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KILOCURIE COBALT-60 SOURCE

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CASTING OF A URANIUM SHIELD FOR A KILOCURIE COBALT-60 SOURCE

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R. J. Dunworth and R. E. Macherey

A large radiation shield of uranium for a kilocurie Co-60 source was required for use in the Argonne Cancer Research Hospital. A revolving source, radiation therapy unit was designed that depended on the use of uranium as a shield instead of lead. According to Lanzl,* a lead shield with an equal Co-60 gamma-ray attenuation would weigh almost four times as much. The finished shield weighed over 400 kilograms and contained 361 kilograms of uranium. A similar shield constructed from lead would weigh over 1500 kilograms. Since the source and shield were expected to revolve around the patient, the engineering problems and costs imposed by the excess of weight in a lead shield are evident.

The uranium shield was built from twelve sound and dense castings. The total weight of castings (including risers) was over 1000 kilograms before machining. The castings had to be machined accurately, since all parts were to fit very closely. Any "chinks" in the shield would allow gamma radiation to escape.

Previous foundry experience with uranium had shown that sound, dense castings would be obtained if the regular foundry practices were followed. These former castings were generally less than 100 kilograms in weight and were limited to rather simple shapes for extrusion or rolling billets. The castings made for this Co-60 shield represented the first heavy castings of a complicated shape whose size, surface smoothness, and density had to be controlled.

Melting Equipment

In the uranium foundry, the metal is melted by induction heating in large vacuum furnaces. The molds and crucibles are machined from graphite to the required size. Heating is supplied by a motor-generator set to an induction heating coil.

A Micarta tube furnace, shown schematically in Figure 1, was used for these large shield castings. The tube was 42 inches high, 26.5 inches in outside diameter, and 24.75 inches in inside diameter. The base and top

*L. H. Lanzl, D. D. Davidson, and W. J. Raine, "Kilocurie Revolving Cobalt-60 Unit for Radiation Therapy," The American Journal of Roentgenology, Radium Therapy and Nuclear Medicine, Vol. LXXIV, No. 5 (November 1955).

Figure 1

No. 3 Micarta Tube Furnace Drawing
(one-fourth size)

cover plate, which were made from mild steel, were water cooled through the annuli shown in the figure. To provide vacuum seals, both the base and the cover plate were provided with flat, restrained, neoprene gaskets. Since a force of over 7000 pounds is exerted on the cover plate, a 1/4-inch-thick gasket extruded rapidly out of the groove, but a 1/16-inch-thick gasket was found to be satisfactory. Additional vacuum seals were provided for various pipes, rods, and covers by neoprene gaskets. Both water and power to the induction coil were supplied by the same connection, as shown in the figure. The induction coil helped to support the rammed zircon insulation. A 50-kw, 3000-cycle motor-generator set supplied power to the induction coil.

A view of the Micarta tube furnace on the pouring balcony is shown in Figure 2. Since fumes and dust are frequently expelled when the furnace is opened, an exhaust hood was provided around the cover plate. A small cover plate, which was sealed to the large cover plate, contained the Vycor observation port and the seal for the stopper rod extension. The small plate is located manually after the furnace is loaded and the large plate has been lowered by means of a hoist onto the Micarta tube. The water-cooling hoses for both plates are shown in the picture.

Figure 2
Micarta Tube Furnace
on Balcony

The extension tube at the bottom of the furnace and the pumping system are shown in Figure 3. Various sizes of extension tubes were built to accommodate different molds. These tubes were also sealed by flat, restrained, neoprene gaskets. A three-inch vacuum pipe line connected the furnace bottom with a 100-cfm mechanical roughing pump. The pump oil reservoir was heated electrically to remove volatile impurities from the oil. A dust filter was installed in the line to protect the pump. The joints in the vacuum line were made to reduce the transmission of pump vibration to the furnace. Just below the flexible line a three-inch syphon bellows vacuum valve was located.

Figure 3
Micarta Tube Furnace
below Balcony

The molds, crucibles, and stopper rods were machined from "CS" grade (National Carbon) graphite. This graphite has the finest grain size and greatest density in the blank size required for these crucibles. This combination of grain size and density results in a high-strength graphite. In addition, the graphite has a very low ash content (0.25%) and so contributes no impurities to the casting. The crucibles were made in two sizes: #13 was 13 inches OD, 11 inches ID, 20 inches high, and the base was 1.5 inches thick; #14 was 14 inches OD, 11 inches ID, 26 inches high, and the base was 2 inches thick. The smaller crucible was used for the lighter castings, as shown in Table I. The larger molds were also constructed with a 2-inch thick bottom and 1.5-inch-thick walls, since the molds usually were required to hold the molten metal at a greater hydraulic pressure than the crucibles. The reason for using crucibles with a 1.5-inch-thick wall was not the height of molten metal in the crucibles, but the lack of strength in larger size blanks. Table II shows the variation of particle size, density, and porosity of graphite grade with the size of blank. Small crucibles (9 inches OD, 7 inches ID, and 15 inches high) with only a one-inch-thick wall frequently hold a greater hydraulic pressure than the large crucibles because they can be made from stronger graphite blanks. In addition, a careful examination of the machined surfaces is required to find cracks that have been uncovered. After several crucibles broke in the furnace from undetermined causes, the wall thickness was increased and the finished crucibles were examined more closely.

Table I

DATA FOR URANIUM SHIELD CASTINGS

Casting No.	Date	Dimensions (inches)	Weight (kg)	Pouring Temp, °C	Remarks
784	9/8/52	6 dia.	45	1400	Casting had a ledge on one side and a 2-in. diameter graphite core (see Figs. 4 and 5). No mold wash.
787	9/16/52	3 x 4 x 15 ht.	50	1400	Casting shown in Figs. 8 and 9.
788	9/17/52	3 x 3 x 20 ht.	49	1200	See Fig. 7, 3/8-in. pouring hole.
792	9/29/52	7.5 dia. x 7.5 ht.	94	1330	3-in. riser included in the height.
813	11/12/52	Irreg., similar to Fig. 10	152	1300	No mold wash, poor surface, deep cold shuts, and splash defects. Casting scrapped.
820	12/1/52	Irreg., similar to Fig. 10	no casting	1540	Crucible #14. 3/4-in. pouring hole. Crucible broke; no casting; relined the furnace.
824	12/23/52	Irreg., shown in Fig. 10	146	1403	Crucible #13. 3/4-in. pouring hole, 33 seconds to pour; excellent surface with no defects.
826	12/30/52	Irreg., similar to Fig. 11	295	1420	Crucible #14. 3/4-in. pouring hole, 105 seconds to pour. Surface poor. Some cold shuts and splash defects. Casting scrapped.
828	1/6/53	6 1/8 dia. x 15 ht	128	1512	Poured too hot, metal reacted with the mold through the wash. 3/4-in. pouring hole, 21 seconds to pour.
835	1/22/53	11.5 dia. x 10 ht.	264	-	3 5/16-in. diameter graphite core. 3/4-in. pouring hole. 1 1/2-in. thick mold walls cracked after pouring; casting scrapped.
836	1/26/53	Irreg., shown in Fig. 11	296	1470	Crucible #14. Very good surface, large blowholes in the top 2 in. of the riser.
840	2/26/53	11.5 dia. x 8 1/8 ht.	216	1410	3 5/16-in. graphite core; excellent surface. 1.5-in. mold walls; offset 3/4-in. pouring hole, 44 seconds to pour.
856	5/1/53	10 7/8 dia. x 9 7/8 ht.	293	1400	Crucible #14 with 3/4-in. pouring hole, 35 seconds to pour; 1.5-in. mold walls.
858	5/11/53	11.75 dia. x 8.75 ht.	293	1405	Crucible #14. 3/4-in. pouring hole, 37 seconds to pour. 1-in. mold walls. Casting scrapped.
881	7/10/53	11.75 dia. x 8 7/8 ht.	296	1490	Crucible #14; good surface.

Crucible No. 14 is 14 in. OD., 11 in. ID., 26 in. high, 2 in. thick base.

Crucible No. 13 is 13 in. OD., 11 in. ID., 20 in. high, 1.5 in. thick base.

The molds were sprayed with MgO-MgSO₄ wash except 784 and 813.

No wash on crucibles

The castings were made in the No. 3 Micarta tube furnace except 788.

Table II

PROPERTIES OF TWO GRADES OF GRAPHITE*

Grade	Size (in.)	Maximum Particle Size (in.)	Density (gm/cc)	Ash (%)	Porosity (%)
CS	1 - 2 in dia.	0.016	1.68	0.25	25
CS	3 - 18 in dia.	0.032	1.67	0.25	25
AUC	0.25 - 1	0.006	1.68	0.02	20
AUC	1 - 8	0.016	1.68	0.02	20
AUC	9 - 16	0.032	1.65	0.02	20

*Data from National Carbon Co. for reactor-grade graphite.

Casting Practice

The general casting practice for the twelve castings listed in Table I was about the same. The crucible was put directly on the top of the mold without any separation by an air gap or insulating bricks. This arrangement produced a good thermal gradient in the mold and generally produced castings free of blow holes. The bottom of the mold was usually separated from the water-cooled base plate by two or four inches of insulating brick. The thermal gradient and temperature in the mold were varied by changing the position of the mold in the induction coil. Some variation in pouring rate was obtained by changing the diameter of the pouring hole.

Two castings were to be cast to size without machining, and so it was necessary to experiment with mold washes to produce a smooth surface and determine the mold shrinkage of uranium. The foundry practice which used uncoated crucibles and unwashed molds produced castings of high carbon content and rough surfaces. A rough surface was particularly undesirable in these castings. Consequently, the simple rectangular and round parts were cast first and various mold washes were tried. These parts required complete machining, which made a smooth surface unnecessary. The surface obtained by casting in an unwashed mold is shown in Figure 4. Many cold shuts and small surface blow holes typify this mold condition. Many small blow holes are also evident on the top view of the same casting, shown in Figure 5. This porosity could be caused by the hot metal releasing some residual pitch in the mold surface. The cold shut defects can be reduced by pouring at a higher temperature in a hotter mold, but then the hot metal and mold react, again producing a surface defect. If the wash is brushed on the mold, the casting parts from the mold easily, but the surface is still rough. The brush marks are plainly visible, as shown in Figures 6 and 7, and surface flakes and cracks appear. In general, the wash applied with a brush is too heavy, and it cracks or flakes into the casting.

Macro 13194

5/6X

Figure 4. Side View of the 6-in Diameter Cored Casting 784 No mold wash.

Macro 13193

5/6X

Figure 5 Top View of Casting 784, Showing Pinhole Porosity

Macro 13192

1.2X

Figure 6. Casting 788, 3 x 3 x 20-in. Brush marks, surface flakes and cracks caused by a heavy mold wash brushed on.

Macro 13190

1.2X

Figure 7. Brush marks, surface flakes, and cracks caused by a heavy mold wash brushed on.

When the wash was sprayed on the mold in a thin coating, the best cast surface was obtained. The cast surface was mostly smooth, except where the wash was sprayed too heavily. This defect is shown in Figures 8 and 9. The two heaviest and most intricate castings (see Figures 10 and 11) had exceptionally smooth surfaces and excellent contour filling. The casting shrinkage was found to be 0.021 in /in. This value of course refers to a hot graphite mold; however, the expansion coefficient of graphite is low (approx. $2 \times 10^{-6}/^{\circ}\text{C}$), so that the value was not markedly affected by temperature variations

Macro 13191

0.43X

Figure 8. Casting 787, 3 x 4 x 15-in. Surface runs caused by heavy spray. On the left, brush marks are visible where an attempt was made to smooth the wash.

Macro 13189

1.2X

Figure 9 Casting 787 A closer view of the surface runs shown in Figure 8.

Macro 13492

0.33X

Figure 10. Casting 824. A 150-kg Casting Poured into a Properly Sprayed Mold. No surface defects.

Macro 13682

0.33X

Figure 11. Casting 836. The 300-kg Casting Poured into a Sprayed Mold. No surface defects. A number of large blowholes are visible at the top of the riser.

Summary

The castings made for the shield proved to be quite satisfactory for Co-60 gamma radiation. The finished shield required extensive machining on all surfaces, except the curved surfaces of castings Nos. 824 and 836. Because of this machining, these castings were examined more extensively than any previous castings. No large blow holes or cracks were uncovered. The method used for obtaining directional solidification in these large castings was thus proved to be adequate.

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