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DPSPU 64-30-16

Conf-640534--1

COBALT-60 PRODUCTION AT SAVANNAH RIVER

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FEB 09 1995
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For presentation at Process Radiation Meeting sponsored by Washington Section of the American Nuclear Society, Washington, D. C., May 13, 1964.

Publisher is requested to include this acknowledgment.

The information contained in this article was developed during the course of work under Contract AT(07-2)-1 with the U. S. Atomic Energy Commission.

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Cobalt-60 Production at Savannah River

Over the past 8 or 9 years, the Savannah River Plant (SRP) has produced close to 4 million curies of cobalt-60 by irradiating cobalt-59 in the production reactors. This paper reviews past and current irradiations, cobalt-60 production methods, and costs.

Past Production

Completed (or soon to be completed) SRP cobalt irradiations are summarized in table 1. The largest irradiation was 1.3 million curies for the Food Process Development Irradiator at Natick, Massachusetts. The next largest was almost one million curies just completed for Brookhaven National Laboratory. The various cobalt shapes were arranged in 0.94-inch-diameter slugs of various lengths.

Table 1. Completed Cobalt Irradiations

	Activity			
Date	Total, curies	Specific, c/g	Shape	Purpose
1955-63	975,700	27-83	Wafers	ORNL — therapeutic; Japanese — experimental
1958-64	1,256,900	15-100	Slabs	BNL; MPDI; SRL; Curtiss-Wright
1959-60	150,000	99-120	Pellets	ORNL — radiography
1961-62	1,448,000	6-17	Rods	FPDI; USBM
	3,830,600			

Current Production

As shown in table 2, we have just started production of some 465,000 curies of cobalt, over two-thirds of which is expected to reach 400 to 500 curies per gram.

In conjunction with the irradiation of about 60 grams of plutonium-242 for Oak Ridge, another 290,000 curies will be produced with specific activities from 150 to 400 curies per gram. The slugs being used for this production are identical with those being used for the higher specific activity production. These slugs are being irradiated in areas of large flux gradient and thus will have a greater than normal range of activity in each slug. The range will depend on both the flux gradient and the length of the slug.

Table 2. Cobalt Irradiations in Progress

Activity			
Total, curies	Specific, c/g	Shape	Purpose
240,000	400-500	Pellets	DID — develop uses for high specific activity cobalt
75,000	400-500	Wafers	
150,000	300	Slabs	
465,000			
52,000	150-300	Pellets	Flux control for transuranium irradiation
125,000	275-400	Wafers	
113,000	175-275	Slabs	
290,000			

Future Production

As shown in table 3, we expect to start production of about 900,000 curies of cobalt-60 in the next fiscal year for replenishing or augmenting USBM, BNL, and Japanese sources.

Table 3. Expected Cobalt Irradiations — Next Fiscal Year

Activity			
Total, curies	Specific, c/g	Shape	Purpose
20,000	15-20	Rods	USBM
700,000	150	Slabs	BNL
175,000	30	Wafers	ORNL; Japanese
895,000			

Slug Designs

Cobalt has been irradiated in a variety of shapes and sizes in 0.94-inch-diameter aluminum cans (slugs), as shown in figures 1 through 4. Slugs have been specially designed for each cobalt irradiation, but it is hoped that many of the future irradiations can use existing designs to reduce design and development costs.

Some of the design criteria are as follows:

Materials. Reactor-grade cobalt, type 1245 aluminum, and type 304 stainless steel are used.

Cobalt Protection. Nickel plating or stainless steel cladding is used to reduce corrosion and contamination during postirradiation handling. Stainless steel cladding also eliminates the need for postirradiation encapsulation.

Canning. Slugs are double-canned, using two aluminum cans or one aluminum can over stainless steel cladding. Both cans are welded and tested for leaks.

Gaps. Metal-to-metal gaps are minimized, to avoid high cobalt temperatures during irradiation. A typical specification is a cumulative gap of 2 mils from the center of the slug to the surface.

Density. The optimum amount of cobalt within a slug depends on the shape of the pieces and the reactor neutron flux parameters. Enough cobalt is added to avoid excessive flux peaking or depression.

Fabrication and handling costs could probably be reduced for slab designs by irradiating larger pieces up to a limit of about 3 inches wide. Although the larger size would benefit only slabs, other shapes could also be accommodated, as shown in conceptual designs in figure 5. A test irradiation in a 3-inch-diameter configuration is planned, to confirm production calculations.

Cobalt Production Technology

Cobalt-60 is formed according to the following equation:

$$\frac{N_{60}}{N_{59}} = \frac{\alpha e^{-\alpha t}}{\beta} (1 - e^{-\beta t})$$

where: $\alpha = \Phi\sigma_{59}$

$\beta = \lambda_{60} + \Phi\sigma_{60} - \Phi\sigma_{59}$

N_{60} = number of atoms of cobalt-60 per cm^3 at time t

N_{59} = initial number of atoms per cm^3 of cobalt-59

Φ = neutron flux in the cobalt per cm^2-sec

σ_{59} = effective cobalt-59 cross section in cm^2

σ_{60} = effective cobalt-60 cross section in cm^2

λ_{60} = cobalt-60 decay constant in sec^{-1}

t = time in seconds

In figure 6, solutions to this equation are plotted, for several values of neutron flux, as curies of cobalt-60 per gram of initial cobalt-59 versus time. Burnup and decay of cobalt-60 prevent its ever reaching the theoretical activity of 1130 c/g for pure cobalt-60.

The cross section of cobalt-59 is well known; hence, to predict the production for a particular irradiation the only problem is to predict the neutron flux in the cobalt. As shown in figure 7, the flux in the cobalt is a function of (1) the amount of cobalt per unit slug volume, and (2) the neutron flux in the fuel surrounding the cobalt. The cobalt flux is shown in figure 7 as a ratio to the flux in the fuel, and the amount of cobalt per unit volume is shown as a unit called blackness index. As shown in figure 8, the blackness index varies with the amount and the configuration of the cobalt.

Cobalt production is usually incidental to the production of other materials; hence, the standard tolerance on an irradiation is ±20% of the activity requested, in addition to a ±5% variation from piece to piece. Production has usually been well within this tolerance.

Plant Capacity

Capacity varies with the number of available reactor positions and with the neutron flux. The flux is a function of the method of loading; in current reactor loadings, up to 8 million curies can be produced per reactor-year as incidental production in standard 0.94-inch-diameter slugs, or about 7 million curies per reactor-year can be produced in a configuration that would fit within a 3-inch-diameter housing. If a reactor charge were designed to produce only cobalt, many tens of million curies per reactor-year could be produced in configurations with a maximum width of 3 inches, in addition to about 8 million curies that could be produced (under current operating conditions) in 0.94-inch slugs.

Cost

The over-all cost of a cobalt-60 source includes costs for slug fabrication, irradiation, shipping, re-encapsulation after irradiation, and sales. Each of these costs has variables that prevent setting one fixed cost for cobalt. Only the slug fabrication and irradiation costs will be discussed here.

Slug fabrication costs are a function of the shape and size of the cobalt pieces, the slug design, and the number of slugs. For example, it costs more to work with 1-mm-diameter by 1-mm-long pellets than 2-cm-diameter wafers. And it costs more per slug to make one slug than a large number of slugs. Some typical slug costs are shown in table 4.

$\frac{100 \times 10^4 \, c}{650/w} = 1.54 \times 10^4 w$ / 15,400 w/Mc

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Table 4. Cobalt Fabrication Costs

			Activity		Cost	
Cobalt Shape	Cobalt Size	Fabricator	Total, curies	Specific, c/g	$ per Slug	$ per Curie
Wafers	1 cm X 1 mm	Du Pont	150,000	27	72	0.005
Pellets	1/16" X 1/16"	Du Pont	150,000	100	216	0.014
Slabs	0.640" X 0.060" X 12"	BNL	977,000	100	200	0.009
Bars	0.725" X 10.25"	Curtiss-Wright	1,348,000	6	163	0.05

Cobalt irradiation costs at SRP are assigned on the basis of neutron usage; therefore, because of decay and burnup of cobalt-60, the unit cost per curie varies with the irradiation schedule. The base irradiation cost for cobalt-60 is less than the lowest AEC price of $0.50 per curie. This base cost includes handling, irradiation, overhead, and depreciation charges connected with operating the reactors. The cost would be increased no more than about 20% because of decay and burnup effects in reaching high specific activities.

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Conclusion

The Savannah River reactors are capable of producing large quantities of inexpensive, high-activity cobalt-60. Considerable latitude is possible in specifying the size and shape of cobalt pieces and their specific activity. The Savannah River Plant is set up to produce cobalt-60 in large quantities; small amounts (normally less than 100,000 curies) have to be obtained elsewhere.

Cobalt-60 orders for the Savannah River Plant are placed through the AEC Division of Isotope Development, Washington, D. C. Inquiries about specifications or schedules may be addressed directly to the AEC Savannah River Operations Office, Aiken, S. C.

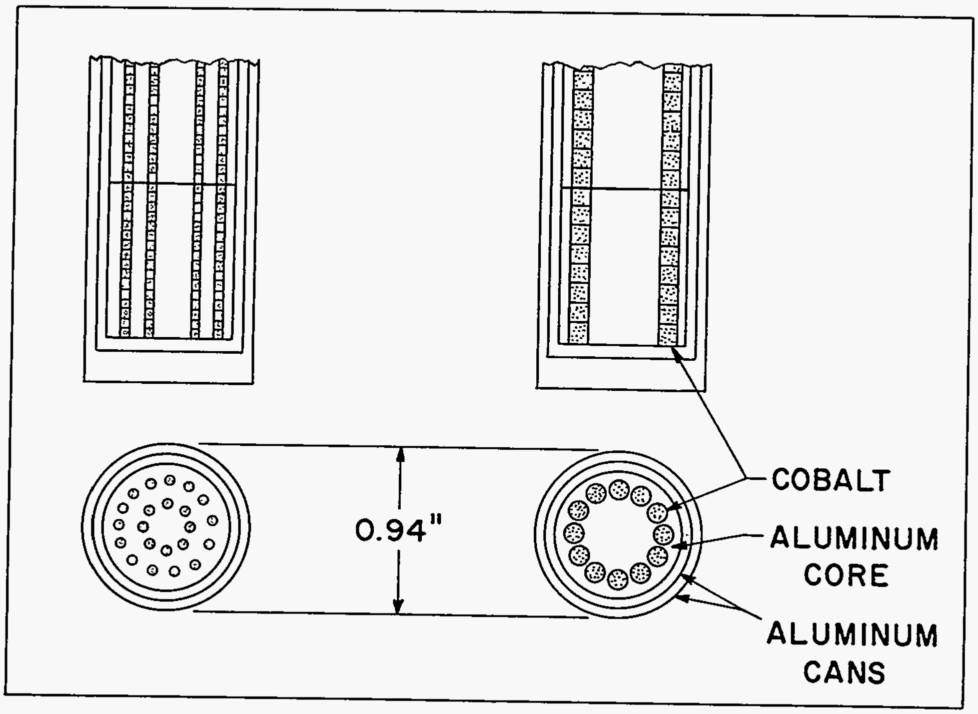

FIGURE 1. PELLET SLUG DESIGNS

Pellet Sizes Irradiated

Size	Density, g/inch
1 mm × 1 mm	12
1/16" × 1/16"	12-48
1/8" × 1/8"	48
1/8" × 1/4"	48

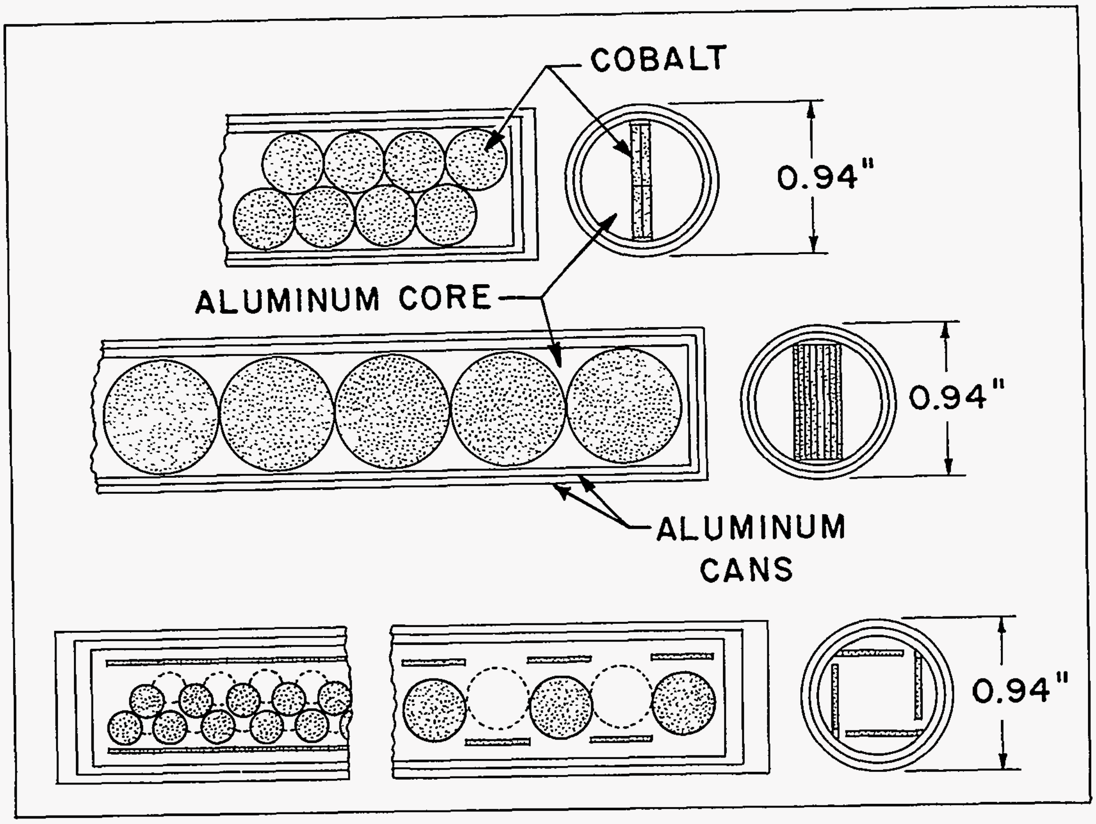

FIGURE 2. WAFER SLUG DESIGNS

Wafer Sizes Irradiated

Size	Density, g/inch
1/2 cm × 1 mm	12
1 cm × 1 mm	12
1 cm × 2 mm	12-48
2 cm × 1 mm	12-48
0.750" × 0.036"	48

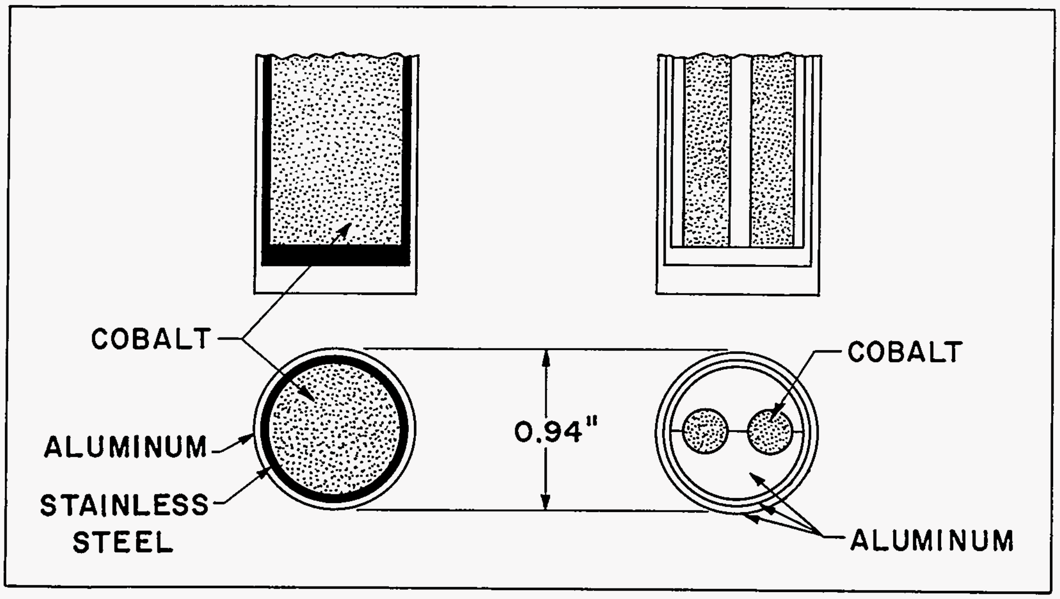

FIGURE 3. ROD SLUG DESIGNS

Rod Sizes Irradiated

Size	Density, g/inch
0.725" × 4.375"	60
0.725" × 10.25"	60

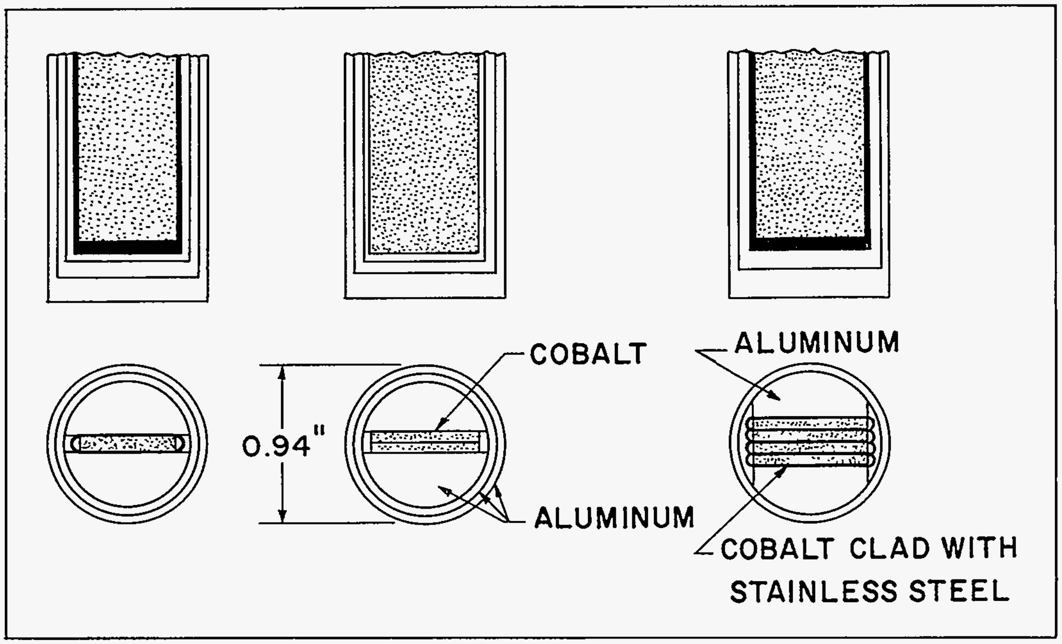

FIGURE 4. SLAB SLUG DESIGNS

Slab Sizes Irradiated

Size, inches			
Width	Thickness	Length	Density, g/inch
0.745	0.033	9.9	28
0.745	0.059	9.9	28
0.745	0.063	9.9	28
0.745	0.260	9.9	28
0.760	0.130	10	14
0.640	0.060	12	5.7-23
0.640	0.060	11	5.7-23

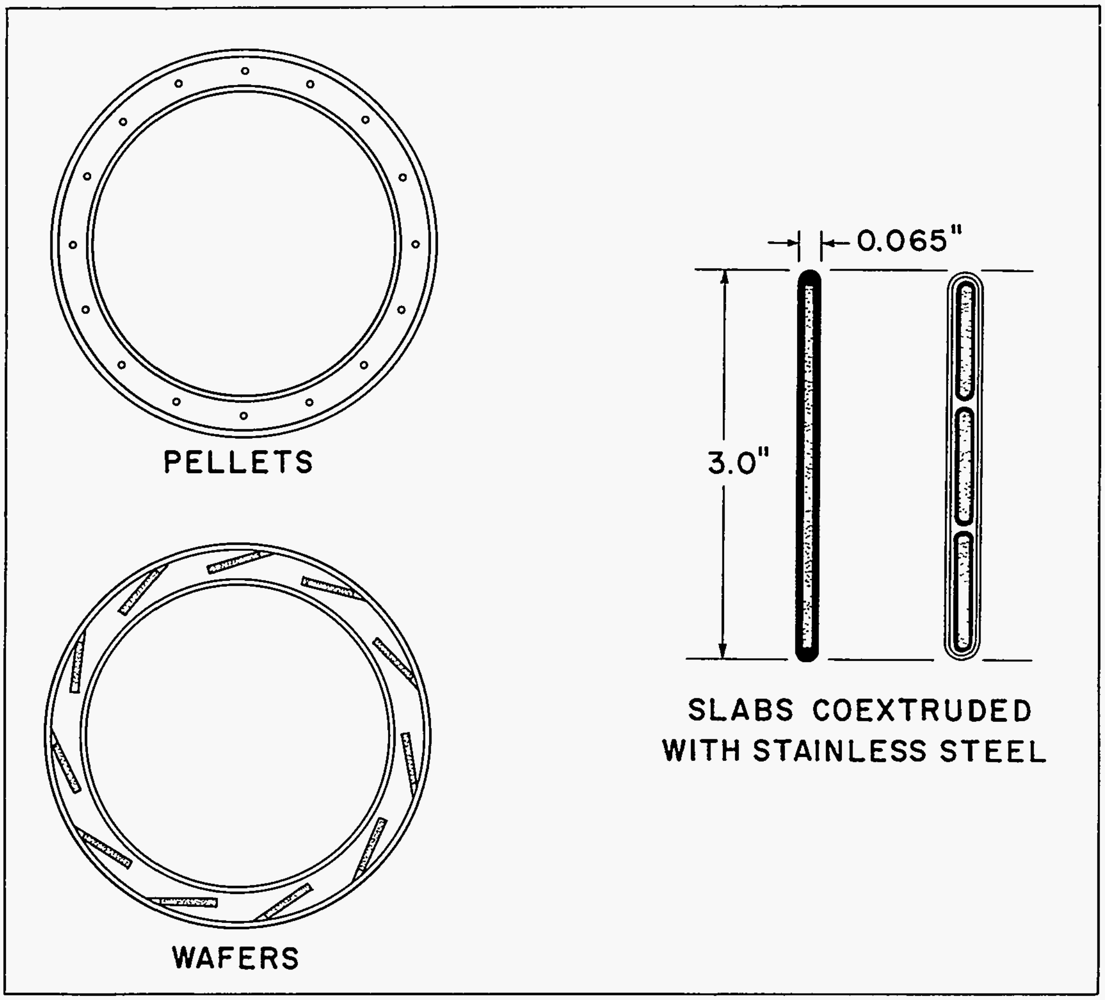

FIGURE 5. CONCEPTUAL THREE-INCH SLUG DESIGNS

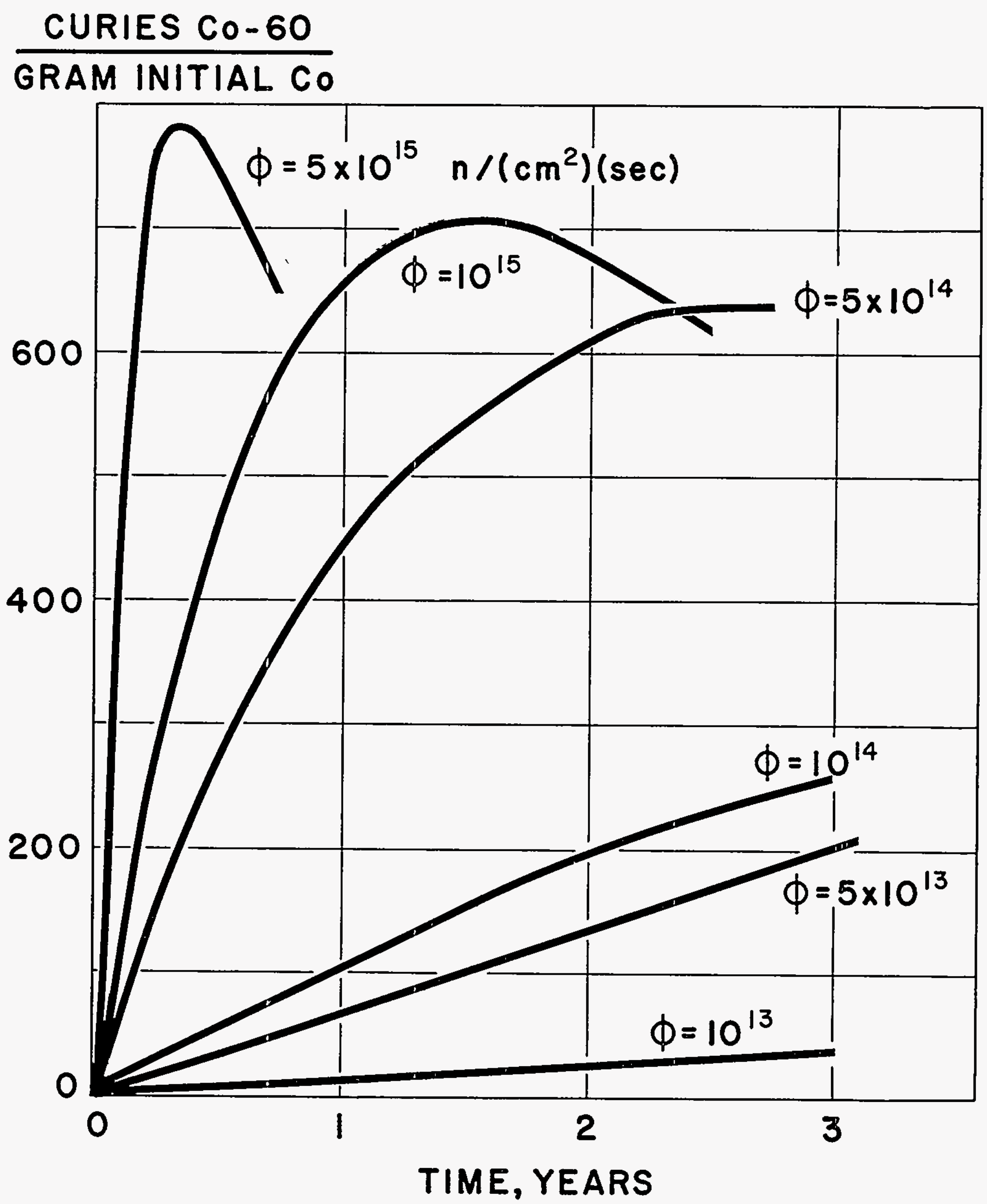

FIGURE 6. COBALT-60 PRODUCTION

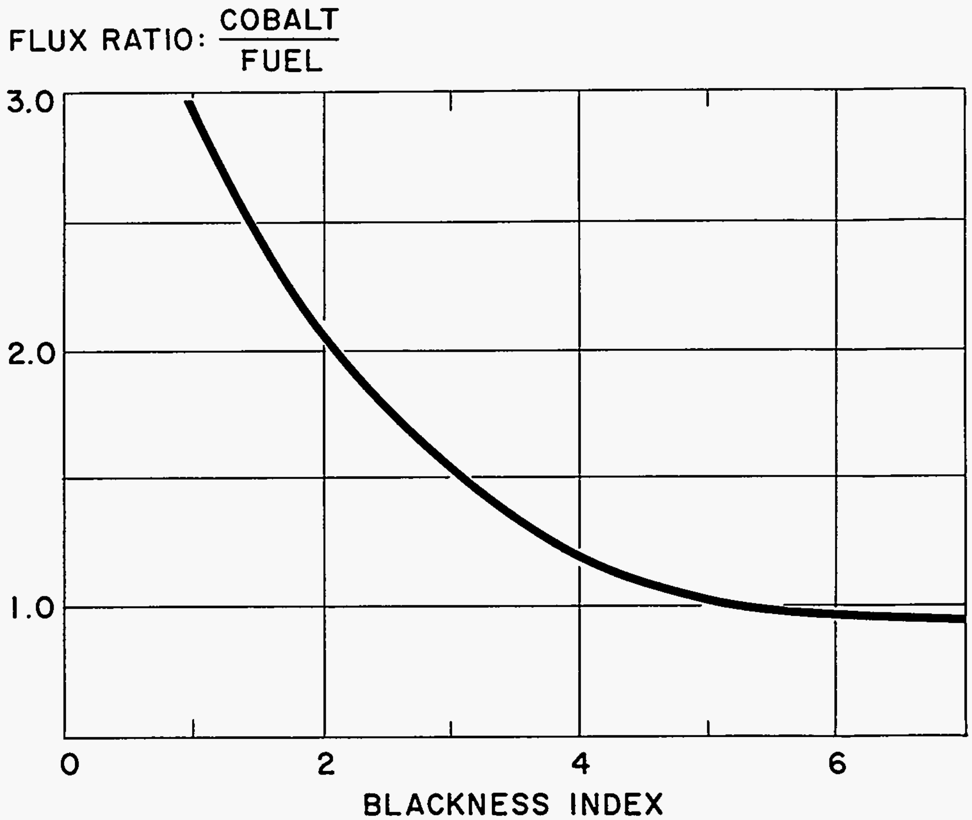

FIGURE 7. COBALT-TO-FUEL FLUX RATIOS

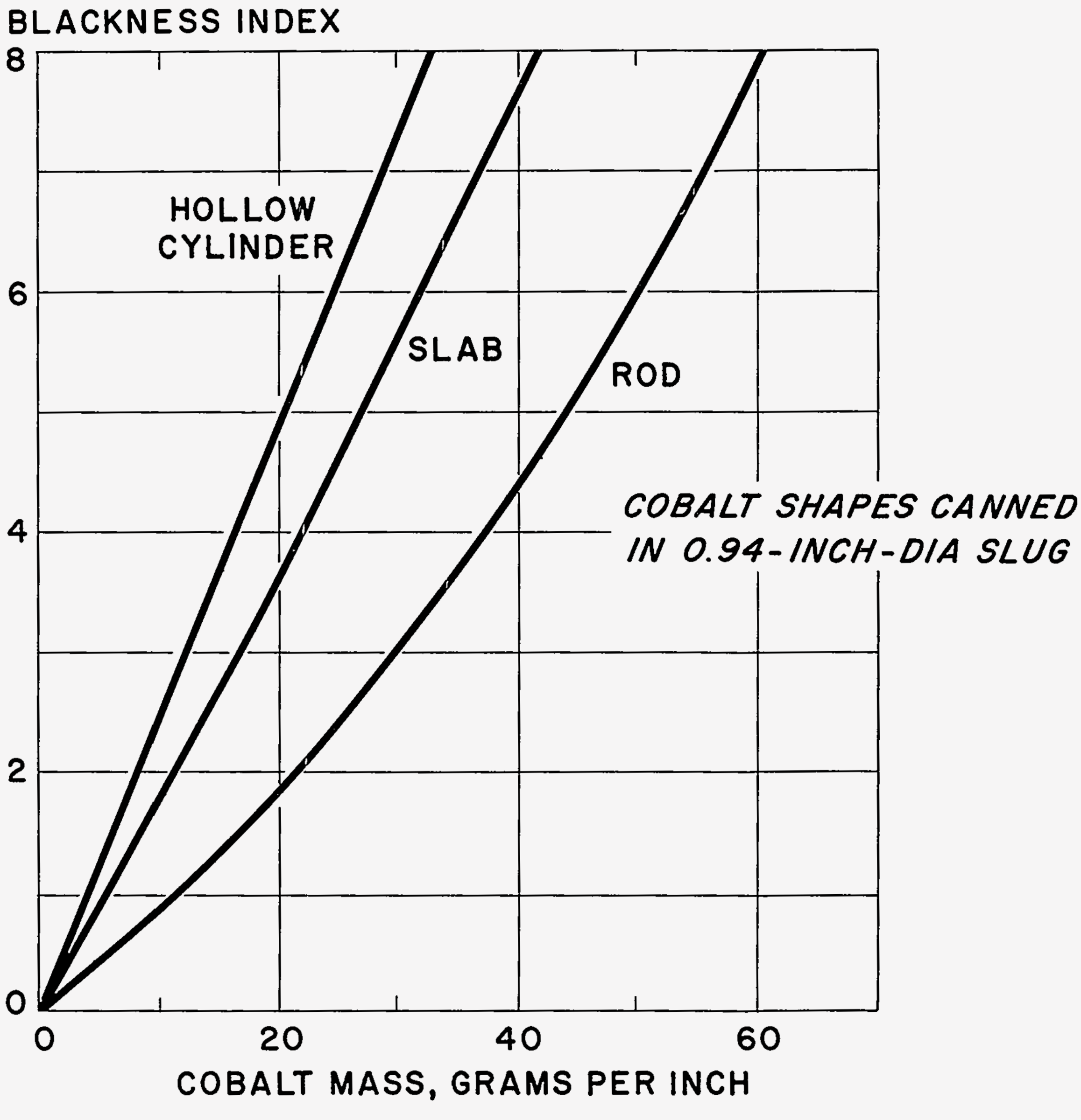

FIGURE 8. COBALT BLACKNESS VERSUS COBALT MASS