000	10/70	12/70	Capsule machined

TABLE IV, Continued

Capsule Material	Fuel Material	Heating Time, hr	Heating Startup	Heating Terminated	Remarks
		1700°C Tests			
Rhenium	CoO	1,000	6/70	8/70	Capsule machined
Rhenium	$Co_{0.5}Mg_{0.5}O$	1,000	5/70	7/70	Capsule machined
Rhenium	$CoAl_2O_4$	1,000	5/70	7/70	Capsule machined
Rhenium	CoO	5,000	6/70	1/71	Capsule machined
Rhenium	$Co_{0.5}Mg_{0.5}O$	5,000	5/70	12/70	Capsule machined
Rhenium	$CoAl_2O_4$	5,000	5/70	12/70	Capsule machined
Rhenium	Best Oxide	10,000	6/70	8/71	Capsule ordered
Rhenium	Best Oxide	50,000	6/70	2/76	Capsule ordered
Iridium	CoO	1,000	10/70	12/70	Capsule ordered
Iridium	$Co_{0.5}Mg_{0.5}O$	1,000	10/70	12/70	Capsule ordered
Iridium	$CoAl_2O_4$	1,000	10/70	12/70	Capsule ordered
		1850°C Tests			
Rhenium	$Co_{0.5}Mg_{0.5}O$	1,000	5/70	7/70	Capsule machined
Rhenium	$CoAl_2O_4$	1,000	5/70	7/70	Capsule machined
Rhenium	$Co_{0.5}Mg_{0.5}O$	5,000	5/70	12/70	Capsule machined
Rhenium	$CoAl_2O_4$	5,000	5/70	12/70	Capsule machined
Rhenium	Best Oxide	10,000	6/70	8/71	Capsule ordered
Rhenium	Best Oxide	50,000	6/70	2/76	Capsule ordered
Iridium	$Co_{0.5}Mg_{0.5}O$	1,000	10/70	12/70	Capsule ordered
Iridium	$CoAl_2O_4$	1,000	10/70	12/70	Capsule ordered

HIGH TEMPERATURE FUEL FORMS

Fabrication of CoO Wafers

The pressing and sintering process was improved to eliminate cracking and to provide higher densities in CoO wafers. Sintering for 12 hr in argon at 1400°C resulted in sound wafers at 90% of theoretical density, whereas the earlier method of sintering in air at 1700°C produced cracked wafers at less than 85% of theoretical density. The cracking is believed to have been caused by Co_3O_4 formation during heating and cooling. Because of the lower sintering temperature, the wafers have a smaller grain size. Because no Co_3O_4 is formed, they are ready for final shaping.

Compatibility of Cobalt Compounds

Neither tungsten nor TZM* alloy will be suitable for containment of cobalt oxides, based on metallographic examination of capsules exposed for 260 hr at 1620°C. Extensive reaction was observed in all capsules, with the following order of increasing interaction: TZM-CoO; TZM-$Co_{0.5}Mg_{0.5}O$, W-$CoAl_2O_4$; TZM-$CoAl_2O_4$; W-CoO. Electron probe microanalysis will be performed on the polished samples to obtain numerical data to substantiate the above conclusions.

Electron probe microanalysis was used to confirm the conclusion reported in DP-1216 of no gross interaction between rhenium capsules and CoO, $Co_{0.5}Mg_{0.5}O$, or $CoAl_2O_4$ wafers exposed for 200 hr at 1525°C. The metallic particles observed within the capsule consisted of rhenium mechanically introduced during sectioning of the capsule. No rhenium was observed to have diffused into the oxide wafers and no cobalt could be detected within the rhenium.

* Product of Climax Molybdenum Co.

HEAT SOURCE DEMONSTRATION TESTS

WANL 30 kw(t) Unit

SRL is providing technical assistance in the program to design, fabricate, and test an experimental heat source containing 30 kw (t) of ^{60}Co. Westinghouse Astronuclear Laboratory (WANL) is in the detailed design phase of this program. This phase is scheduled to be completed in September.

The concept selected for detailed design in phase II consists of (1) a nickel core containing twelve ^{60}Co fuel pins and passages for flow of a gas coolant, (2) sodium heat pipes for emergency cooling, and (3) a steel biological shield. The fuel pins can be charged and discharged in the field by a refueling cask. This design was selected because of its high outlet temperature, its versatility for coupling to power conversion systems, its scalability to larger sizes, and its low cost and state-of-art materials.

Radiation streaming tests with a steel shield block at SRL confirmed that a single bend in each coolant inlet or outlet pipe would be adequate to prevent excessive radiation fields outside the biological shield. Figure 1 shows the dose rates obtained at three locations with thermo-luminescent dosimeters (TLD). Other TLD's were positioned in or near other ducts in the shield. Analysis of the measurements and comparison to calculated values is being made by WANL. Calibration of the ^{60}Co source used in these measurements showed that it contains about 0.051 curie.

Final selection of materials for the inner and outer fuel capsules will be based on examination of the ^{60}Co capsules heated for 10,000 hr at 1000°C and on results of oxidation and compatibility tests at possible emergency temperatures to be started during the next quarter.

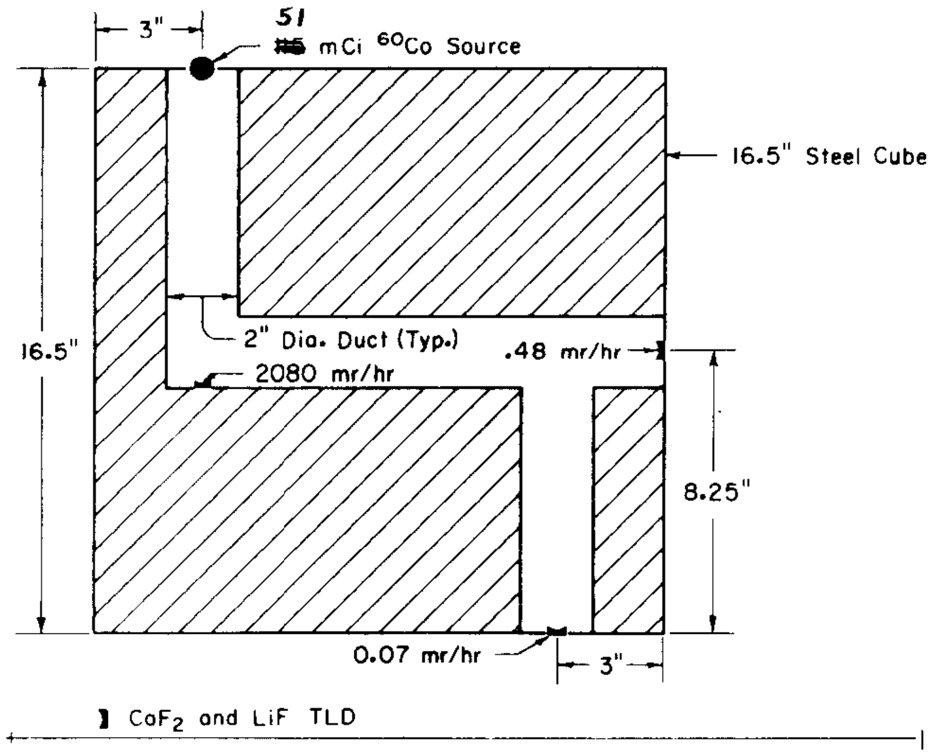

FIGURE 1

SHIELD BLOCK FOR ^{60}Co GAMMA STREAMING TEST

SRL 3 kw(t) Unit

The biological shield cask was ordered for a demonstration of ^{60}Co heat source feasibility at SRL. The power conversion device, a tubular thermoelectric module, was removed from its test stand at WANL and prepared for shipment to SRL. Capsule components were fabricated and welding parameters were established using electrical heaters to duplicate heat generation by the ^{60}Co.

Capsules are scheduled to be fabricated during the next quarter, and assembly of the entire test unit is scheduled for the following quarter.

^{60}Co LOAN PROGRAM

SRL is providing technical liaison for the AEC's loan program for high activity cobalt, established in January. This program makes available significant quantities of radioactive cobalt metal at 200 - 450 Ci/g for research and development on possible thermal applications.

The ^{60}Co that will be available for loan under this program is listed in Table V.

Further information may be obtained from:

N. J. Donahue
Savannah River Operations Office
U. S. Atomic Energy Commission
Aiken, South Carolina 29801

TABLE V

Savannah River High Activity ^{60}Co for Heat Source Development

Cobalt Shape: Diameter, in.	Cobalt Shape: Thickness, in.	No. of Pieces	Wt. of Cobalt, g/piece	Average Specific Activity, Ci/gCo	Total Activity, MCi	Total Power, kw(t)	Date Available (Activity calculated as of this date)
Wafers, Ni-plated							
0.745	0.040	2090	2.5	270	1.41	22.0	6-70
		3800[a]	2.5	220	2.09	32.5	6-70
0.745	0.057	112	3.5	450	0.18	2.8	6-70
0.745	0.073	3240	4.5	450	6.56	102.1	6-70
		2660	4.5	450	5.38	83.8	3-71[c]
		1700	4.5	250	1.91	29.7	6-70
		4560	4.5	200	4.10	63.8	3-71
0.800	0.040	391[b]	2.8	250	0.27	4.3	6-70
Half wafers, Ni-plated							
1.00	0.073	682	4.1	450	1.26	19.6	3-71[c]
1.25	0.073	434	6.4	450	1.26	19.6	3-71[c]
1.49	0.073	620	9.1	450	2.52	39.2	3-71[c]
Slabs							
3.00 x 0.64 x 0.060" Ni-plated		93	16.6	250	0.39	6.0	6-70
2.96 x 0.735 x 0.092" SST-canned		93	13.5	240	0.30	4.7	6-70
3.00 x 0.740 x 0.072" SST-bonded		124	11.8	250	0.37	5.7	6-70

a. 152 wafers have central hole 0.070-in. diameter.
b. 68 wafers have central hole 0.070-in. diameter.
c. <450 Ci/g can be provided if required, by early removal from reactor.

SAVANNAH RIVER LABORATORY ^{60}Co PUBLICATIONS

QUARTERLY PROGRESS REPORTS

"Savannah River Laboratory Isotopic Power and Heat Sources Quarterly Progress Report

DP-1088	July - September 1966
DP-1094	October - December 1966
DP-1105-I	January - March 1967, Part I - Cobalt
DP-1120-I	April - June 1967, Part I - Cobalt
DP-1129-I	July - September 1967, Part I - Cobalt
DP-1143-I	October - December 1967, Part I - Cobalt
DP-1155-I	January - March 1968, Part I - Cobalt
DP-1169-I	April - June 1968, Part I - Cobalt
DP-1177-I	July - September 1968, Part I - Cobalt
DP-1192-I	October - December 1968, Part I - Cobalt
DP-1196-I	January - March 1969, Part I - Cobalt
DP-1206-I	April - June 1969, Part I - Cobalt
DP-1216	July - September 1969
DP-1226	October - December 1969

TOPICAL REPORTS

DP-974 "^{60}Co Heat Sources for 10-60 kw(e) Generators" by A. H. Dexter, July 1965.

DP-1012 "Radioactive Cobalt for Heat Sources" by J. W. Joseph, H. F. Allen, C. L. Angerman, and A. H. Dexter, October 1965.

DP-1051 (Rev. 2) "Properties of ^{60}Co and Cobalt Metal Fuel Forms", June 1968.

DP-1096 "Development of ^{60}Co Capsules for Heat Sources" by C. P. Ross, C. L. Angerman, and F. D. R. King, June 1967.

DP-1145 "Experimental ^{60}Co Heat Source Capsules" by J. P. Faraci, May 1968.

JOURNAL ARTICLES

A. H. Dexter, W. R. Cornman, and E. J. Hennelly. "The Advantages of ^{60}Co for Heat and Radiation Sources", *Nucl. Appl. 2(2)*, 99-101 (1966).

C. P. Ross. "Cobalt-60 for Power Sources", *Isotopes and Radiation Technology, 5(3)*, 185-94 (1968).

C. L. Angerman, F. D. R. King, J. P. Faraci, and A. E. Symonds. "^{60}Co Heat Source Encapsulation", *Nucl. Appl. 4(2)*, 88-95 (1968).

C. L. Angerman and J. P. Faraci. "Heating Tests of Encapsulated Cobalt Heat Sources", *Nuclear Metallurgy, Vol. 14, Symposium on Materials for Radio-Isotope Heat Sources,* D. E. Thomas, W. O. Harms, and R. T. Huntoon (Editors), American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, New York, pages 309-22 (1969).

J. A. Donovan and W. R. McDonell. "Cobalt-Rhenium Alloys for High Temperature ^{60}Co Heat Sources", *Trans. Amer. Nucl. Soc. 12(2)*,480-1 (1969).