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DRILLING URANIUM BILLETS ON A LEBLOND-CARLSTEDT RAPID BORER

BY

R. J. JANSEN

AEC RESEARCH AND DEVELOPMENT REPORT

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DRILLING URANIUM BILLETS ON A LEBLOND-CARLSTEDT RAPID BORER

By

R. J. Jansen*

TECHNICAL DIVISION
NATIONAL LEAD COMPANY OF OHIO

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Approved By:

S Marshall

Technical Director

Approved By:

Carl E. Polson

Head, Metallurgical Department

Mr. Jansen is presently with Westinghouse Electric Company, Pittsburgh, Pa.

NATIONAL LEAD COMPANY OF OHIO
Box 39158, Cincinnati, Ohio 45239
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The work reported herein was performed
under the direction of

H. Davis
Supervisor, Process Metallurgy

J. F. Schiltz
Supervisor, Metallurgical Services

Technical illustrations, composition, and printing by Records Management Department, J. Pool, Supervisor

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ABSTRACT

Solid uranium castings were bored with a LeBlond-Carlstedt Rapid Borer to produce hollow billets for extrusion. The ability of the machine to drill dimensionally accurate billets was demonstrated. Holes up to 2 inches in diameter were bored in billets 20 inches long in less than 10 minutes. Analysis of the tool life and the production capabilities show a cost savings can be obtained by drilling solid billets with this machine rather than casting hollow billets. The cost of drilling is more than offset by the higher casting yield obtained with solid ingots and the lower cost per billet for the graphite mold components.

1. INTRODUCTION

Uranium billets for extrusion into tubing are produced at the National Lead Company of Ohio by casting a hollow ingot, cropping the top, and cutting it in half. Casting a hollow ingot requires a graphite mold, core, and distributor plate. The core and distributor plate add cost and complexity to the operation, and mold life is shorter when compared with solid casting. Also the casting yield is lower for hollow ingots. Considering the over-all cost, it was reasoned that a substantial savings could be realized if the hollow billet could be produced from a solid casting by an efficient drilling method.

Previous drilling of uranium billets at this site had been performed on conventional equipment using high-speed twist drills. Billets bored by this method were limited in length to 14 inches. Such drilling was slow, and frequent tool regrinding was necessary. To maintain concentricity, a between-centers turning operation was required after the billets were drilled. On a production basis, the cost of this type of drilling would exceed the cost of hollow casting.

An investigation was made into the available machine tools capable of drilling 1 to 3-inch diameter holes in billets as large as 11 inches in diameter and 24 inches long. Few machine tools are capable of drilling holes to these specifications with speed and accuracy; however, the Carlstedt Rapid Borer built by the R. K. LeBlond Machine Tool Company, Cincinnati, Ohio, appeared to meet the requirements.

The Rapid Borer is capable of drilling carbon steel, stainless steel, brass, and other metals in diameters up to 12 inches and in lengths up to 10 feet. One company is using two such machines to drill nickel, monel, Inconel, and stainless steel billets for extrusion into tubing. In this instance, holes are drilled in billets 6 to 12 inches in diameter and 30 inches long.

Arrangements were made with R. K. LeBlond Machine Tool Company to conduct tests in their plant to determine the feasibility of drilling uranium billets with the Carlstedt Rapid Borer. Two series of tests were performed.

2. SUMMARY OF RESULTS

The first billet drilling test was conducted in January, 1961. Fourteen uranium billets 7 inches in diameter and approximately 21 inches long were successfully drilled, and the feasibility of the drilling operation was demonstrated.[1] The drill used was $1\frac{17}{32}$ inches in diameter and was hollow to permit the return of coolant and chips. Bore size, straightness, and concentricity were well within acceptable limits. Drilling was accomplished at good penetration rates, but in many cases severe fracturing of the carbide-tipped cutting tool occurred. Best results were obtained at a cutting tool penetration rate of $2\frac{1}{4}$ inches per minute and a workpiece rotational speed of 500 rpm. Drilling time per billet was approximately $8\frac{1}{2}$ minutes.

A second billet drilling test was conducted with the same machine in August and September, 1961. Twenty-nine 7-inch-diameter billets were drilled (solid bored) to produce $1\frac{17}{32}$-inch holes. Twenty-six $7\frac{3}{8}$-inch-diameter billets were trepanned to obtain 2-inch holes. (In trepanning, the hollow tool generates a solid core; and since less metal is cut, less power is required than in solid boring.) In both drilling and trepanning, penetration rates and dimensional results were excellent. A cutter life of five to six billets per grind and 20 to 30 billets per tool can be expected.

Tool life was improved considerably in the second tests. Complete fracturing of the carbide tip was eliminated, but minor chipping of the cutting edge was still experienced. Noticeable guide-pad wear was detected on both the boring and the trepanning tools. Under present conditions, the removable guide pads must be replaced after drilling about 12 billets. Of the four grades of carbide used for cutting tips, Kennametal E7560 was the most reliable. The time required to bore a $1\frac{17}{32}$-inch-diameter hole in a 21-inch-long billet was about 7 minutes. The time required to trepan a 2-inch-diameter hole was about 9 minutes.

3. DESCRIPTION AND OPERATION OF EQUIPMENT

The LeBlond-Carlstedt Rapid Borer (Figure 1) is approximately 3 feet wide and 28 feet long. It was designed for high-speed, precision boring using special hollow cutting tools of the types shown in Figur 2. Coolant is forced between the boring bar and the periphery of the bore to cool the cutting tip an pressure pads. The coolant returns through the passage in the bar and carries the chips with it. Th cutter is self-aligning, thereby controlling concentricity of the hole. The entire operation of the machine, except for loading and unloading, is conducted from a control desk (Figures 1 and 3).

To provide the high penetration rates of this machine, a 60-hp, d-c, variable-speed, main drive moto is used. Spindle speeds up to 2200 rpm are available. The spindle is belt driven to minimize vibration The spindle nose contains a conical, serrated driver for fast clamping and rotation of the workpiece The front bore of the spindle is fitted with a seal to contain the coolant when the tool breaks throug the end of the workpiece.

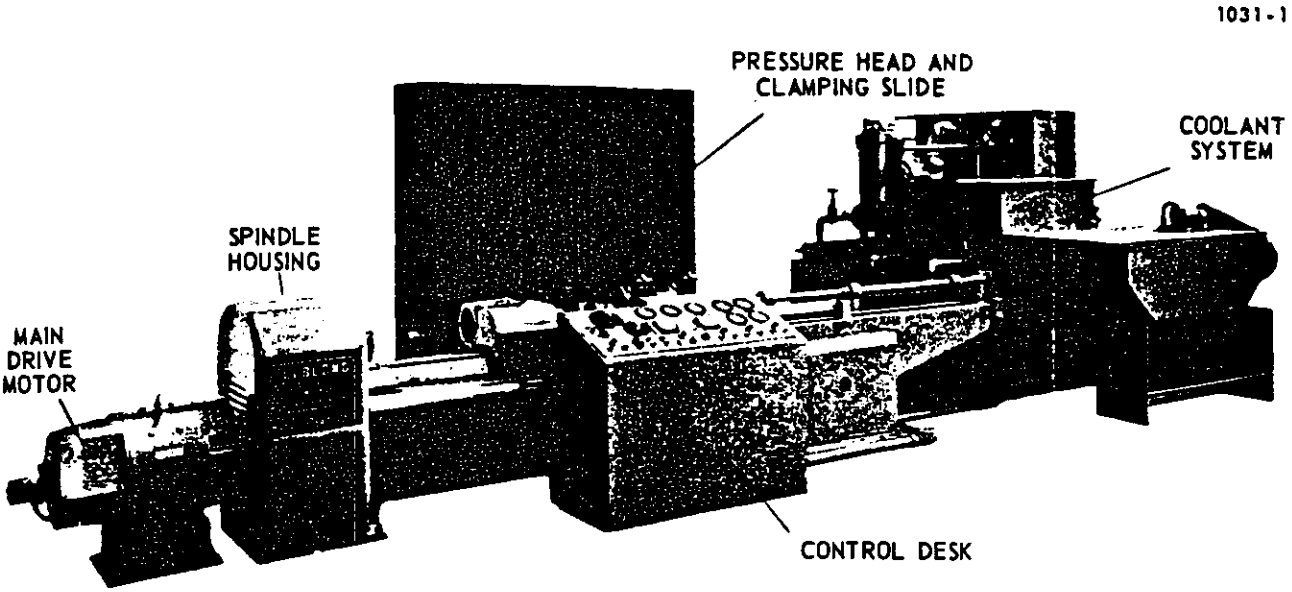
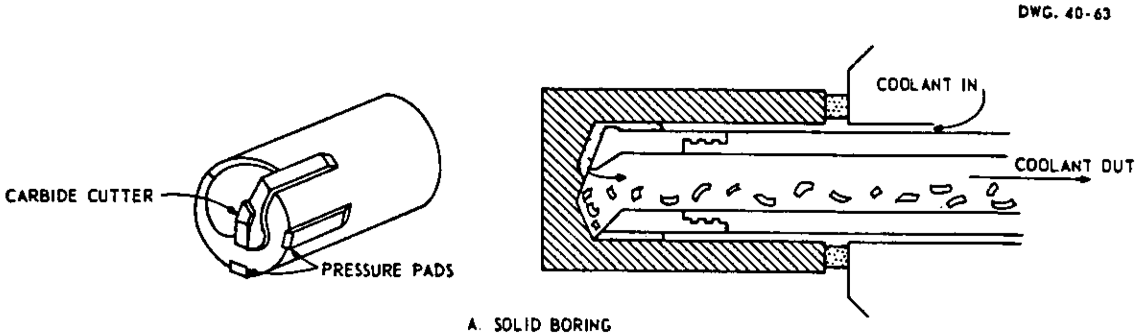
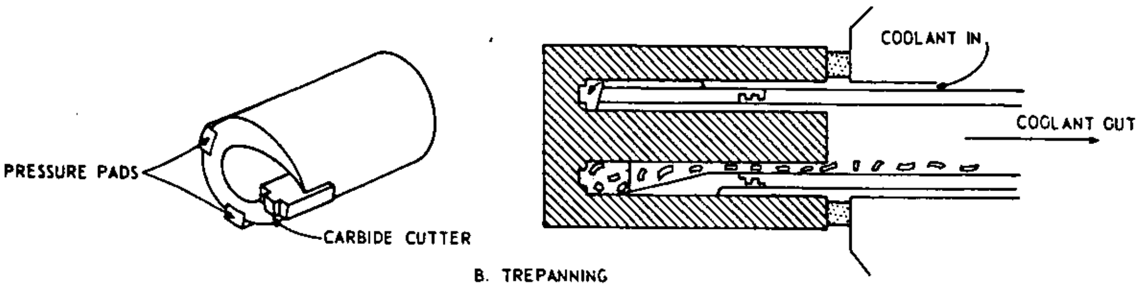


FIGURE 1 LeBlond-Carlstedt Rapid Borer



A. SOLID BORING



B. TREPANNING

FIGURE 2 Cutting Tools

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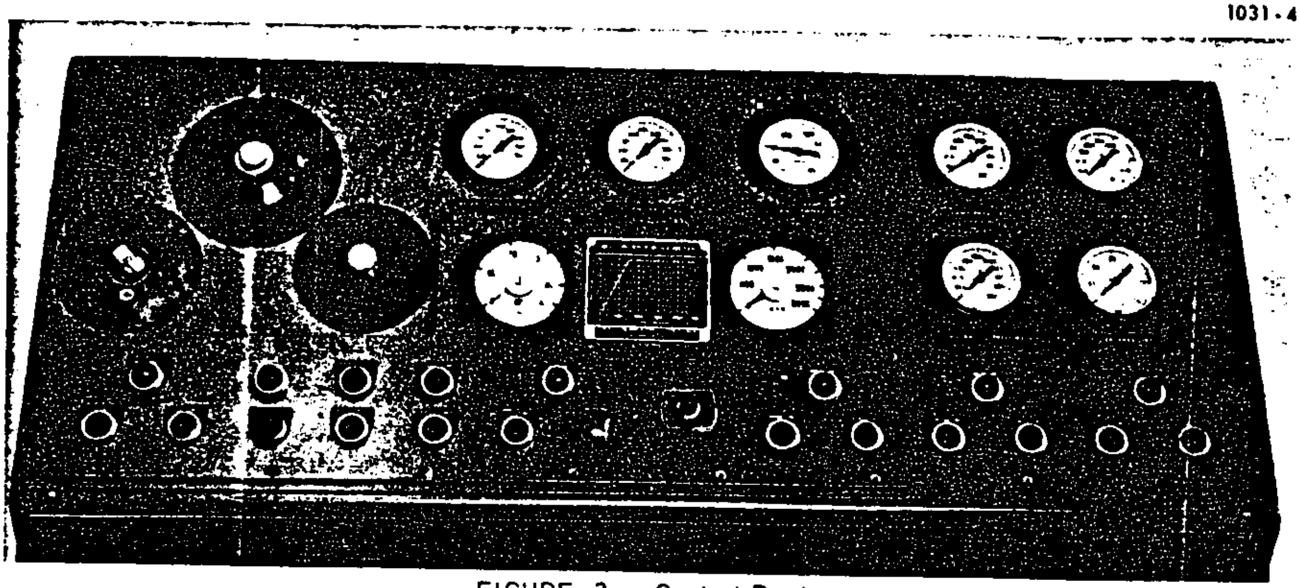

FIGURE 3 Control Desk

The end of the workpiece opposite the spindle is supported by the pressure head, which is mounted on the clamping slide (Figure 4). The pressure head guides the coolant to the outside of the boring bar,

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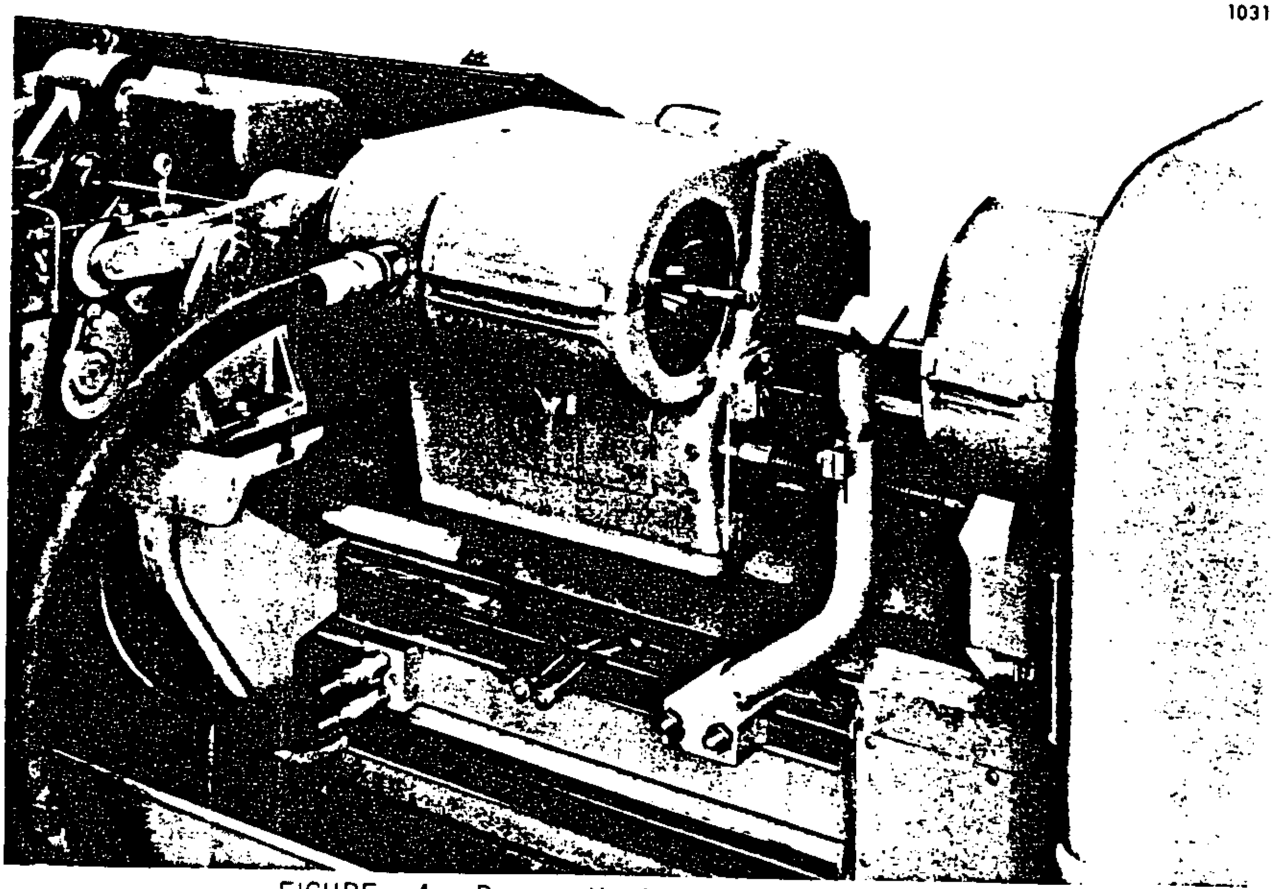

FIGURE 4 Pressure Head and Clamping Slide Assembly

nd seals it against leakage. It provides a rotating clamping ring for holding the workpiece and a bushng to guide the cutter into the work. The clamping slide is gibbed to the bed to provide a rigid mounting or the pressure head. A hydraulic cylinder with a $3\frac{1}{2}$-inch stroke moves the entire unit toward the spindle. By this action the workpiece is held between the clamping ring in the pressure head and the serrated driver in the spindle. A rapidly rotating lead screw adjusts the slide position for workpieces of ifferent lengths.

The boring slide holds the boring bar and feeds it through the pressure head into the work. A hydraulic ylinder gives the boring slide its feed motion. Variable feed, necessary in matching feed with speed o obtain optimum penetration, is adjusted from the control desk (Figure 3). If drilling pressure exceeds preset level, the boring slide retracts automatically to prevent tool damage.

ince heavier feeds are generally used on the Rapid Borer than on conventional boring equipment, bar supports (Figure 5) are necessary to dampen vibration and prevent buckling of long boring bars. They re hydraulically operated by means of a torsion motor. When the directional control valve is in one

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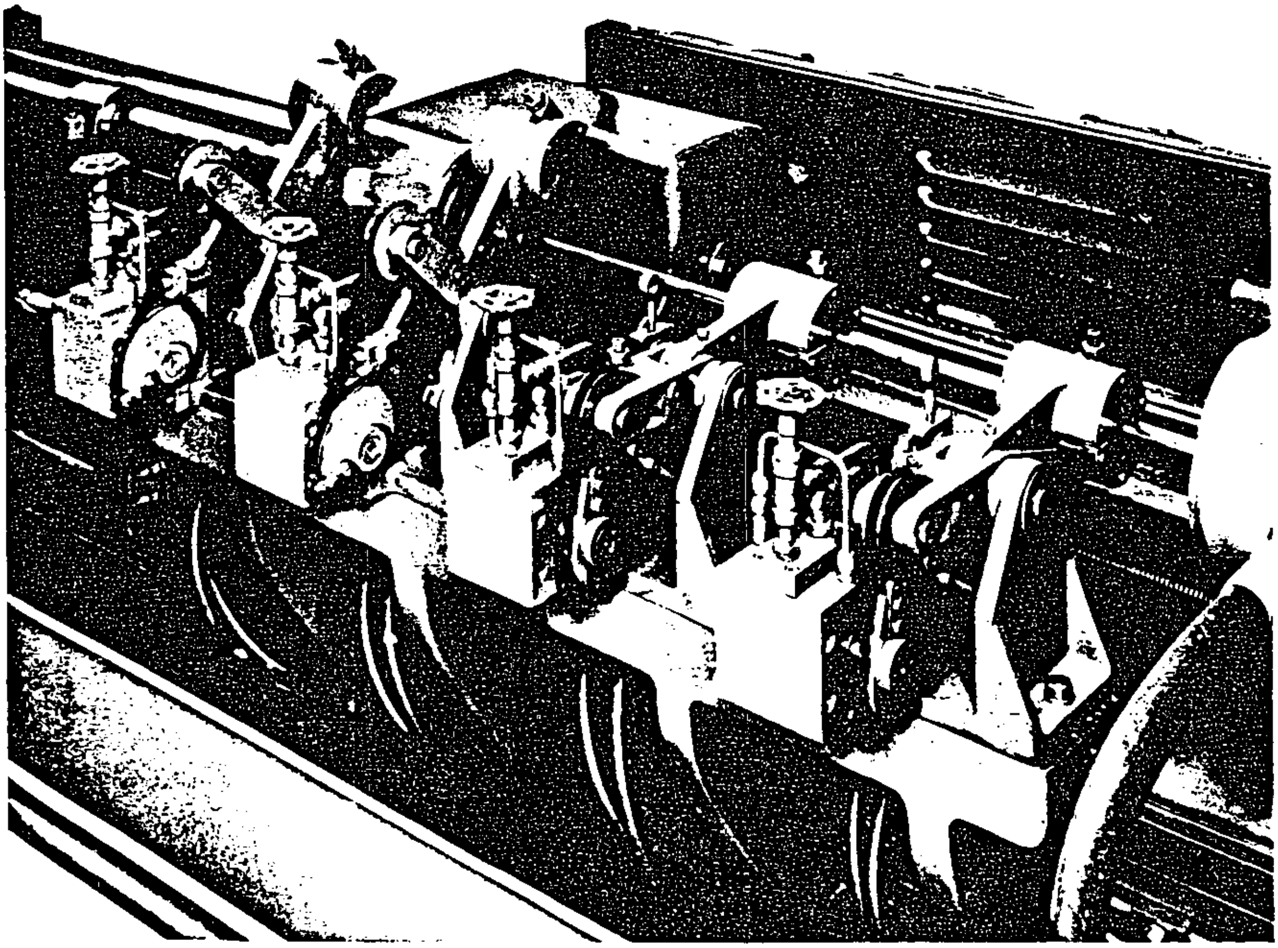

FIGURE 5 Boring Bar Supports

position, coolant is supplied by the hydraulic system, tightening the jaws around the boring bar. As the boring slide feeds, an automatic trip mechanism opens the jaws allowing the boring slide to pass as it moves along the bed.

The Rapid Borer coolant serves two purposes: (1) it cools and lubricates tool cutting edges and pads, and (2) it removes chips as it returns through the hollow boring bar. The coolant discharges from the boring bar through a telescopic coolant tube into a cyclone, which reduces velocity. It is then discharged into an enclosed filtering system. Here the coolant flows first into a tank where the chips are separated. From the tank the coolant is pumped through a fine (10 micron) filter into a clean section. A large-capacity, high-pressure pump then forces the coolant back to the pressure head.

4. FIRST BILLET DRILLING TEST

4.1 FEEDSTOCK

Fourteen normal uranium billets were provided for the test. Solid cast ingots were cut into two pieces to produce billets 7-inch diameter and approximately 21-inches long. To facilitate the use of tooling on hand at LeBlond, one end of the billet was faced and turned down to $4\frac{5}{16}$ inches in diameter for a length of 2 inches. Eleven of the billets were triple beta heat treated (salt heated-water quenched) prior to drilling; the other three were left in the as-cast condition.

4.2 TOOLING

A list of tooling required to drill a hole on the Rapid Borer appears in the Appendix (Table IV).

For this test, a $1\frac{17}{32}$-inch diameter solid boring tool was used. This particular tool was chosen because it was near the bore size of a production I&E extrusion billet and was a standard tool used by the LeBlond Company for drilling lathe spindles. Therefore, it was not necessary to purchase special tooling. Eight of these solid boring tools were provided for the test. The tool is made by brazing a carbide cutter and two carbide pressure pads into a tool steel body (Figure 2). The body is hollow to permit coolant and chips to flow out along its axis. Internal threads are machined into the body for quick attachment of the tool to the boring bar. The solid boring tool produces two chips as it penetrates the work.

Each chip has a width approximately $\frac{1}{4}$ the diameter of the hole. A chip breaker ground into the top face of the cutter helps curl the chip and breaks it into short lengths. The cutting edges can be resharpened 4 to 10 times on a cutter grinder, depending upon the severity of the cutting edge wear.

Four grades of carbide were tested during the test: Krupp TT-1, Carboloy 350, Carboloy 907, and Kennametal 5860. For the pressure pads, a Krupp TT-10 was used on all the tools.

4.3 AUXILIARY EQUIPMENT

An intermediate filter system was purchased to prevent uranium from contaminating the Rapid Borer's coolant system. This unit was placed so that the cutting oil and chips flowed directly from the machine into it. The oil was then pumped through the intermediate filter into the regular coolant system.

The auxiliary coolant system consisted of a 500-gallon tank to hold chips and settle out fines, a 5-hp motor-pump unit capable of delivering coolant at 110 gpm, and a float switch to maintain the coolant level in the tank.

4.4 RESULTS

Fourteen, 21-inch-long uranium billets were successfully drilled during the test. Test conditions and data are shown in Table I.

TABLE I First LeBlond-Carlstedt Test Data

Piece No.	Penetration Rate (ipm)	Speed		Load hp	Drilling Time	Eccentricity* (TIR)(in.)
		rpm	sfpm			
1	2 to $3\frac{5}{16}$	630	250	7	**	0.022
2	$3\frac{5}{16}$			7	6 min 20 sec	0.050
3	$3\frac{5}{16}$			7	6 min 17 sec	0.050
4	$3\frac{5}{16}$			7	6 min 20 sec	0.030
5	2 to $3\frac{5}{16}$			7	7 min 10 sec	†
6	2			4	10 min 35 sec	0.011
7	$3\frac{5}{16}$			7	††	0.027
8	$3\frac{5}{16}$			8	7 min 20 sec	0.020
9	$3\frac{5}{16}$			8	††	0.018
10	$2\frac{1}{2}$	500	200	6.5	8 min 35 sec	0.013
11	$2\frac{1}{2}$			5	8 min 27 sec	0.009
12	$2\frac{1}{2}$			5	8 min 29 sec	0.038
13	$2\frac{1}{2}$			5	8 min 23 sec	0.010
14	$2\frac{1}{2}$			5	8 min 30 sec	0.013

* Eccentricity was measured by rotating the drilled billet while a dial indicator, graduated in thousandths of an inch, was held against the surface of the drilled hole at the end of the billet where the boring tool broke through. The total sweep of the pointer over the face of the dial indicator was recorded; hence, the term "total indicator reading" (TIR) was used as the value of eccentricity.

** Drilling time was not recorded.

† Billet was not drilled through; eccentricity could not be measured.

†† Drilling was interrupted and time was not recorded.

NOTE: Coolant pressure was 500 psi throughout the test. The drilled holes were from 0.001-inch to 0.006-inch larger than the boring tool.

4.4.1 Tool Life

While drilling the first 10 billets, severe fracturing of the carbide tools occurred. Because each billet was drilled through its entire length, it was first believed that the fracturing occurred as the tool broke through the end of the work. This was disproved by drilling several billets halfway through and then retracting the tool; fracturing still occurred.

Another possibility was that the carbide cracked immediately during the drilling cut but was held together during the remainder of the operation by the cutting forces. Thus, when the tool broke through the workpiece and the cutting forces were relieved, the carbide fell apart. This mechanism could not be substantiated during the test.

Up to this point it had been standard practice to stop the spindle after drilling was completed but before the tool was retracted. In several billets lines or grooves caused by retracting the tool were apparent on the ID wall. These lines indicated that binding existed between the tool and the ID wall. If the binding were severe enough, the carbide fracturing could have occurred during retraction. A billet was bored and the tool was removed from the boring bar before it was retracted through the billet. No damage was observed on the tool.

At this point, three test billets remained. To determine if the carbide breakage had occurred during retraction and to obtain an estimate of tool life, a new tool was selected. Two of the billets were drilled, the machine was stopped, and the tool was removed each time before retracting the boring bar. On the last billet, the tool was retracted with the billet rotating. The purpose was to see if the tool would cut its way out of the rotating billet. This was successful; the carbide cutter was extracted without fracture. Pitting and galling of the carbide pressure pads was most severe after the first drilling pass but did not increase appreciably on succeeding drilling passes.

Since no more billets were available for drilling, no accurate estimate of the tool life could be made; however, the prevention of premature tool breakage had been accomplished. Future tests were needed to obtain tool life data.

4.4.2 Dimensions

The hole sizes of all of the drilled billets were within the dimensional tolerances set for extrusion billets. The hole was from 0.001-inch to 0.006-inch larger than the drill size when measured from billet to billet. In any single billet, the maximum range in bore size was 0.003 inch. The bore at each end of the billet was slightly smaller than that in the center portion. With a sharp tool, the hole size was very close to the tool diameter; as the cutting edge wore, the bore size increased.

Eccentricity at the breakthrough end of the billets ranged from 0.009-inch to 0.050-inch TIR (See Table I). At the drill entrance end, the eccentricity did not exceed 0.005-inch TIR. Three factors contributed to eccentricity: (1) squareness of the billet end faces, (2) roundness and surface condition of the billet and (3) runout of the tool during drilling. The entrance end of the billet was turned and faced, and a bushing guided the drill as it entered the billet. Therefore, this end was more concentric than the breakthrough end.

4.4.3 Penetration Rate

Tool penetration or feed rates (see Table I) from 2 ipm to $3\frac{5}{16}$ ipm (inches per minute) were used. A wider range was not attempted because the speed of completing a hole was considered satisfactory and the limited number of test pieces precluded a more thorough investigation. It is anticipated that under optimum conditions a faster penetration rate would be achieved.

Drilling time for a 21-inch-long billet was about 8.5 minutes at the $2\frac{1}{2}$-ipm feed rate and about 6.5 minutes at the $3\frac{5}{16}$-ipm feed rate. For both penetration rates, the chip load (feed rate in inches per revolution) was held constant. When the penetration rate was reduced, the rpm was lowered thus reducing the cutting speed (surface feed per minute).

4.4.4 Chip Formation

Chip formation is important in the LeBlond-Carlstedt drilling operation because the chips must be small enough to be flushed through the hollow center of the drill after being generated at the cutting edges. The most desirable chip is a short curled one. The chips generated during the uranium test were approximately 2 inches long. Although they were longer than desired, they flushed from the drill satisfactorily. Attempts to alter the shape of the chip during the test were unsuccessful.

5. SECOND BILLET DRILLING TEST

5.1 FEEDSTOCK

Billets for the test were produced by casting solid ingots, removing the top crop, and cutting the remaining section into two equal lengths. Thirty billets 7 inches in diameter by 21 inches long were prepared for drilling with a $1\frac{17}{32}$-inch diameter tool. This produces a billet with a bore suitable for extrusion into I&E tubing. Thirty-one billets $7\frac{5}{16}$ inches in diameter by 21 inches long were prepared for trepanning with a 2-inch diameter tool. This produces a billet suitable for extrusion into Mark V-B outer fuel element tubing. Half of the billets in each of the above groups were triple beta heat treated prior to drilling; the remaining billets were triple beta heat treated after drilling. The purpose was to evaluate the structures obtained with each method and to see if heat treatment had any effect in the drilling step.

5.2 TOOLING

The tooling required to solid-bore the $1\frac{17}{32}$-inch hole was the same as that used in the previous test. A complete list appears in the Appendix (Table IV). Six standard solid boring tools were provided for the test. Three carbide grades, Kennametal E7560, Kennametal 5860, and Krupp T-10, were used as cutters. Two tools were fabricated from each grade. The cutters were brazed to the solid boring head and ground to a standard geometry as shown in Figure 6.

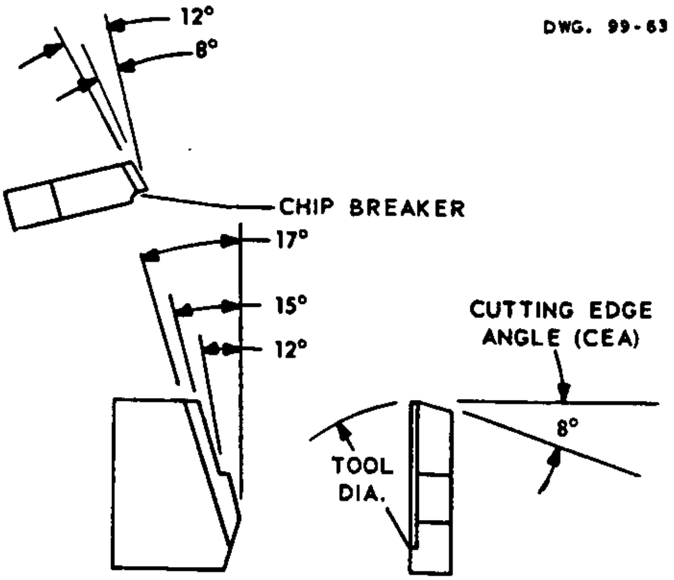

FIGURE 6 Carbide Cutter for Solid Boring Tool

Special tooling required for trepanning the 2-inch diameter hole is listed in the Appendix (Table V). This tooling was made by the R. K. LeBlond Machine Tool Company and the American Heller Company, Detroit, Michigan. The trepanning tool is composed of a tool steel body with mechanically held cutter and two pressure pads. The circular body is hollow to permit chips to be flushed out with the coolant and to allow space for the core generated during boring. Internal threads are machined into the body at the back end for quick attachment to the boring bar. A flat seat is milled onto the body with a keyway slot and a threaded hole for location and attachment of the cutter. Two dovetailed slots are milled into the body, each with a threaded hole at one end for attachment of the pressure pads. The cutter consists of a carbide tip brazed to a steel base. The pressure pad was made either of a carbide rectangle brazed to a steel base, as shown in Figure 7, or was made entirely of high-speed steel.

One trepanning head with 18 cutters and 18 pairs of pressure pads were obtained for the test. Cutters were made of four grades of carbide; six Kennametal 5860, four Kennametal E7560, four Kennametal K21, and four Krupp N14. Fourteen pairs of pressure pads were made of high-speed steel with a hardness of 63 R_c to 65 R_c.

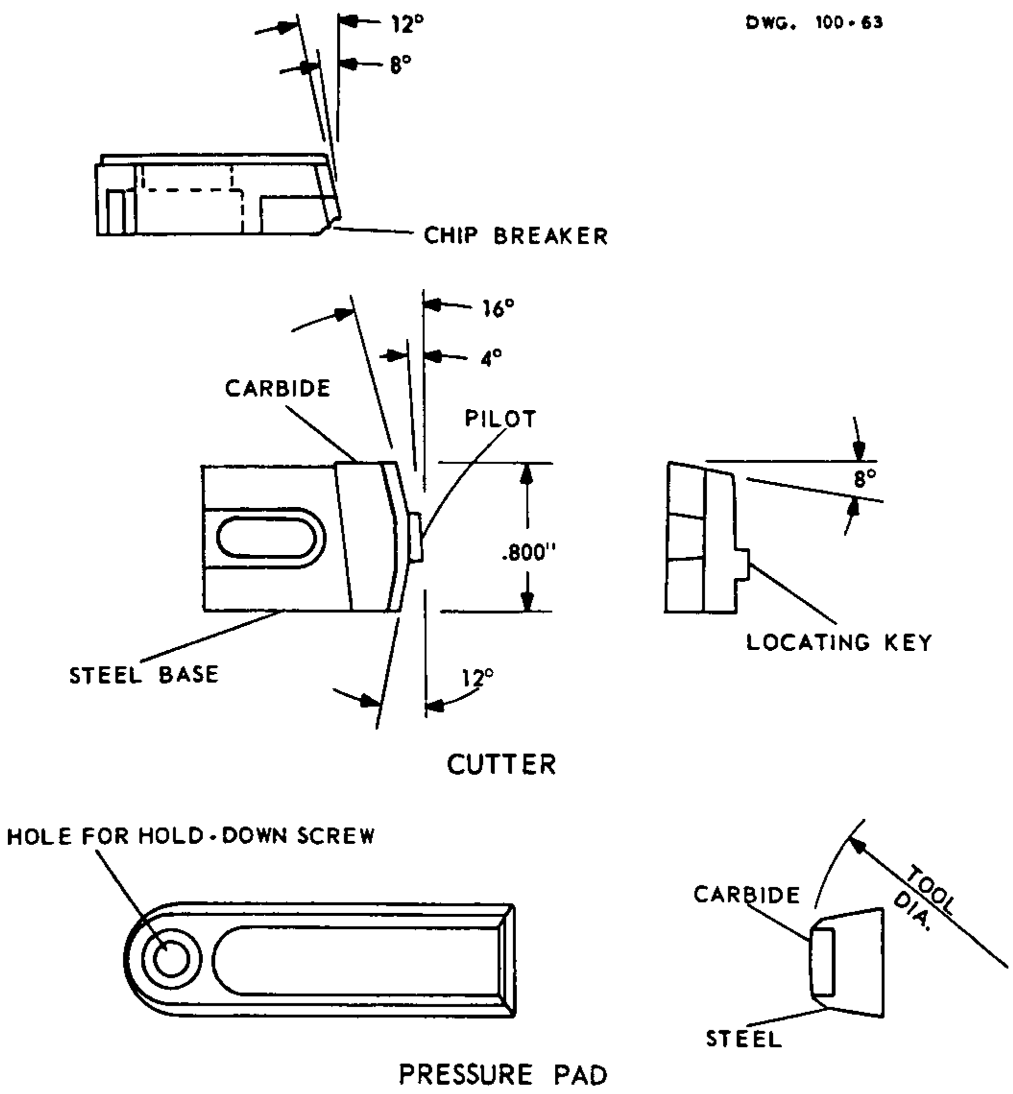

FIGURE 7 Replaceable Components for Trepanning Tool

5.3 DESCRIPTION OF THE TEST

5.3.1 Drilling with Solid Boring Tools

Solid boring of the $1\frac{17}{32}$-inch diameter hole in the 7-inch diameter billet was the first step in the program. Test conditions and data are shown in Table II. The beta heat-treated billets were bored first in one lot, and the as-cast billets bored in a second lot. A standard-ground solid boring tool with a Kennametal E7560 carbide cutter was used.

During boring of the first four billets, the bushing seal failed on several occasions. This seal prevents leakage of coolant between the billet face and the guide bushing. In addition to the seal failure, eccentricity of the finished hole was excessive. An investigation revealed that the billet end faces were between $\frac{3}{16}$ and $\frac{5}{16}$ inch out of square with the OD. The bushing seal would not seat properly on the out-of-square surface, and when the high pressure coolant was turned on, the O-ring seal blew out of it groove causing leakage of the coolant. When this happened, the boring operation was stopped. The out of-square ends also caused the billet to shift in the holding centers so that the bored hole was nc concentric with the billet OD. It was decided that any billet out of square in excess of 1/8 inch (se Figure 8) was unacceptable and would be excluded from the test.

TABLE II Solid Boring Test Data

Test No.	Load hp	Drilling Time (min)	Hole Size Over Drill (in.)	Eccentricity (TIR) (in.)		Test No.	Load hp	Drilling Time (min)	Hole Size Over Drill (in.)	Eccentricity (TIR) (in.)	
				Front	Rear					Front	Rear
1	8.0	7.2	0.003	0.020	0.180	16	9.0	7.0	0.003	0.005	0.075
2	7.5	7.2	0.004	0.015	0.140	17	9.0	6.8	0.004	0.012	0.119
3	7.5	7.3	0.006	0.030	0.100	18	8.0	7.0	0.003	0.005	0.170
4	7.5	7.3	0.003	0.017	0.140	19	8.0	7.0	0.003	0.015	0.026
5	8.0	7.2	0.002	0.015	0.055	20	8.0	7.0	0.003	0.025	0.004
6	8.0	7.0	0.003	0.016	0.017	21	7.0	7.1	0.003	0.015	0.010
7	7.5	7.1	0.004	0.010	0.037	22	8.0	7.2	0.003	0.020	0.015
8	7.5	7.3	0.003	0.010	0.015	23	8.5	7.0	0.004	0.010	0.030
9	8.0	7.0	0.003	0.010	0.010	24	8.5	7.0	0.003	0.010	0.010
10	7.5	7.1	0.003	0.018	0.035	25	9.0	7.0	0.004	0.005	0.175
11	8.0	7.0	0.003	0.032	0.030	26	9.0	7.0	0.002	0.015	0.025
12	7.0	7.2	0.002	0.015	0.063	27	9.0	7.1	0.004	0.032	0.008
13	7.0	7.3	0.002	0.015	0.150	28	8.0	7.0	0.003	0.015	0.048
14	8.0	7.1	0.002	0.015	0.018	29	7.5	7.1	0.003	0.009	0.015
15	8.5	7.0	0.003	0.010	0.185						

NOTE: Throughout the test the following parameters were held constant: (1) The penetration rate was held at 2 7/8 ipm; (2) the workpieces were rotated at 500 rpm (200 sfpm cutting speed); and (3) coolant pressure was 500 psi.

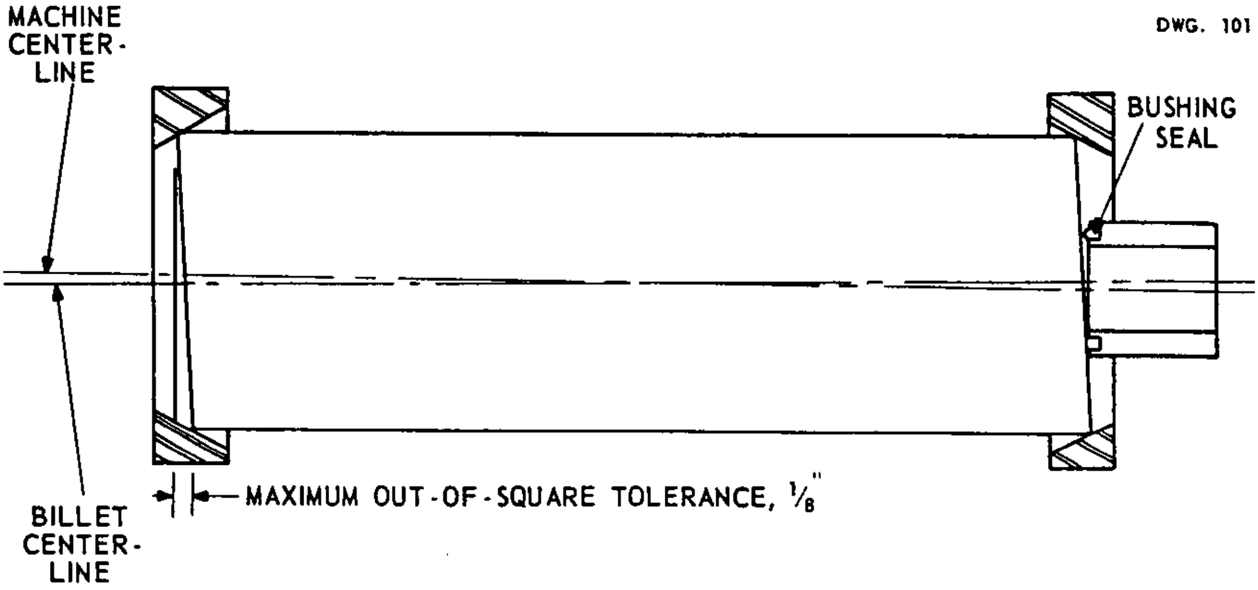

FIGURE 8 Schematic Diagram of Billet with End Faces Out of Square Chucked in Rapid Borer

As soon as the out-of-square end problem had been recognized and solved, it was quickly apparent that the penetration rate was satisfactory, the dimensional results were good, and carbide tool fracturing was not experienced. Because of the limited number of remaining billets, it was considered appropriate to devote the main effort to improving pressure pad life, which was very short at the beginning of the test.

Pressure pad wear began as small particles of carbide spalling from the surface. This was noticeable after just one hole had been drilled. The condition became more severe on the second boring, and after the third or fourth complete hole, the pad failed by chipping and cracking. To correct this condition, a 5° relief angle was ground on the pressure pad for 60% of its width (Figure 9). This relief allowed cutting coolants to flow under and lubricate the pad. A 5% addition of lard oil was made to the Shell Garia H coolant to further improve lubrication between the pressure pad and the hole wall. Also, powdered lubricant, molybdenum disulfide was rubbed into the surface of the pads each time before the tool was used. These three corrective measures increased the pressure pad life to 6 or 7 billets.

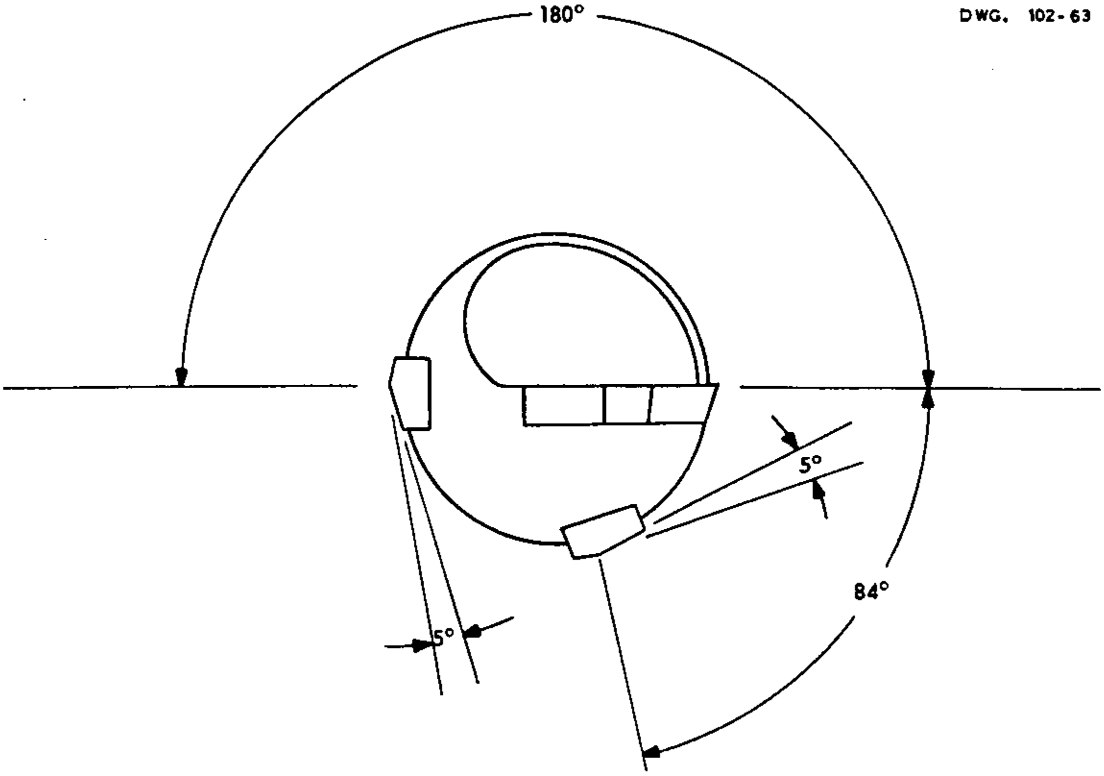

FIGURE 9 Solid Boring Tool, 5° Relief on Pressure Pads

The more severe pressure pad wear occurred on the pad located 84° from the cutting edge. It was reasoned than an equal distribution of pressure between the two pressure pads would improve tool life. To change the distribution of pressure, the cutting edge angle (CEA) (Figure 6) was varied. The standard 15° CEA was first changed to 18°, which shifted the more severe wear to the 180° pad. It was finally determined that a 16½° CEA would give an even distribution of the pressure and, hence, even wear on both pads. This angle was used throughout the remainder of the test.

The last nine billets were bored with a tool having high-speed steel pressure pads hardened to 63 R_c t 65 R_c. The pads and tool were still serviceable upon completion of the test. Pitting, spalling, an cracking of the high-speed steel pad was not evident, but a 0.002-inch loss in diameter of the tool du to wear of the pad was noted. Because of a slight chipping of the cutting edge, it was necessary to re grind the cutting edge once after completion of the fifth billet.

Of the various grades of carbides tested, only the Kennametal E7560 performed satisfactorily. Th Kennametal 5860 and Krupp T-10 tools chipped on the cutting edge and required regrinding after drillin one or two billets. The E7560 carbide tools developed shallow chipping after completion of five or si billets.

5.3.2 Drilling with Trepanning Tools

In trepanning, a hole is bored with a hollow tool that simultaneously generates a solid cylindrical cor along the longitudinal axis of the billet. The 2-inch diameter trepanning tool used in the test produce a 0.400-inch-diameter solid core (Figure 10).

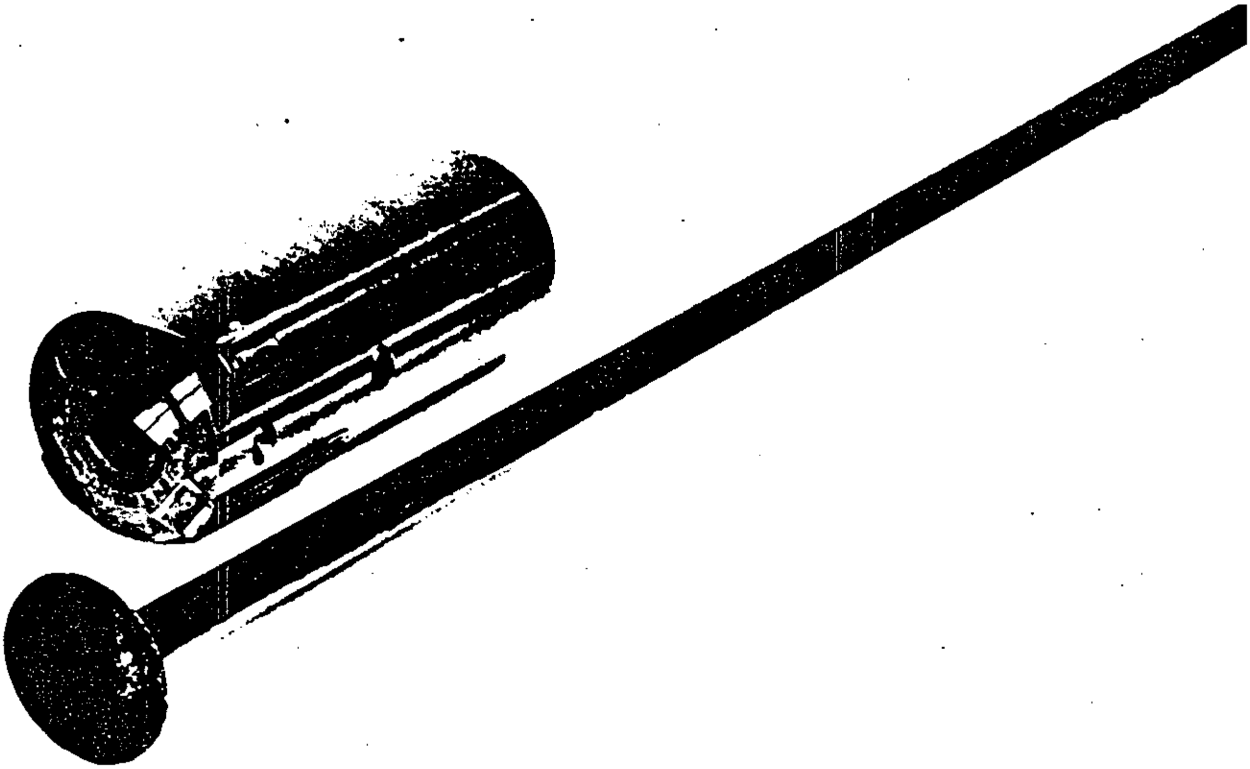

FIGURE 10 Trepanning Tool and Solid Core

Test conditions and results for the 26 billets trepanned are given in Table III.

TABLE III Trepanning Test Data

Test No.	Penetration Rate (ipm)	Coolant Pressure (psig)	Load hp	Drilling Time (min)	Hole Size Over Drill (in.)	Eccentricity (TIR) (in.) Front	Eccentricity (TIR) (in.) Rear
31	$1\frac{11}{16}$	410	8.0	12.3	0.002	0.041	0.018
32	2	410	7.5	10.3	0.002	0.009	0.058
33		400	8.0	10.0	0.003	0.025	0.032
34		400	8.0	10.8	0.003	0.012	0.025
35		400	8.0	10.4	0.003	0.019	0.040
36		400	9.0	10.5	0.003	0.015	0.007
37		440	9.0	10.2	0.001	0.001	0.011
38		440	8.0	10.0	0.000	0.008	0.021
39		400	8.0	10.2	0.001	0.010	0.049
40		400	8.0	10.1	0.001	0.011	0.027
41		390	8.0	*	0.002	0.010	0.025
42		400	8.0	*	0.006	0.025	0.022
43		380	8.0	10.0	0.004	0.024	0.030
44		380	8.0	10.5	0.003	0.025	0.015
45		380	9.0	10.2	0.002	0.025	0.058
46	$2\frac{3}{16}$	450	9.5	9.5	0.002	0.017	0.024
47		400	10.5	9.0	0.003	0.008	0.058
48		420	10.0	9.0	0.003	0.032	0.015
49		420	9.5	9.2	0.002	0.010	0.050
50		420	10.0	9.0	0.003	0.010	0.030
51		420	9.0	9.1	0.004	0.015	0.060
52		420	9.0	9.0	0.003	0.007	0.042
53		420	9.0	9.4	0.007	0.026	0.017
54		420	9.0	9.2	0.008	0.010	0.020
55		420	8.5	9.0	0.006	0.003	0.030
56**	$2\frac{3}{16}$	420	8.0	—	0.004	0.020	0.020
	$3\frac{1}{2}$		15.0				
	5		17.0				

* Chip clogging in the exhaust channel required withdrawal of the tool before the hole was completed. The hole was finished using another tool.

** The penetration rate was increased during test No. 56; at a rate of 5 inches per minute, the tool's carbide tip broke. The hole was completed using another tool.

NOTE: Rotation of the workpiece was held constant throughout the test at 500 rpm (260 sfpm cutting speed).

During the trepanning run, chipping of the carbide cutting edge was experienced. This occurred at the completion of the hole when the solid core fell loose. Due to the geometry of the cutter, a 1½-inch diameter head is produced on the core at the breakthrough end. The flushing action of the coolant caused the head of the core to strike the tool and chip the cutting edge. Efforts to resolve this problem occupied the first half of the test.

The carbide chipping occurred on the inside corner of the pilot. Although the chipping was not severe, regrinding of the cutter was necessary to restore the tool to a usable condition. It may be noted on

Figure 7 that the 4° cutting edge angle to the pilot produces a projecting point to its inner corner. By grinding an 8° angle, 1/16-inch wide in the opposite direction, as shown in Figure 11, chipping was reduced. However, the life of the cutting edge was still unpredictable, and the investigation was continued.

Since carbide chipping was not a problem during the solid boring test, it was decided to grind a trepanning cutter to the same geometry as had been used on the solid boring cutter (see Figure 12). Several billets were drilled with cutters of this geometry. Because the trepanning tool has a small area for passage of coolant and chips, the wider chips produced by the solid boring cutting edge design were extremely difficult to flush. In one case chips packed and blocked the coolant passage causing a complete failure of the cutter.

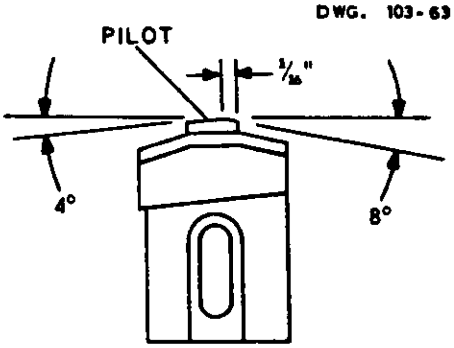

FIGURE 11 Trepanning Cutter with Altered Pilot Geometry

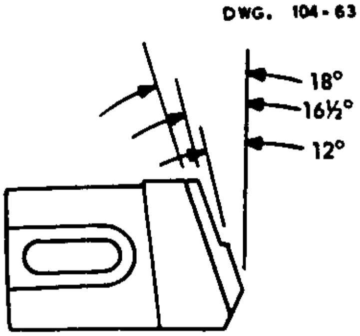

FIGURE 12 Trepanning Cutter with Solid Boring Tool Geometry

The head produced on the core generated during trepanning can be eliminated by machining a centerhole in the exit end of the workpiece (see Figure 13). Without the head, the core should flush out of the hole without striking and chipping the carbide cutters. One billet was shallow drilled with a center hole and then trepanned on the Rapid Borer. The carbide cutter again chipped, and the drilling of center holes was abandoned.

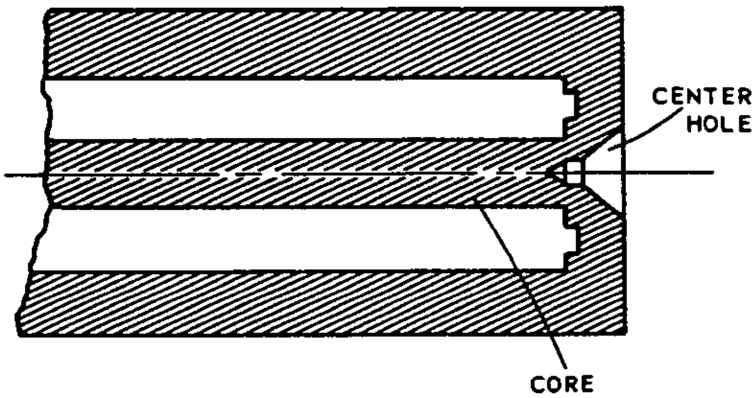

FIGURE 13 Schematic Diagram of Centered Billet Just Prior to Completion by a Trepanning Tool

The Rapid Borer has a large cavity in the unit which sealed the coolant at the exit end of the billet. When the trepanning tool breaks through the end, there is a short time during which this cavity fills up with coolant and back flushing stops. The core, which is now loose, moves forward into the cavity about 4 inches. When the cavity is filled with coolant, back flushing begins again causing the core to move rapidly toward the rear. This movement stops when the head of the core, which is larger than the internal coolant passage, strikes the carbide cutter. The action usually causes the cutter to chip. To reduce the movement of the core, the sealing unit cavity was packed with heavy grease. This eliminated the flow of coolant into the cavity and the interruption of back flushing. The core then would remain substantially stationary. With this technique, 12 billets were trepanned. Carbide chipping at the pilot of the cutter was completely eliminated. Regrinding of the carbide cutter was required after completing the fifth billet. All but one of the remaining billets were used during this run. The results obtained were sufficient to show that uranium billets could be successfully trepanned on the Carlstedt-Rapid Borer.

The last billet was used to estimate the maximum penetration rate possible with the trepanning tool. The tool was started into the work at the penetration rate of 2$\frac{3}{16}$ inches per minute. While in the cut, the penetration rate was gradually increased to 3$\frac{1}{2}$ inches per minute. This rate was maintained for 3 minutes and then gradually increased to 5 inches per minute. After 12 seconds at 5 inches per minute, the carbide cutter failed. Complete fracturing of the carbide occurred. During the test, the power requirement rose from 8-hp at 2$\frac{3}{16}$ inches per minute to 17 hp at 5 inches per minute feed. It is estimated that the maximum feed that can be obtained consistently without tool failure is approximately 4 inches per minute.

Carbide evaluation during the trepanning test again showed the Kennametal E7560 carbide to be superior. The other grades tried, Krupp T-10 and Kennametal 5860, chipped rapidly.

High-speed steel and carbide pressure pads were used on the trepanning tool. The high-speed steel pads wore rapidly and lost about 0.008 inch of the wear surface in drilling ten billets. However, no chipping or pitting occurred on the high-speed steel pads. The standard carbide pads exhibited the same pitting and chipping as did the pads on the solid boring tools. A set of carbide pads with diagonal lubricating grooves were used on the last eight billets (Figure 14). These pads showed very little wear or pitting at the completion of the test. This design appears satisfactory.

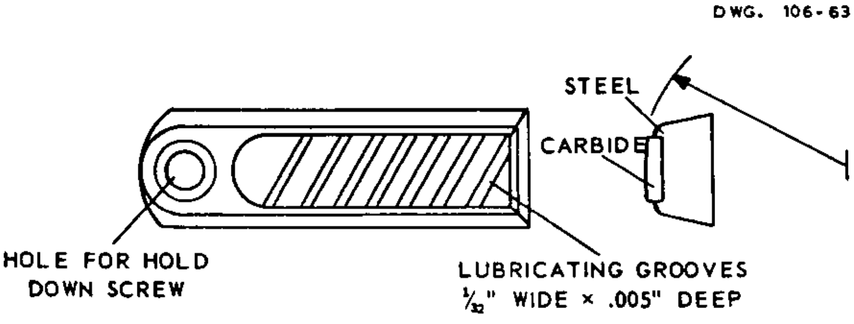

FIGURE 14 Grooved Pressure Pad

5.4 RESULTS

5.4.1 Dimensions

The drilled billet hole size, considering both the solid boring tool and the trepanning tool, was from 0.001 to 0.006 inch greater than the tool diameter. (See Tables II and III) Within any one billet, the range in hole size from end to end did not exceed 0.003 inch. It was noted that a sharp tool produced a hole very close to the tool diameter. As wear on the tool increased, the hole size increased. Hole size was well within the present production limit of ±$\frac{1}{16}$ inch.

Concentricity of the ID with the OD was another dimensional factor considered. During the solid boring test, the holes in several billets exceeded the tolerance limit of 0.063-inch TIR. The out-of-tolerance holes were attributed to deficiencies in the machine and workpiece setup. The first billets run did not seat properly in the holding center. This was corrected by grinding the female center to proper size. After four billets were drilled out of tolerance, the boring tool guide bushing was inspected and found t have been improperly located. In two cases, billets with end faces extremely out of square caused th finished hole to be eccentric. In the trepanning test, all of the billets were bored within the eccentricit tolerance, the average eccentricity being 0.033-inch TIR.

Concentricity of the drilled billet is mainly dependent on the squareness of the billet end faces. Wit parallel and square faces, the eccentricity would not exceed 0.020-inch TIR, all of which would b attributed to runout of the trepanning tool.

5.4.2 Surface Finish

The hole surface finish, estimated at 150 rms, was considered satisfactory for extrusion billets. Som smearing of the ID surface was apparent. This was attributed to the severe wear on the tool's pressu pads. An improvement in pressure pad life should improve the surface finish quality.

5.4.3 Penetration Rate

For solid boring, the penetration rate was held constant at $2\frac{7}{8}$ ipm. The peripheral cutting speed wa 200 sfpm. Average time for completing one billet was 7.2 minutes. Higher penetration rates are u doubtedly possible, but a fixed rate was used to permit concentration upon other aspects of the tes

Trepanning was performed mainly at two penetration rates, 2 ipm and $2\frac{3}{16}$ ipm. Average drilling time p billet was 10.3 minutes and 9.2 minutes at the two penetration rates, respectively. The peripheral cutti speed was maintained at 250 sfpm. The one billet trepanned to estimate the maximum penetration ra indicated that 4 ipm is feasible and that a higher rate is possible.

5.4.4 Chip Formation

Chip formation was satisfactory during the solid boring work, although the short curled chip desi could not be obtained. The major portion of the chips were approximately 2 inches long and $\frac{3}{8}$ inch wi

Flushing of the chips presented no problem. At the feed rate of 0.006 inch per revolution, some crowding of the chips occurred which resulted in chip thickness of about 0.009 inch.

Chips produced during the trepanning test are shown in Figure 15. Owing to the differences in cutter geometries, three chips were produced during trepanning, while only two chips were produced during solid boring. Under these conditions, the trepanned chip is a narrower chip than the solid bore chip for an equivalent hole size. The trepanned chips were approximately 2 inches long by ¼ inch wide by 0.006 inch thick. Chip flushing was adequate as long as the standard trepanning tool geometry was used. When billets were trepanned using the solid boring tool geometry, clogging of the coolant exhaust passage occurred. This was attributed to the wide chip produced.

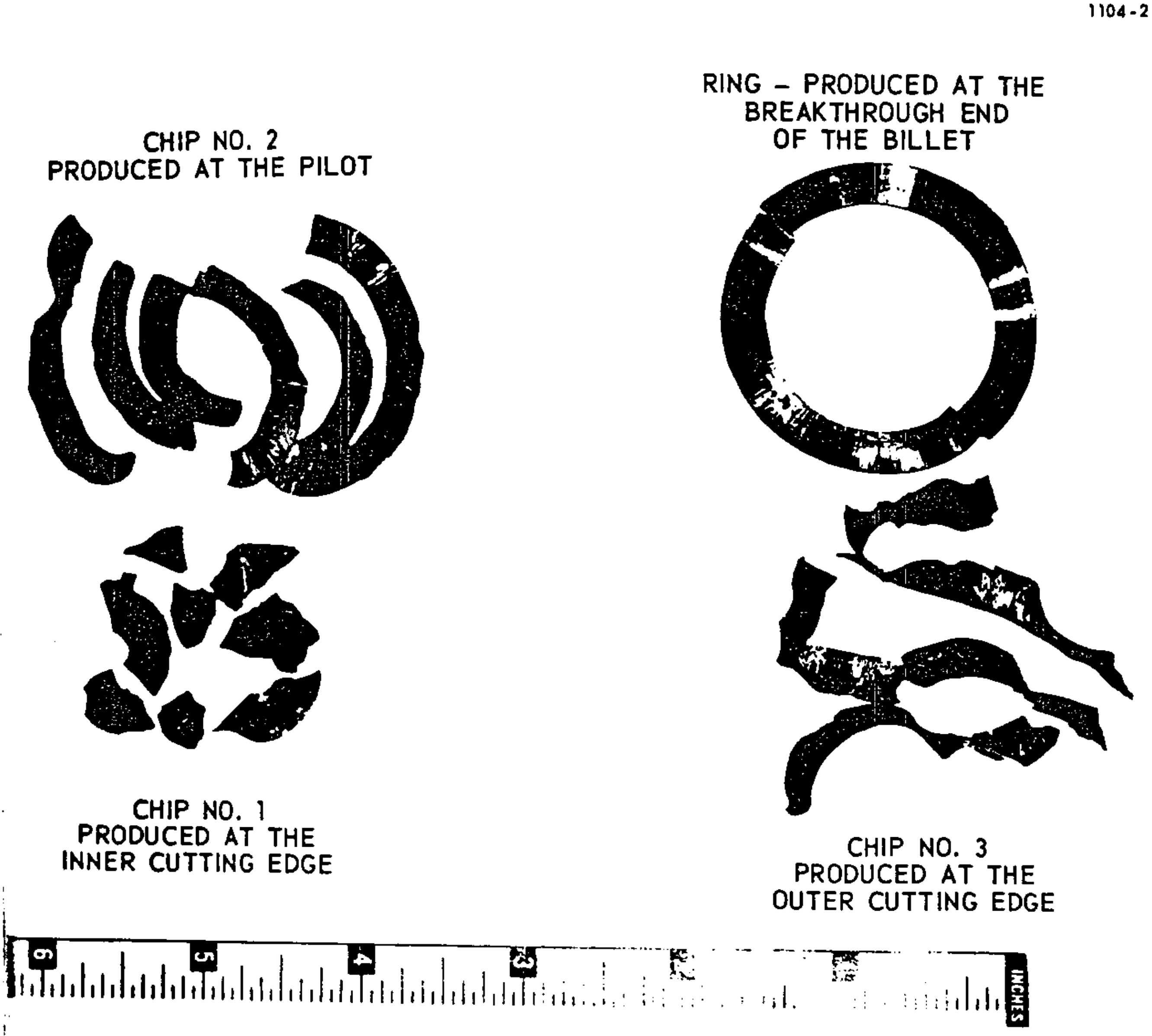

FIGURE 15 Chips Produced During Trepanning

5.4.5 Tool Life

The life of both the solid boring and trepanning tools is dependent upon cutter life and pressure pad life. Although the cutter wears faster than the pressure pads, the cutter can be reground several times. Pad wear is on the peripheral surface, and regrinding would reduce the tool diameter.

The solid boring tool has the cutter and the pads brazed into the steel body. The cutter life was five to six billets per grind with four to five regrinds possible. The carbide pressure pads were used for approximately seven billets before wear became excessive. The high-speed steel pads were used for nine billets and were still serviceable. It is estimated that 20 billets could have been drilled using these pads. The pressure pad life would be the determining factor in figuring the total life of this type of tool.

The trepanning tool has a replaceable cutter and pads which are mechanically held to the steel body. Cutter and pressure pad life were similar to those obtained on the solid boring tool, but the components can be replaced as required. Best results were obtained with carbide pads grooved to allow coolant tc flow under the pads and thereby provide better lubrication. Eight holes were completed with a set of such pads before the supply of test pieces was exhausted. Only slight pad wear was evident at that time.

6. CONCLUSIONS AND RECOMMENDATIONS

1. The LeBlond-Carlstedt Rapid Borer is an excellent machine for producing hollow extrusion billets from solid castings. The penetration rate is good, and the dimensional results are well within the desired limits.

2. Although tool cutter and pad life are considered acceptable, a substantial improvement is anticipated through future development work.

3. Whenever possible, heads with replaceable cutters and wear pads should be used to bore or trepan uranium. At the present time, a 1½-inch-diameter tool is the smallest that can be made with replaceable components.

4. In preparing feedstock for the Carlstedt Rapid Borer a method for cutting ingots should be developed that would insure that the end faces are not more than ¼ inch out of square with the OD.

7. ACKNOWLEDGMENTS

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The assistance of W. E. Stephens of the National Lead Company of Ohio is gratefully acknowledged, both in the performance of the test and in the subsequent evaluation of the data.

8. REFERENCE

[1] R. J. Jansen and J. F. Schiltz. "Billet Drilling on a LeBlond-Carlstedt Rapid Borer," Summary Technical Report for the Period January 1, 1961, to March 31, 1961, USAEC Report NLCO-826, p. 67. May 5, 1961.

9. APPENDIX

TABLE IV Tooling for Solid Boring

1 — Boring Tool - $1\frac{17}{32}$ inches in diameter

1 — Boring bar - 1.299 inches in diameter by 101 inches long

3 — Sets of inserts for boring bar supports - 1.299 inches in diameter

1 — Pair collets to fit tandem collet chuck to hold 1.299-inch-diameter boring bar.

1 — Spindle seal assembly complete for $1\frac{17}{32}$-inch bore diameter.

1 — Boring bar seal for 1.299-inch-diameter boring bar.

1 — Serrated clamping ring to fit 7-inch-diameter workpiece.

1 — Boring bushing for $1\frac{17}{32}$-inch bore diameter.

1 — Friction collet for 1.299-inch-diameter boring bar.

1 — Housing seal for 1.299-inch-diameter boring bar.

1 — Sealing ring for telescopic tubing used with 1.299-inch-diameter boring bar.

1 — Regrinding arbor to fit $1\frac{17}{32}$-inch-diameter solid boring head.

TABLE V Tooling for Trepanning

1 — Trepanning head - 2 inches in diameter with cutter and two pressure pads.

1 — Boring bar - $1\frac{11}{16}$ inches in diameter by 60 inches long.

3 — Sets of inserts for boring bar supports - $1\frac{11}{16}$ inches in diameter.

1 — Pair collets to fit tandem collet chuck to hold $1\frac{11}{16}$-inch-diameter boring bar.

1 — Spindle seal assembly complete for 2-inch bore diameter.

1 — Boring bar seal for $1\frac{11}{16}$-inch-diameter boring bar.

1 — Serrated clamping ring for $7\frac{5}{16}$-inch workpiece diameter.

1 — Boring bushing for 2-inch bore diameter.

1 — Friction collet for $1\frac{11}{16}$-inch-diameter boring bar.

1 — Housing seal for $1\frac{11}{16}$-inch-diameter boring bar.

1 — Sealing ring for telescopic tubing used with $1\frac{11}{16}$-inch-diameter boring bar.

1 — Regrinding arbor to fit 2-inch-diameter trepanning head.