AD-A010 351

MACHINABILITY PROGRAM FOR DEPLETED URANIUM ALLOY PENETRATORS

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AMMUNITION TECHNOLOGY DIVISION
LAKE CITY ARMY AMMUNITION PLANT
INDEPENDENCE, MISSOURI 64056

MACHINABILITY PROGRAM

FOR

DEPLETED URANIUM ALLOY PENETRATORS

ATD Project Report 74-2

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TABLE OF CONTENTS

SUMMARY

A machining program was conducted to produce GAU-8 uranium alloy penetrators, using industrial facilities and procedures. There were two additional goals of this effort: 1) to assess the relative machinability of two basic alloy types (U-3/4 Ti and U-3/4 Quad) having various minor compositional and major processing differences; and 2) to generate a cost estimate for a larger production run of 1,000,000 penetrators.

The starting material was in the form of six-foot lengths of extruded bar stock in the solution heat-treated condition. Prior to receipt of this material from National Lead of Ohio, special facilities were established for the safe and proper handling of uranium. In addition, gages and tooling were designed and fabricated for use in this program.

A total of 3,638 acceptable penetrators were made. The main problems encountered were non-linearity and poor diameter uniformity of the supplied bar stock. In terms of tool life and machining speed, one of the U-3/4 Ti materials showed the best machinability. Using the data generated in this program, two cost estimates (based on two different forms of starting material) were developed for a larger production effort of 1,000,000 penetrators.

INTRODUCTION

This machining program was a joint effort by the Air Force Materials Laboratory, Frankford Arsenal, and the Ammunition Technology Division (ATD), LCAAP to establish the necessary manufacturing technology for the production of uranium alloy armor piercing projectiles.

The A-10 close support aircraft armed with the GAU-8/A 30mm gun is incorporating depleted uranium alloy projectiles in the AP rounds. The Army's Bushmaster may also use a DU round.

Extensive Research and Development work by the Air Force, Army, Navy, and Atomic Energy Commission has shown the DU alloy can be made into rods by extrusion and the rods can be machined in automatic sequences.

This program has been reviewed by and has the support of the Bushmaster Office; A-10 SPO; Air Force Armament Laboratory; Eglin Air Force Base; Army Materials and Mechanics Research Center, Watertown; and the Navy Phalanx Project Office. This program was recommended as a new cooperative project by the Tri-Services Manufacturing Technology Advisory Group.

In the past (time frame 1961 to 1964) a production facility was established and a significant number of M101 type projectile bodies were manufactured from D38 Uranium Alloy, MIL Spec. U-46045 (Uranium/Molybdenum - 92/8) by Remington Arms Company, Inc., under the technical supervision of ATD personnel at Lake City Army Ammunition Plant. Because of this experience, the ATD and Remington Arms Company, Inc., were asked to participate in a program of machining DU alloy penetrators.

OBJECTIVE

The objective of this machinability program was to determine the machining characteristics of two DU alloys: 0.75% Ti and 0.75% Quad. The effects of relatively small changes in the composition of a given DU alloy on machinability, the machine speeds and feeds to be used in the machining of DU alloys, and the effects of negative and positive rake on tool design were to be established.

This data was required in order to determine if penetrators could be made satisfactorily on multi-spindle automatic screw machines. This data would also be used in preparing a cost estimate for establishing a production line for 1,000,000 penetrators at the rate of 100,000 per month for 10 months on a 1-shift/8-hour day/5-day week/20-day month.

APPROACH

Remington Arms Company, Inc., was instructed to manufacture a maximum of 500 penetrators each of nine material conditions, supplied as 11/16" diameter bar stock (straightness of the uranium alloy material was not to vary 1/4" from the longitudinal axis in any 6' lengths). To accomplish this, a building was set up with the necessary machine tools, washing facilities, ventilation equipment, and waste disposal equipment required for DU work. Perishable tools were designed and fabricated.

The material schedule in this program was as follows, with the alloys supplied by National Lead of Ohio.

URANIUM PENETRATOR PROGRAM PARAMETERS

A. MATERIAL CONDITIONS (NINE)

Alloy Type	Nominal Composition (Wt%) Mo	Zr	Nb	Ti	Solution Treated Only	Rod No.	Solution Treated+Aged	Rod No.	As Extruded No Solution Treatment	Rod No.
U-3/4 Ti	-	-	-	0.65			X	4		
	-	-	-	0.75	X	3	X	2A & 2B		
	-	-	-	0.85			X	1 & 1A		
U-3/4 Quad	0.65	0.65	0.65	0.40			X	8		
	0.75	0.75	0.75	0.50	X	7A	X	6,6A&7C	X	7D
	0.85	0.85	0.85	0.60			X	5		

The originally specified bar diameter of 11/16" was changed to 3/4" bar diameter. This change required the procurement of different size collets for the machine tools used in this program.

The nine different experimental lots of penetrators made from the various DU alloys were produced on turret lathes, chuckers, a monomatic lathe, and Hardinge lathes. This equipment was chosen because of availability, ease of changing perishable tools, machining feeds, machining speeds, and access to make observations during the machinability program.

The machining was done according to LCAAP Drawing LC-SK-982 (as subsequently amended). To complement this drawing, the following Inspection Plan was prepared by LCAAP:

INSPECTION PLAN

1. Drawing: LC-SK-982 dated 20 Sep 73 (subsequently amended with Revision A dated 21 Mar 74 and Revision B dated 30 May 74)

2. Applicable Documents:

   MIL-STD-105
   MIL-STD-109
   MIL-STD-1168
   MIL-STD-1169
   ASTM E18-67 Method of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials

3. Requirements:

   a. The penetrator shall be in accordance with the requirements of Drawing LC-SK-982 with all requirements of the drawings and specification shown thereon.

   b. Hardness. The penetrator shall be in accordance with hardness requirements of Drawing LC-SK-982.

   c. Workmanship. The requirements for workmanship are as specified by applicable drawings, reference specifications and the following:

   (1) Processing Defects: The penetrator shall be free of dents, deep scratches, cuts, sharp edges, burrs, metal flaws, excessive surface roughness and other forms of substandard workmanship.

   (2) Cleanliness: The penetrators shall be free of all foreign matter.

   d. Defect characteristics are to be considered individually to determine acceptability.

Individual:

Major	0.25%
Minor	0.40%

e. Classification of Defects:

Critical: None defined.

Major:

Body diameter	Gage
Length of body diameter	Gage
Length, overall	Gage
Runout, tapered end with datum surface	Gage
Angle of long taper	Gage
Perpendicularity of base with datum surface	Gage
Weight	Balance

f. Tests:

Test	Sample Size
Hardness, Penetrator 1/	13

1/ If two or more units of the sample fail to comply with the hardness requirements, the lot shall be rejected. If one unit fails to comply with the requirement, a second sample consisting of the same number of units as specified for the first sample shall be tested. If, in the accumulated samples, two or more units fail to comply with the hardness requirements, the lot shall be rejected. (Since some of the received solution treated material had abnormally low or high hardness, the prescribed aging treatment for each alloy system (Ti and Quad) resulted in some hardnesses outside the requirement ranges. Therefore, in this program, no lots were rejected. The average hardness of the penetrators before and after aging is included in the Appendix on Page 30.)

The angle of the long taper on the penetrator could not be inspected without additional information on production drawing LC-SK-982. Revision A dated 21 Mar 74 corrected this discrepancy. Gage designs were prepared, evaluated, and approved. The gages were then built and certified .

RESULTS AND DISCUSSION

A. MACHINABILITY

Originally the configuration of the penetrator permitted centers at both ends. Subsequently, instructions from the Air Force requested that the final penetrators be without center holes. Therefore, Revision B was made to production drawing LC-SK-982 on 30 May 1974. The elimination of centers resulted in an additional machining operation and increased the required length of the stock from 4.75 inches to 5.00 inches to provide additional material for a false center that was cut off after machining operations were completed.

Originally it was intended to use Process "A" to machine DU alloy penetrators. This process required 15 machining elements using turret lathes and a Hardinge lathe. Process "A" is included in the Appendix on page 18.

Due to the condition of the bar stock as received, Process "B", shown on pages 19 and 20 of the Appendix, which requires 21 machining elements was used to machine DU alloy penetrators using turret lathes, chuckers, and a monomatic lathe. Conditions of some of the bars, as received, are included in the Appendix, pages 25, 26, 27, and 28.

The material which could not be fed in a turret lathe for the first machining element of Process "B" had to be cut into 5-inch slugs on an abrasive cut-off machine. This added another machining element to Process "B" (referred to as Process "C" on page 21 of the Appendix). The machining operation sheets for Processes "A" and "B" are included in the Appendix on pages 22, 23, and 24.

Problems were encountered in manufacturing DU alloy penetrators. These included the following:

1. Piping.-Some bar stock had centerline voids, remaining from insufficient ingot cropping.

2. Inconsistent Cutting Pattern.-Some work pieces and penetrators from the same bar stock were more difficult to machine, resulting in longer machining time and shorter tool life. Variations in pyrophoric effects were also noted for the same bar stock.

3. Eccentric Parts.-Parts not truly round and concentric with their axes of rotation produced a surge of pressure on the turning tool approximating impact. It was necessary to advance the tool radially at a small feed per revolution until the tool was cutting all around the work piece.

4. Interrupted Cuts.-There was a definite impact on the cutting tool every time a break in the cylindrical surface of the work piece occurred.

5. Grinding.-The removal of metal by grinding causes the face of the grinding wheel to wear and become irregular in its outline. Therefore, the grinding wheel must be dressed to true up the wheel face. When penetrators made of Quad alloy were ground, the face of the grinding wheel had to be dressed 3 to 4 times as often as when penetrators made of Ti alloy were ground.

6. Residual Stresses.-The bar stock was received at Lake City Army Ammunition Plant with residual stresses. It was possible that these residual stresses were induced by mechanical straightening of the bar stock prior to shipment of the bar stock to LCAAP. The bar stock with residual stresses had excessive distortion and were severely warped. After taking a machining cut the residual stresses were relieved in the work

piece material. Consequently, after taking a machining cut the work piece material was eccentric and had dimensional changes. The work piece material thus stress relieved had to be subjected to additional machining cuts to compensate for the eccentricity and dimensional changes. Due to the additional machining elements required by the residual stresses, additional stock for grinding had to be left on the work piece material. As a result the machining time and grinding time for each penetrator were increased.

7. The originally prescribed salt bath for aging caused large scale corrosion and had to be replaced by a lead-tin aging medium.

The machinability and tool life data developed during the DU alloy machinability program are shown in the Appendix, page 29. The hardnesses measured in the various alloys both before and after aging are given in the chart on page 30 of the Appendix.

During the machinability program, 3,638 units meeting the specifications of LC-SK-982 and the inspection plan were manufactured from nine different DU alloy conditions. These were delivered to AAI Corporation, Eglin Air Force Base, Frankford Arsenal, and Sandia Laboratories. The production methods, tooling, equipment, and raw material and inspection procedures were established during this program, which was completed on 18 October 1974. The most promising DU alloy condition from machining considerations was indicated to be the 0.75% Ti alloy - alloy No. 2A.

B. COST ESTIMATE

The appropriate results of the machining program were used to generate a cost estimate for establishing a production line for 1,000,000 DU alloy penetrators to be produced at the rate of 100,000 per month for 10 months on a 1-shift/8-hour day/5-day week/20-day month. Recurring cost data cover the manufacture of 1,000,000 penetrators. This estimate reflects the following four considerations:

1. This estimate was prepared based on the assumption that the required equipment, with the exception of electrostatic precipitators and special heat-treating equipment, will be available from DOD Industrial Equipment Reserves. It is also assumed that facilities for installation of the equipment will be made available by the Government. Approximately 25,000 square feet of floor space will be required to house the additional equipment.

2. Perishable tool costs are based on the cost of tools utilized during the manufacture of 3,638 penetrators. The cost of setting up the line is shown separately from the labor and material cost for the manufacture of the penetrators.

3. This estimate is based on using DU alloy bar stock 3/4" in diameter (straightness of the DU alloy material not to vary 1/4" from the longitudinal axes in any 6' lengths).

4. The estimate is based on 1974 dollars.

The machining operations for this estimate are shown on page 32 of the Appendix; and the pertinent flow sheets are on pages 33 and 34.

ESTABLISH PRODUCTION LINE

Lead time required to set up the production line is 10 months after funding is received.

Labor, Burden and Material Costs for 1,000,000 Penetrators

Item: Non-recurring Cost Data

1.	Building and Facilities (25,000 sq. ft. area) to be made available by Government. In the event the penetrator program is expanded, an estimate will be prepared for establishing scrap disposal facilities. Included in Item 1, of Recurring Cost Data, is the cost for packing and off-plant shipment of scrap for disposal.	---------
2.	Equipment required, conversion, machine attachments, tool holders and installation.	$ 976,256.00
3.	Miscellaneous production aids.	50,000.00
4.	Fabricate gages.	25,000.00
5.	Initial perishable tool cost is included in tool cost for 1M penetrators.	---------
6.	Engineering: Establish process and manufacturing capability.	30,000.00
7.	Reconversion (after the program) of 18 automatic screw machines from chuckers to bar feed.	90,000.00
	Restoration of manufacturing area to original status cannot be estimated until the area of manufacture is established.	
	Shipping cost for equipment from Industrial Reserves to Lake City Army Ammunition Plant.	100,000.00
	Total Non-Recurring Costs	$1,271,256.00

Item: Recurring Cost Data

1.	Tools, grinding wheels, packing material and protective clothing.	$1,223,800.00
2.	Raw material (depleted uranium, bar stock 6 feet long).	GFM
3.	Direct labor plus 250% burden.	$4,436,320.00
	a. Engineering plus 105% burden.	21,472.00
	b. Maintenance plus 105% burden.	60,480.00
4.	Manufacturing overhead (included in Item 3).	---------
5.	General & Administrative cost (included in Item 3).	---------
6.	Proposed fee - To be negotiated when project is funded.	---------
	Total Recurring Costs	$5,742,072.00
	Grand Total	$7,013,328.00

However, after the cost estimate to establish a production run of 1,000,000 DU alloy penetrators from 3/4" bar stock 6 feet long (straightness not to vary 1/4" from the longitudinal axis in any 6-foot length) was prepared, LCAAP was requested to prepare a revised cost estimate for the 1,000,000 DU alloy penetrators to be manufactured from GFM slugs or cut-to-length pieces of DU alloy bar stock with the following specifications:

Material:	Government-furnished Alloy 2A - 0.75% Ti Alloy Solution Treated Aged to Rockwell Hardness RC 44 to RC 48
Length:	4.530 + .063 inches - .000
Outside Diameter:	0.640 + .005 inches - .000
Runout-Warp (Total Dial Indicator Reading):	0.005 inch
Surface Roughness:	250 RMS Maximum

The revised estimate eliminates cutting the GFM bar stock into slugs, one forming operation, and the heat-treating operation included in the original cost estimate. The required floor space is also reduced from 25,000 square feet to 22,000 square feet.

Perishable tool costs are based on the cost of tools utilized during the manufacture of 3,633 penetrators. The cost of setting up the line is shown separately from the labor and material cost.

The estimate is based on 1974 dollars.

The machining operations for the revised estimate are shown on page 35 of the Appendix, and the flow sheet is on page 36.

ESTABLISH PRODUCTION LINE

Lead time required to set up the production line is 10 months after funding is received.

Labor, Burden and Material Costs for 1,000,000 Penetrators

Item: Non-recurring Cost Data

1.	Building and Facilities (22,000 square feet area) to be made available by Government. In the event the penetrator program is expanded, an estimate will be prepared for establishing scrap disposal facilities. Included in Item 1, of Recurring Cost Data, is the cost for packing and off-plant shipment of scrap for disposal.	-------
2.	Equipment required, conversion, machine attachments, tool holders and installation.	$ 619,154.00
3.	Miscellaneous production aids.	45,000.00
4.	Fabricate gages.	25,000.00
5.	Initial perishable tool cost is included in tool cost for 1M penetrators.	-------
6.	Engineering: Establish process and manufacturing capability.	30,000.00
7.	Reconversion (after the program) of nine automatic screw machines from chuckers to bar feed. Restoration of manufacturing area to original status cannot be estimated until the area of manufacture is established.	45,000.00
	Shipping cost for equipment from Industrial Reserves to Lake City Army Ammunition Plant.	90,000.00
	Total Non-Recurring Costs	$ 854,154.00

Item: Recurring Cost Data

1.	Tools, grinding wheels, packing material and protective clothing.	$1,053,800.00
2.	Raw material (depleted uranium, slugs or cut-to-length bar stock).	GFM
3.	Direct labor plus 150% burden.	$2,896,812.00
	a. Engineering plus 105% burden.	21,472.00
	b. Maintenance plus 105% burden.	60,480.00
4.	Manufacturing overhead (included in Item 3).	--------
5.	General & Administrative cost (included in Item 3).	--------
6.	Proposed fee - To be negotiated when project is funded.	--------
	Total Recurring Costs	$4,042,564.00
	Grand Total	$4,896,718.00

CONCLUSIONS:

The use of DU alloy for the fabrication of penetrators on a production basis using automatic screw machines is feasible provided the quality of material is maintained at a consistent high level. Although production of DU alloy penetrators has been arduous and difficult, the progress made to date indicates the advancements which can be made as the DU alloy penetrator program proceeds.

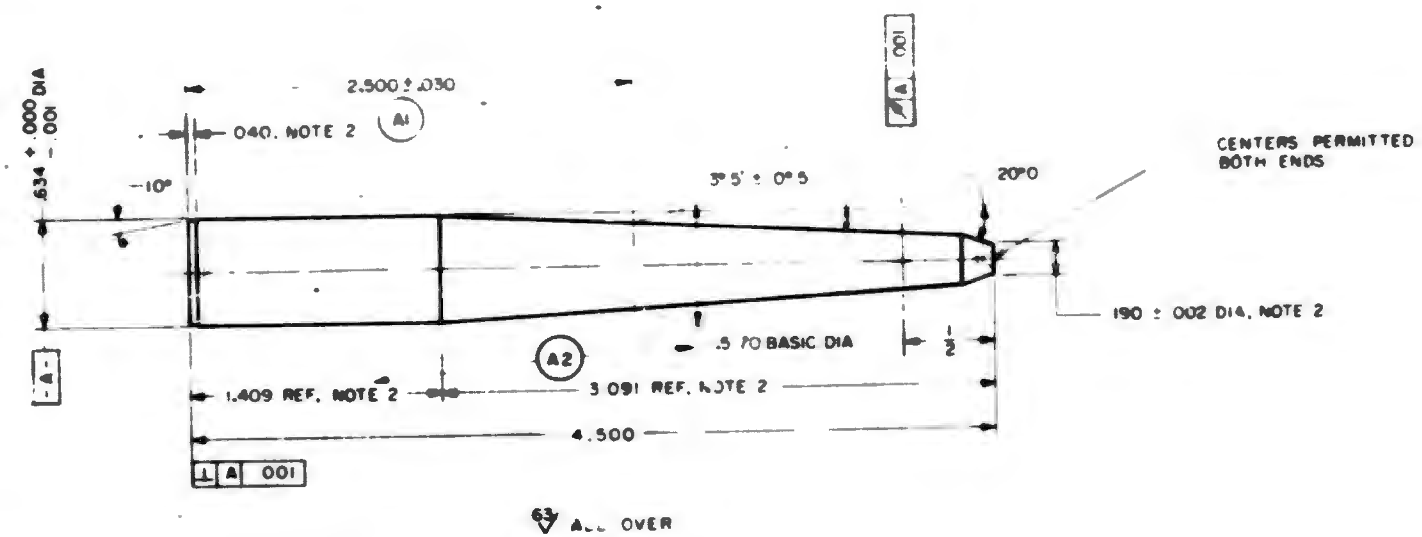
One of the biggest problems yet to be overcome is the inconsistent quality and configuration of DU alloy material. Considerable improvement in the uniformity of the material will be required to insure continued improvement in the manufacturing processes. It is felt that with uniform quality and configuration of the material, automatic screw machines could be utilized to increase the production rates and decrease the manufacturing cost of DU alloy penetrators.

Depleted uranium 0.75% Ti alloy was determined to have the best machining characteristics.

It was estimated that a production line for 1,000,000 penetrators made from slugs or cut-to-length DU 0.75% alloy bar stock could be set up at less cost than a production line for 1,000,000 penetrators utilizing 6-foot long DU 0.75% alloy bar stock.

INDEX OF APPENDIXES

A 21 ADDED .5 70 BASIC DIA AT A DISTANCE OF 2.500 ± .030 FROM REAR OF PENETRATOR. CHANGED "1.409, NOTE 2" TO "1.409 REF, NOTE 2" — 3-21-78



NOTES -
1. SPECIFICATION MIL-A-2550 APPLIES
2. DIMENSION APPLIES AT THEORETICAL INTERSECTION OF SURFACES.
3. DIMENSIONAL REQUIREMENTS APPLY AFTER HEAT TREATMENT, IF REQUIRED
4. MATERIAL TO BE EITHER FURNISHED OR SELECTED BY THE GOVERNMENT DESIGN ACTIVITY

REFERENCE
DESIGN DATA WAS DETERMINED FROM AA DRAWING NO C56328-4 1 4

PART NO. LC-SK-982

SEE ENGINEERING RECORDS	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES ON DECIMALS ± .005	
MATERIAL	DEPLETED URANIUM ALLOY, NOTE 4
HEAT TREATMENT	NOTE 3
ORIGINAL DATE OF DRAWING	SEP 20, 1973
LAKE CITY ARMY AMMUNITION PLANT, INDEPENDENCE, MISSOURI	
TITLE	PENETRATOR
CODE IDENT NO	19201
SIZE	C
DRAWING NO	LC-SK-982
SCALE	2/1

FIGURE 1

C LC-SK-982

Table 1. **MACHINING DU ALLOY PENETRATORS**

PROCESS A

1st Operation — #4 TURRET LATHE

Length of Part = 5.00 inches   Diameter of Bar Stock = 3/4"

Element Number	Description
1	STOCK OUT APPROXIMATELY 4-3/4"
2	SINGLE POINT FOR 1/4" TO .639+.002 TO TRUE END OF BAR STOCK
3	BOX MILL .639+.002 FOR 4-3/4"
4	END FORM 20° ANGLE - HANDFED
5	SPECIAL BOX MILL - TURN TAPER
6	CUT-OFF
7	SINGLE POINT - FACE OFF BAR END
2nd Operation	**HARDINGE LATHE**
8	CHUCK ON .639 DIAMETER, WITH NOSE IN COLLET AGAINST STOP
9	FACE TO OVERALL LENGTH
10	CHAMFER 10° ANGLE
3rd Operation	**HEAT TREAT**
11A	3/4 Ti - 830°-850°F FOR 1 HOUR & 15 MINUTES
11B	3/4 Quad - 600°F ± 10° FOR 2 HOURS
4th Operation	**CENTERLESS GRINDER**
12	GRIND OUTSIDE DIAMETER, TAPER AND 20° ANGLE
5th Operation	**SURFACE GRINDER**
13	GRIND END FACE OF .634 DIAMETER
6th Operation	**HARDINGE LATHE**
14	CHAMFER 10° ANGLE
7th Operation	
15	CLEAN

Table 2. **MACHINING DU ALLOY PENETRATORS**

PROCESS B

1st Operation — #4 TURRET LATHE

Length of Part = 5.00 inches   Diameter of Bar Stock = 3/4"

Element Number	Description
1	STOCK OUT APPROXIMATELY 2"
2	SINGLE POINT FACE TOOL TO TRUE AND SQUARE END
3	SINGLE POINT 1/4" LONG FOR BOX ROLLERS
4	ROLLER TURN FOR 1.6" LENGTH (.641 DIAMETER)
5	STOCK OUT AND PART OFF TO 4.850 LENGTH
2nd Operation	**#3 W&S CHUCKER**
6	CHUCK SLUG ON .641 DIAMETER
7	CENTER DRILL
8	CENTER SUPPORT
9	SINGLE POINT TO CLEAN AT .500 DIAMETER FOR 3/4" LONG
10	BOX MILL FORM .220 DIAMETER BY .300 LONG - FALSE CENTERS
3rd Operation	**MONOMATIC TRACER LATHE**
11	CHUCK ON .641 OUTSIDE DIAMETER
12	POSITION CENTER SUPPORT
13	CYCLE START - 3 CUTS REG 3/4 Quad ALLOY 1 CUT REG 3/4 Ti ALLOY
4th Operation	**#3 W&S CHUCKER**
14	CHUCK ON .641 OUTSIDE DIAMETER
15	POSITION SPECIAL ROLLER STEADY REST - REAR POSITION CROSS SLIDE
16	FACE OFF FALSE CENTER - MODIFIED BOX MILL - NO ROLLERS

PROCESS B (Cont).

5th Operation	HEAT TREAT
Element Number	Description
17A	3/4 Ti - 830°-850°F FOR 1 HOUR & 15 MINUTES
17B	3/4 Quad - 600°F ± 10° FOR 2 HOURS
6th Operation	CENTERLESS GRINDER
18	GRIND OUTSIDE DIAMETER, TAPER AND 20° ANGLE
7th Operation	SURFACE GRINDER
19	GRIND END FACE OF .634 DIAMETER
8th Operation	HARDINGE LATHE
20	CHAMFER 10° ANGLE
9th Operation	
21	CLEAN

Table 3. MACHINING DU ALLOY PENETRATORS

METHOD	NO. OF ELEMENTS	*LENGTH OF PART IN INCHES
PROCESS A TURRET LATHE HARDINGE LATHE	15	5.00
PROCESS B TURRET LATHE CHUCKER MONOMATIC LATHE CHUCKER	21	5.00
PROCESS C ABRASIVE CUT-OFF MACHINE TURRET LATHE CHUCKER MONOMATIC LATHE CHUCKER	22	5.00

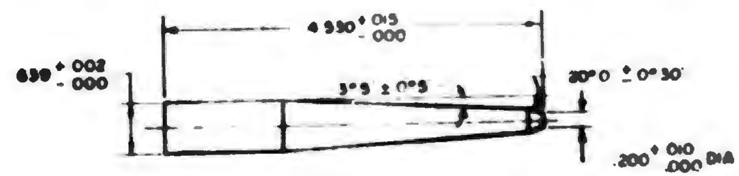
NOTE: DUE TO ELIMINATION OF CENTERS LENGTH OF PART HAD TO BE INCREASED FROM 4.75 INCHES TO 5.00 INCHES.

FIGURE 2. 1st, 2nd, and 3rd Operation Process "A" and 5th Operation Process "B"

MACHINING DU ALLOY

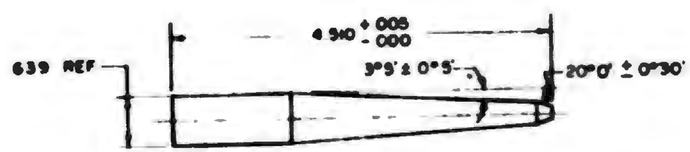
PENETRATORS

PROCESS "A" & "B"



1ST OPERATION

#4 TURRET LATHE



2ND OPERATION

HARDINGE LATHE

3RD OPERATION PROCESS "A" & 5TH OPERATION PROCESS "B"

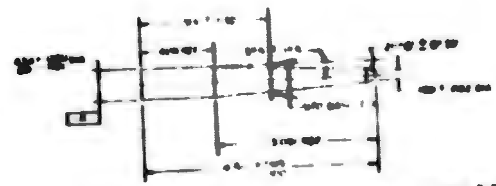
HEAT TREAT

(IF REQUIRED)

FIGURE 3. 4th, 5th, 6th and 7th Operation Process "A" and 6th, 7th, 8th and 9th Operation Process "B"

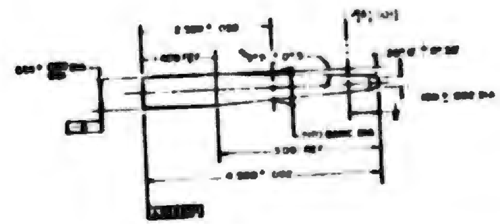
PENETRATORS

PROCESS "A" & "B"



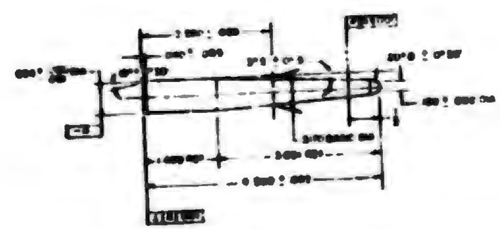
4th OPERATION PROCESS "A" & 6th OPERATION PROCESS "B"

CENTERLESS GRIND



5th OPERATION PROCESS "A" & 7th OPERATION PROCESS "B"

SURFACE GRINDER



6th OPERATION PROCESS "A" & 8th OPERATION PROCESS "B"

MACHINE LATHE

7th OPERATION PROCESS "A" & 9th OPERATION PROCESS "B"

CLEAN

FIGURE 4. 1st, 2nd, 3rd and 4th Operation Process "B"

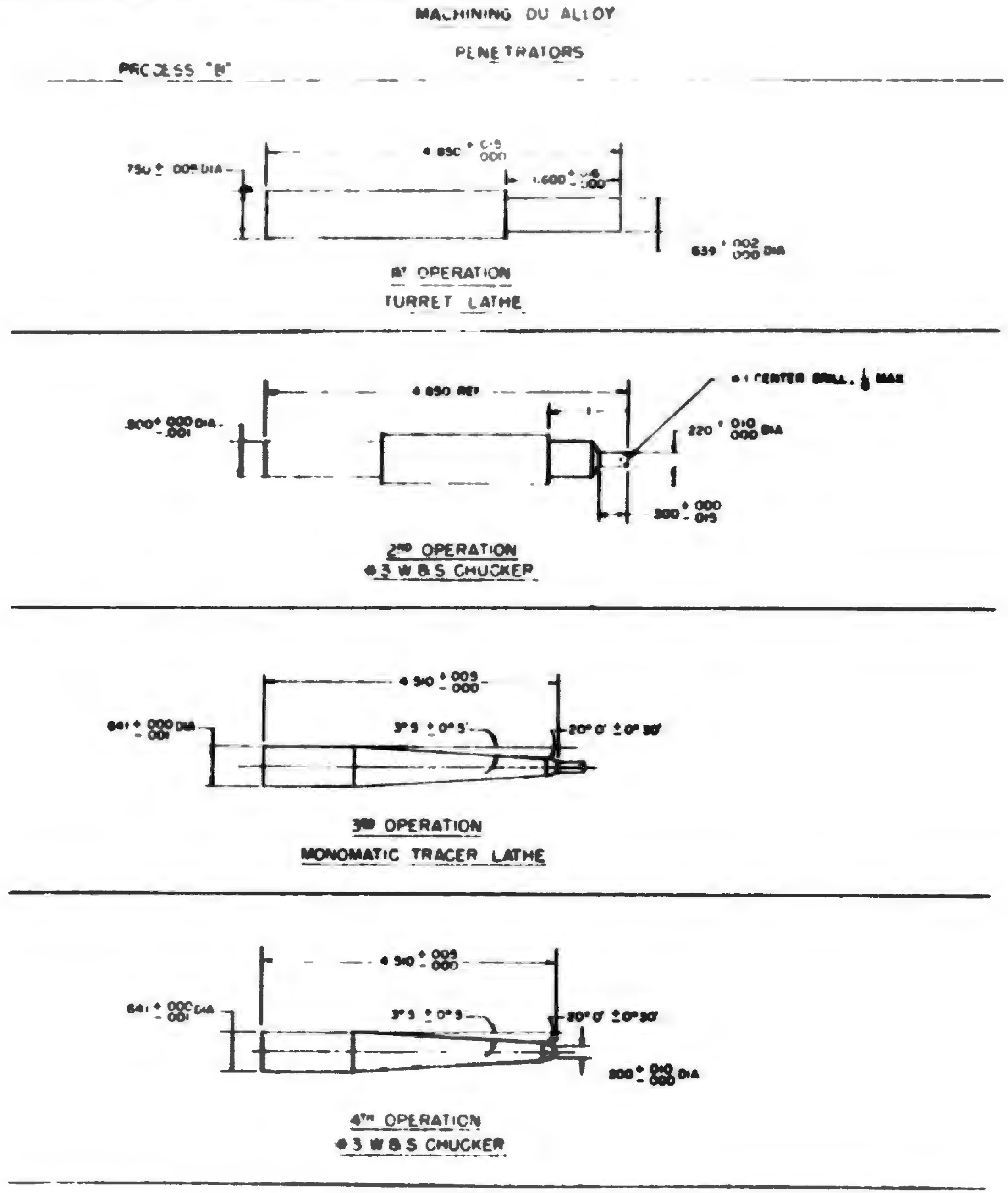


FIGURE 5. Alloy as Received at ICAAP.

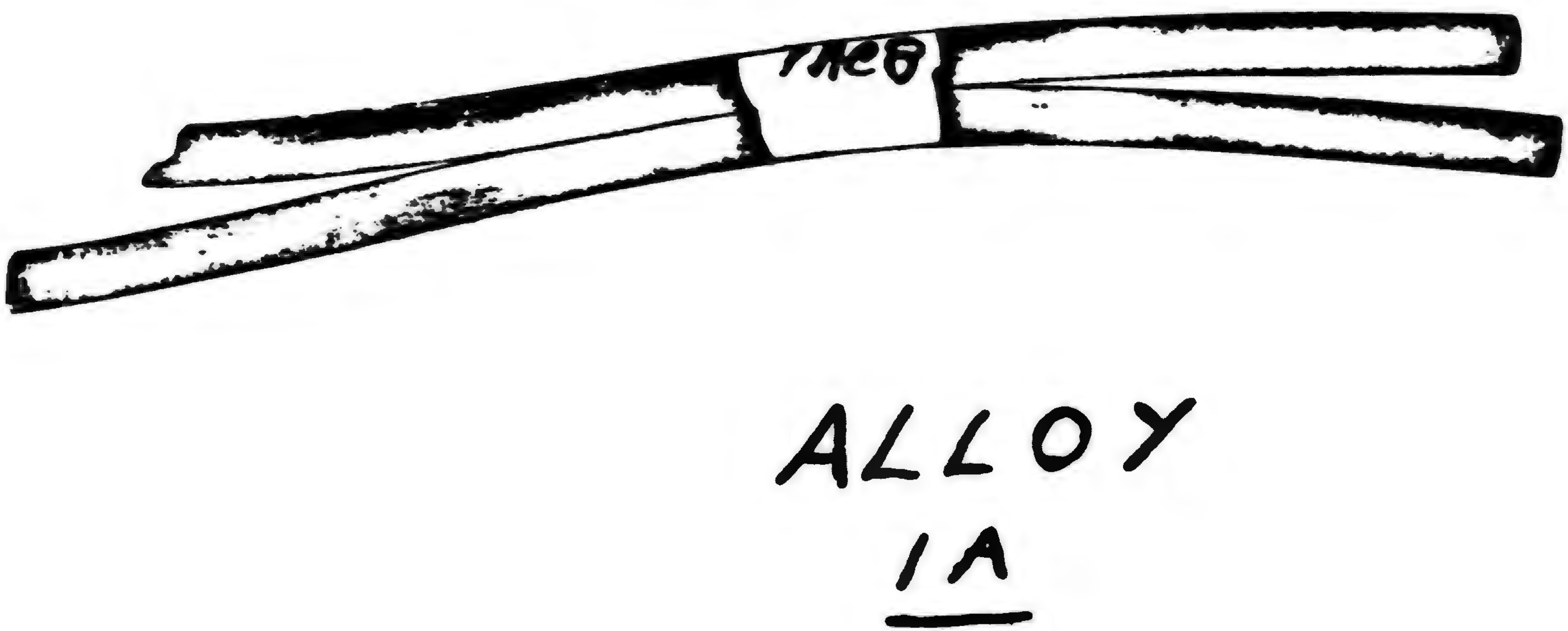


FIGURE 6. Alloy No. 6A as Received at LCAAP.

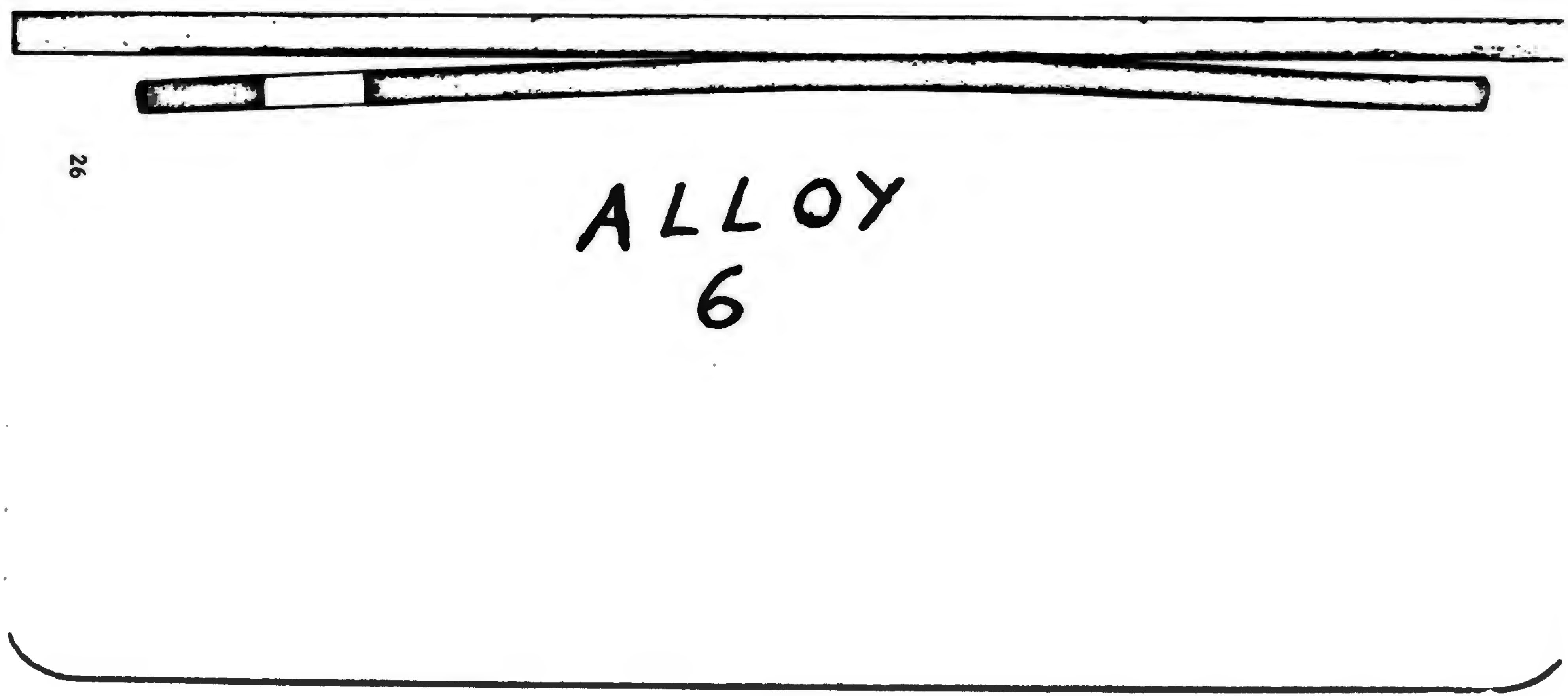


FIGURE 7. Alloy 7A as Received at LCAAP.

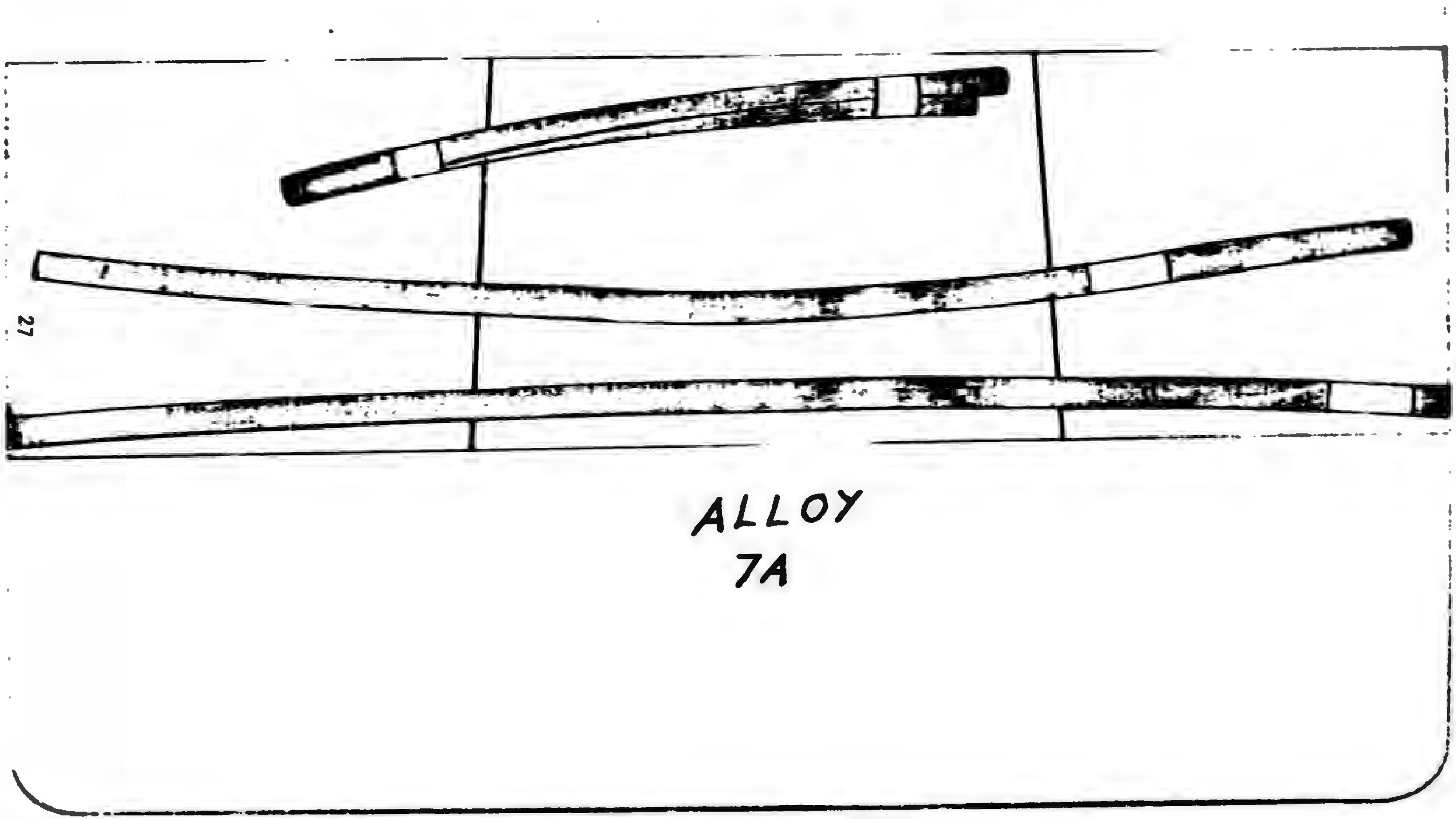


FIGURE 8. Alloy as Received at ICAAP.

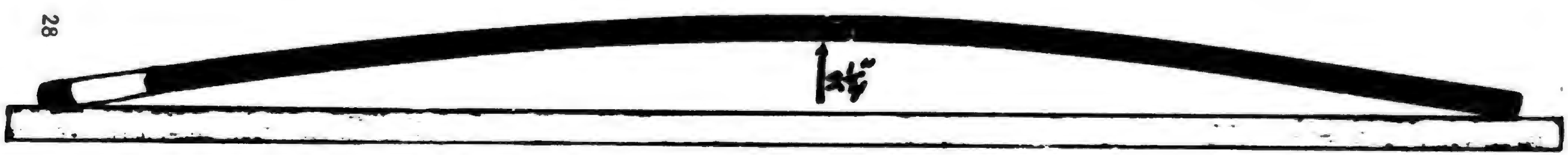
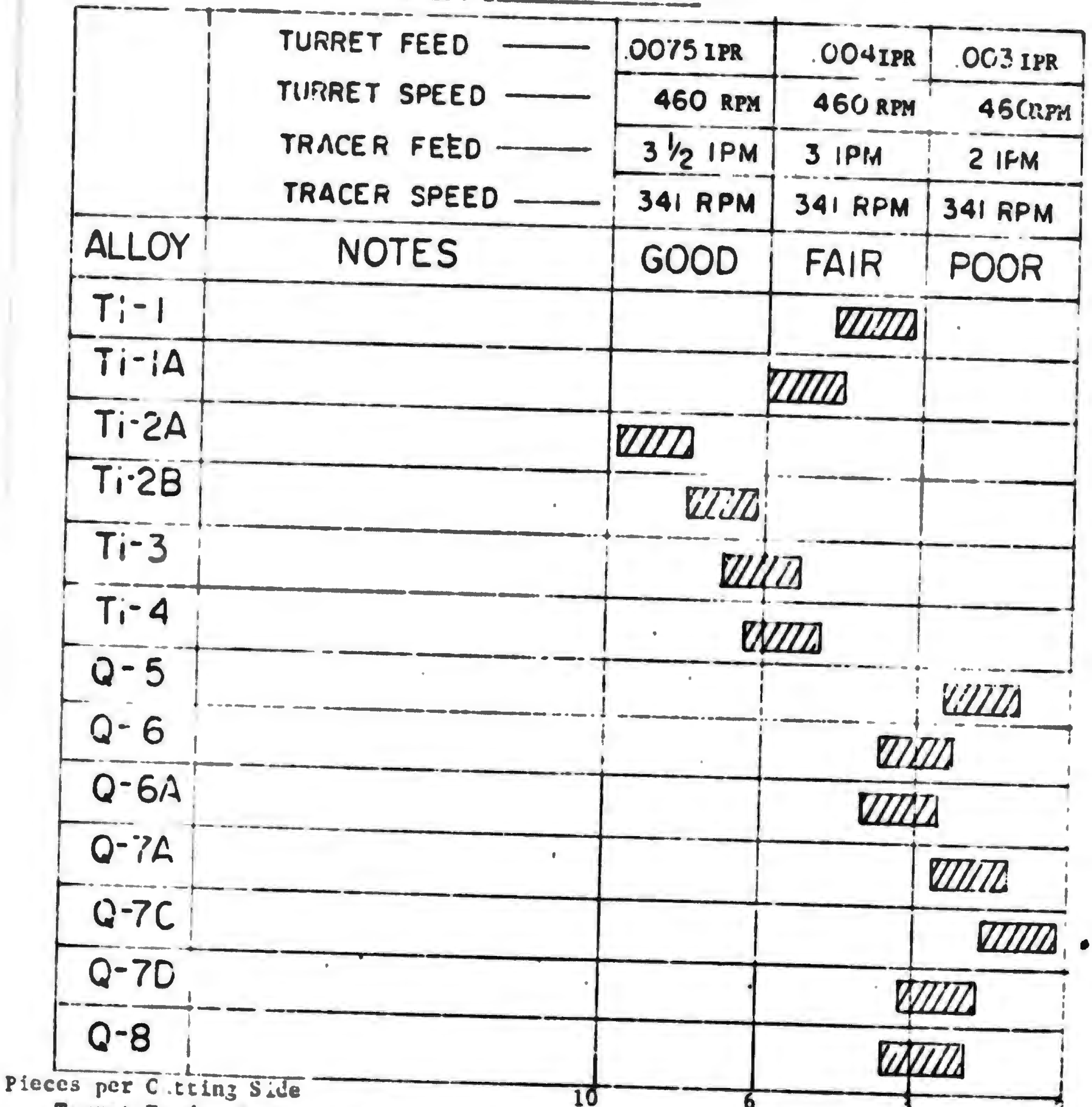


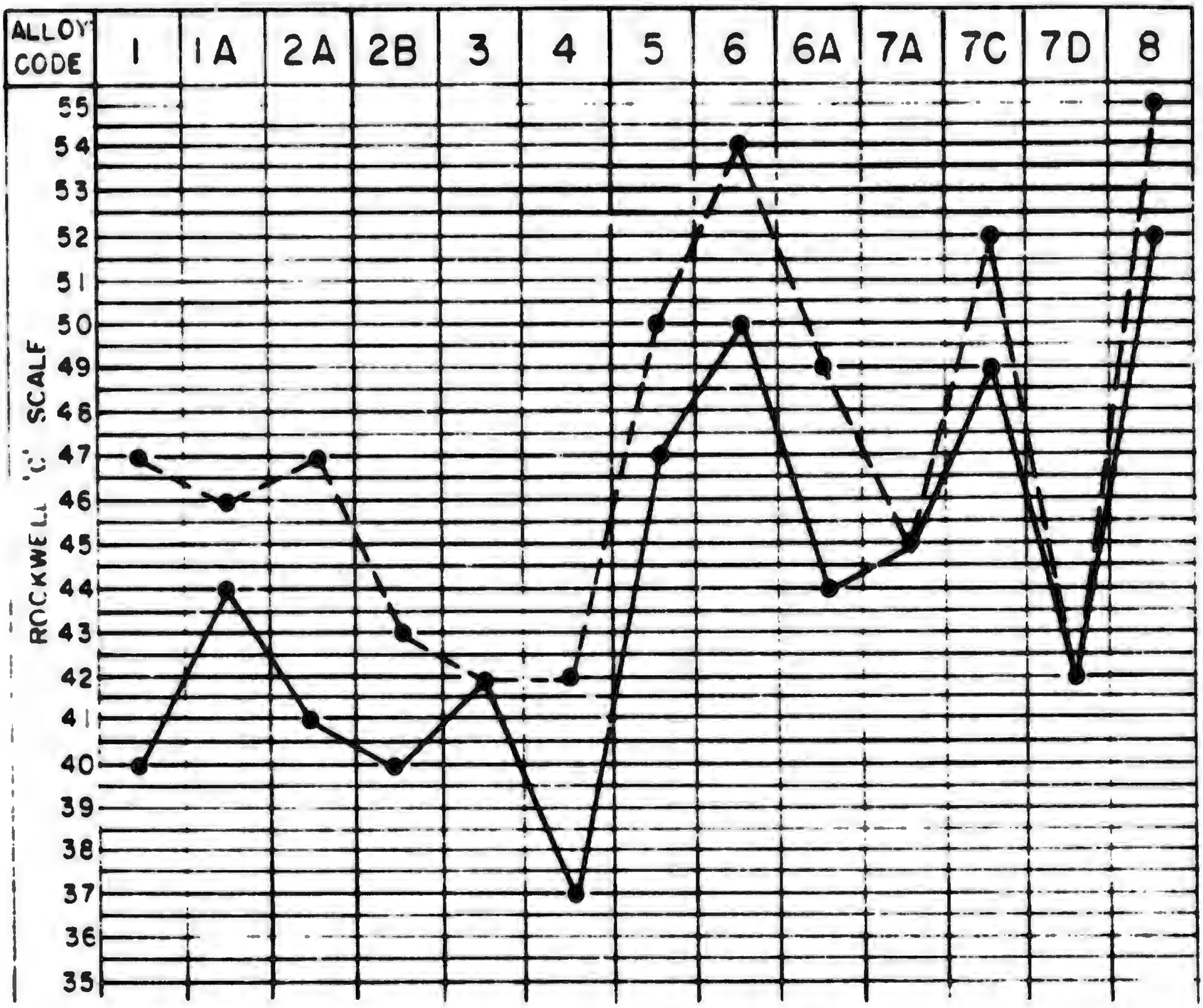
CHART 1

MACHINABILITY AND TOOL LIFE



Turret Feed = Inch per revolution
Turret Speed = Revolution per minute
Tracer Feed = Inch per minute
Tracer Speed = Revolution per minute
Triangular Carbide Inserts - 3 cutting sides
Good = 7 to 10 work pieces per cutting side = 21 to 30 cuts
Fair = 4 to 6 work pieces per cutting side = 12 to 18 cuts
Poor = 2 to 3 work pieces per side = 6 to 9 cuts
Positive Rake was used on all cutting operations except the Monomatic Tracer Lathe.
Negative Rake was used exclusively on the cutting operations of the Monomatic Tracer Lathe.

CHART 2. AVERAGE HARDNESS OF DU ALLOY PENETRATORS BEFORE AND AFTER AGING



LEGEND: ——————— As Received (Solution Treated)

— — — — — After Aging

NOTE: Alloys 3 and 7A were not aged.
Alloy 7D was only extruded (not solution treated or aged).

Table 4. Average Hardness of DU Alloy Penetrators Before and After Aging

Alloy Code	1	1A	2A	2B	3	4	5	6	6A	7A	7C	7D	8
mber of mples	236	31	37	33	39	117	34	79	40	41	57	47	57
erage rdness fore ing	40	44	41	40	42	37	47	50	44	45	49	42	52
nge fore ing													
w	36	40	37	38	37	33	42	42	40	41	45	38	44
gh	49	47	44	44	47	42	52	55	49	48	57	47	57
rage rdness ter ing	47	46	47	43	*	42	50	54	49	*	[illegible]	*	[illegible]
nge ter ing													
w	40	43	43	42	*	40	47	46	45	*	50	*	[illegible]
gh	53	50	49	46	*	47	55	58	52	*	59	*	[illegible]

NOTE: Alloys 3 and 7A were not aged (only solution treated).
Alloy 7D was only extruded (not solution treated or aged).

FIGURE 9. MACHINING OPERATIONS FOR MANUFACTURE OF 30MM PENETRATORS LC-SK-982-#2 ALLOY(DU)

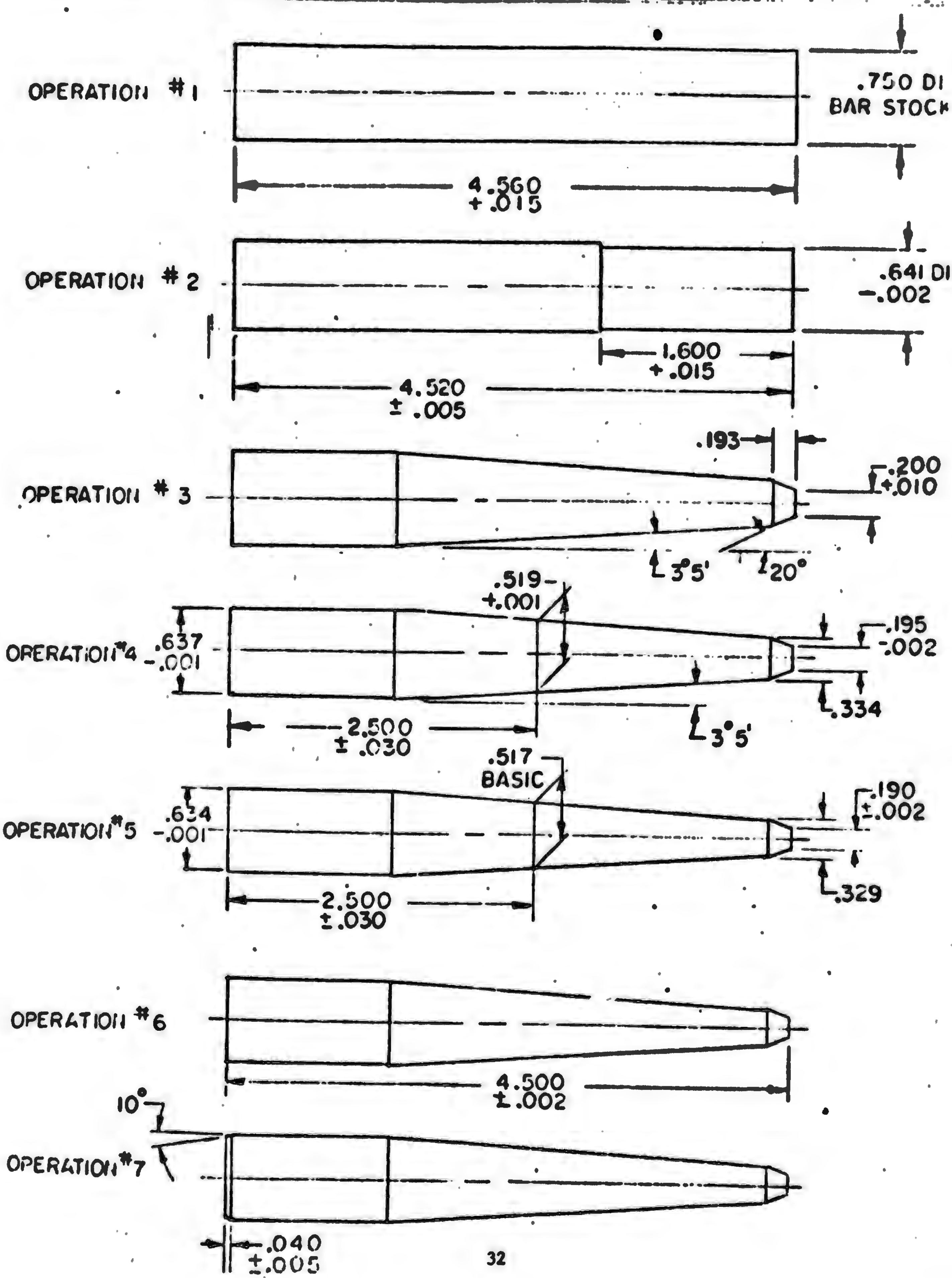


FIGURE 10. 30MM PENETRATOR LC-SK-982 "ALLOY 2A"

Flow Sheet

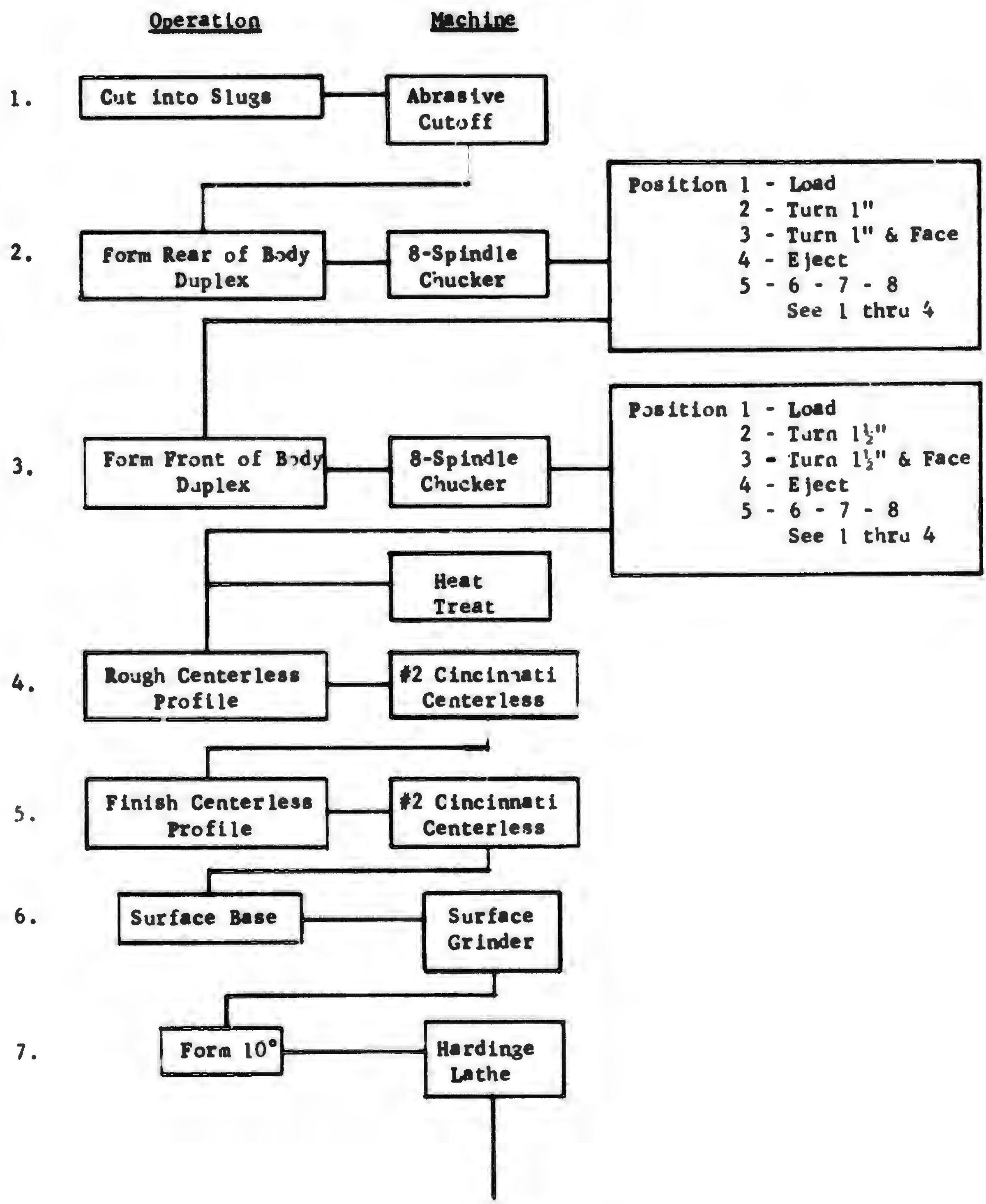


FIGURE 10. 30MM PENETRATOR LC-SK-982 "ALLOY 2A"

Flow Sheet, Continued

Operation Machine

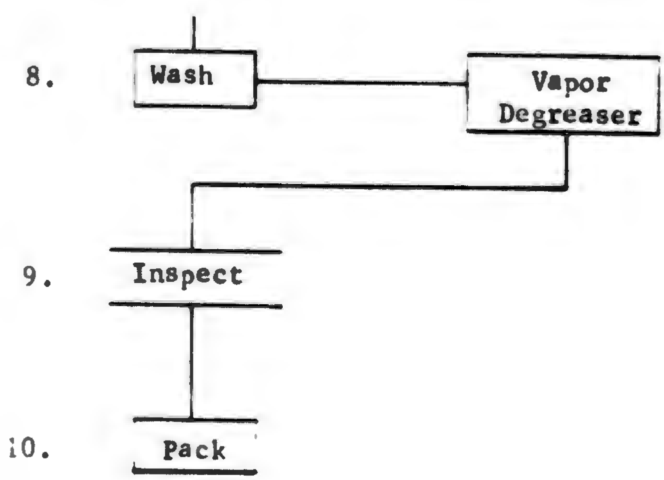


FIGURE 11. MACHINING OPERATIONS FOR MANUFACTURE OF 30MM PENETRATORS LC-SK-982-#2 ALLOY (DU) HEAT TREATED SLUGS

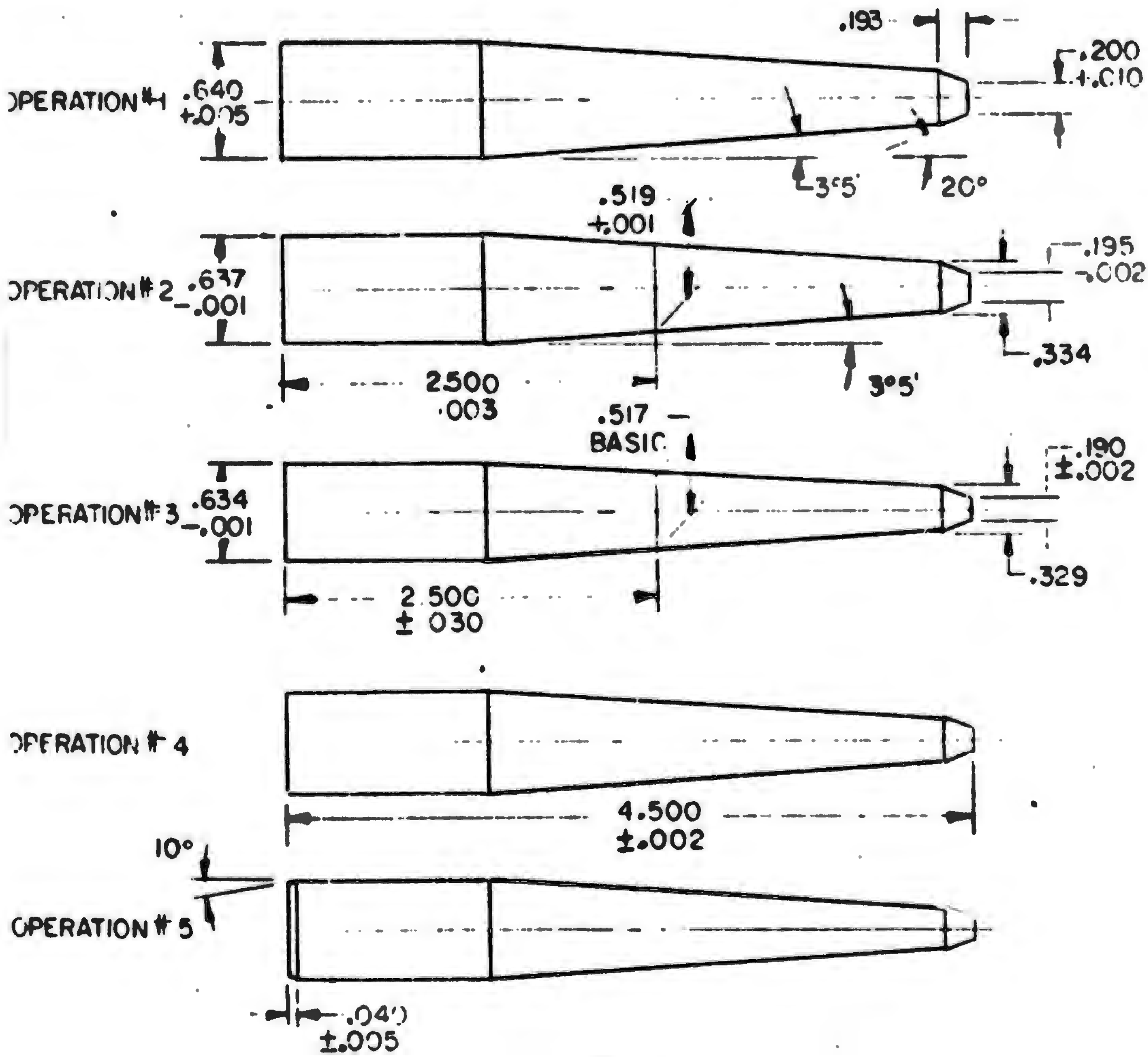


FIGURE 12. 30MM PENETRATOR LC-SK-982 "ALLOY 2A"

HEAT TREAT BLANKS

Flow Sheet