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UNITED STATES ATOMIC ENERGY COMMISSION

FABRICATION OF URANIUM WIRE

by

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ABSTRACT

The present report describes experimental work performed to establish a procedure for the production of uranium metal wire. In all cases, the size of the initial rod was 1/2 inch diameter. Three materials were used: hot extruded tuballoy rod, high purity cast tuballoy rod, and cast U-235 rod.

Copper and silver coatings were placed on the uranium to prevent oxidation and facilitate working. Silver proved the better covering.

Hot swaging (550-600°), warm swaging (250-300° C), and cold swaging (room temperature) were employed to reduce the rod to size for wire drawing. Cold swaging was adopted as most suitable.

A satisfactory procedure was established in which the silver plated rod was cold swaged from 0.500 inch to 0.042 inch diameter. Intermediate anneals at 400° C in vacuum followed each 75 percent reduction in area.

Reduction from 0.042 inch to final wire size was accomplished by wire drawing, using aquadag as a lubricant. After approximately each 75 percent reduction in area, the wire was annealed in vacuum at 400° C.

Wire was produced to 0.0033 inch diameter in tuballoy and to 0.010 inch diameter in U-235. There appears to be no difference in response to fabrication between tuballoy and U-235.

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INTRODUCTION

The work described in this report was undertaken to satisfy a request from the Physics Division for wire of 0.010 ± 0.002 inch diameter in depleted uranium (U-238), normal uranium (tuballoy), and enriched uranium (U-235). It was indicated in the request that 200 inches of each metal were required.

A literature search showed that Elelmann* (1) had produced tuballoy wire 0.020 inch in diameter by swaging.** He also succeeded in producing short lengths of 0.013 - 0.014 inch diameter wire by drawing. The major difficulties encountered in his work were listed as pointing, lubrication and lack of proper equipment. Failures arising from the inertial forces caused by starting the Vaughn commercial drawing machine resulted in the design and construction of a low speed machine, Figure 1.

Successful drawing of tuballoy wire through sapphire dies by employing a 0.0005 inch thick coating of electroplated copper on the wire was reported by Thompson (2). The coated tuballoy wire was cold swaged to 0.03 inch, then

*References listed on Page 22.

**Tuballoy wire 0.020 inch in diameter had been made in 1945 by swaging rod. No formal report on that work was written as the experimental data were very limited.

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drawn to 0.02 inch diameter. At this point, failure of the copper coat by spalling necessitated replating of the wire. The replated wire was then drawn to 0.012 inch diameter when the copper coat again failed.

Experiments (2) were made in which bare tuballoy wire was drawn, using ordinary lubricants such as oils, greases, paraffin, soap and graphite. None of the lubricants appeared to be satisfactory and were discarded in favor of the copper plate. It was indicated that a covering of lead, tin or silver on the tuballoy wire would ease the drawing in the manner similar to copper. However, Thompson used copper as it permitted annealing at 600° C in air.

Cleaves (3) was successful in drawing tuballoy wire to 0.030 inch, 0.020 inch, and 0.010 inch diameters in fifty foot lengths. The wire was drawn through steel or sapphire dies. His most satisfactory results were obtained when the wire was coated with copper to a thickness of 0.0005 to 0.001 inch. Although the larger diameter wires could be drawn through several dies before it was necessary to replate, when 0.010 inch diameter was approached, it became necessary to replate after each pass. The wire was annealed in a helium atmosphere at 600° C after each ten percent, or at most fifteen percent, reduction in diameter (19-28 percent reduction in area).

In 1943, Battelle Memorial Institute (4) made annealing experiments on cold drawn tuballoy rod. It was found that the hardness was not reduced appreciable by a two hour anneal at 350° C. An apparent annealing effect was noted at 450° C and at 480° C the softening was marked.

At M. I. T. (5) tests have been made to relate the annealing temperature with the percent of reduction by cold rolling. These tests were carried to 45 percent reduction. The relation of the amount of cold work to the recrystallization temperature is shown in Figure 3 (reproduction of the M. I. T. curve). The curve is fairly flat at 450° C from 15 to 45 percent reduction. This indicates that increased reduction beyond 45 percent would not decrease substantially the temperature of recrystallization.

The work herein reported does not represent a complete investigation. The pressure of time required that wire in the desired sizes be produced without an extensive investigation of the variables concerned in the process. It is hoped that a more complete examination of the process can be made at a later date.

EXPERIMENTAL WORK

A study of the results of earlier investigations on the reduction of uranium rod to wire indicated that a process to fabricate wire of small diameter could be obtained. It appeared that a metal coated rod of uranium could be processed to wire by swaging and drawing in suitable steps. It remained to establish a procedure as a series of reductions from rod to wire inclusive of intermediate anneals as required.

Rod of extruded stock was used in the majority of tests and, although its exact origin was not known, it was thought to be 1/2 inch alpha extruded. The high purity tuballoy and the U-235 stock were cast as 1/2 inch bars in the Los Alamos Scientific Laboratory. Table I lists the carbon and spectrographic analyses of the high purity stock, the normal tuballoy and the U-235.

Each metal rod was machined to remove adhering oxide and to secure a smooth, even surface for electroplating. In addition, the smooth surface would reduce any tendency for the metal to enfold during swaging. The rod was then plated with silver to a thickness of about 0.003 inch*. The plated rod was annealed at 600° C in order to produce

*The procedure used to plate the uranium bars with silver is discussed on pages 39 and 40.

an adherent silver coat. It has been shown (1, 6) that an unannealed silver plate tends to spall when cold worked. The spalling was attributed to hydrogen embrittlement as a result of plating.

The purpose of the silver coat was to facilitate the drawing operations and to protect the uranium from oxidation while annealing. In drawing the coated wire, the silver remained as a continuous, adherent coat which, on stripping 0.005 inch and 0.010 inch diameter wire, appeared to be on the order of 0.0001 inch in thickness.

A silver coat gave improved performance as compared to a copper coat. The copper appeared to work harden at a different rate than tuballoy and required frequent annealing to prevent spalling.

Hot swaging, warm swaging and cold swaging were each utilized as a means of reducing the rod to a size which could be handled in the largest wire drawing die available.

A 1/2 inch diameter tuballoy rod was surface machined, after which it was jacketed in a 1/8 inch wall copper tube by swaging the tube about the rod and plugging the tube ends with copper rod. The jacketed rod was heated in air to the 600° C hot swaging temperature in an electrically heated muffle furnace.

The heated rod was swaged in a 550 -600° C temperature

range. After each swaging pass, the rod was reheated to the 600°C temperature. The copper and tuballoy worked at nearly the same rate until a copper wall thickness of about $1/64$ inch was attained. When this thickness was reached, the copper began to peel away from the tuballoy. Peeling occurred while reducing $3/16$ inch diameter rod in a $5/32$ inch swaging die. Measurement of the stripped tuballoy rod showed a diameter of approximately $1/8$ inch.

Because of the action of the swaging dies and the pronounced plasticity of the tuballoy, at the $550^{\circ} - 600^{\circ}\text{C}$ temperature, the metal tended to twist with the dies to produce a torsional effect. As a result of this action, the rod assumed a helical shape with about one full turn in two inches of length. As a result of the twisting, the oxidation of the tuballoy, and the difficulty of handling hot material, the method was not pursued.

For the fabrication of power pile discs (6), a technique was utilized in which tuballoy strip was prepared by rolling the metal at $250-300^{\circ}\text{C}$. This procedure proved very successful and formed the basis for the second method of approach to the wire fabrication problem.

A silver-coated tuballoy rod $1/2$ inch in diameter was heated in silicone oil to about 300°C and processed through the several swaging steps.

The swaged rod was reheated to the forming temperature (300°C) after each swaging reduction. Cooling of the rod during swaging gave a working temperature range of approximately $250\text{--}300^{\circ}\text{C}$. Satisfactory results were secured by this warm swaging method on rod above $1/4$ inch diameter; however, on smaller rod, the dissipation of heat from the rod to the surroundings was sufficiently rapid to cause the warm swaging operation to approach cold forming. Annealing was found to be necessary to soften the swaged rod. In addition, rupture of the silver plate was more noticeable than in cold swaging.

A satisfactory explanation for the failure of the silver plate during warm swaging was not found. It was thought that several factors, such as the working temperature, heating in silicone oil, or a porous silver coat which permitted oxidation of the uranium may have, singly or in combination, contributed to the plate failure. It may also be that rupture of the plate was more noticeable in that bared spots would oxidize more readily at the advanced temperature.

The third procedure investigated consisted of cold swaging silver-plated tuballoy rod. It was found that rod could be cold swaged from 0.500 to 0.042 inch diameter (99 percent reduction in area) without intermediate anneal. Temperatures taken with "Tempilistiks" on the rods immediately

after swaging indicated a considerable evolution of heat during working. Bars swaged from 1/2 to 1/8 inch in several steps in a heavy duty Waterbury Farrel No. 3 machine showed temperatures ranging from 120° to 200° C. This rise in temperature may have helped to secure the 99 percent reduction in area. However, rod so treated showed end splitting, Figure 4, and a metal structure which appeared to be fibrous. The apparent fibrous structure revealed itself as a darkened area in the center of the swaged rod. This structure seemed to be present throughout the rod, as the rod could be split and separated for long lengths without difficulty.

A silver-coated tuballoy rod was reduced from 0.500 inch to about 0.012 inch by a series of swaging steps. The rod was intermediately annealed when the degree of work hardening tended to cause flashing during the reduction. This flashing generally occurred when some 80 percent reduction in area was obtained and thus indicated that a softening treatment would be required. Flashing of metal can occur from improper adjustment of equipment or from poor swaging technique; however, flashing was found to be more prevalent when swaging hard or work hardened rod than found when working soft rod.

Because of the inherent character of the swaging operation, a variation of 0.001 inch was found in wire passed

through the 0.012 inch swaging die. In the smaller die sizes, flashing of the metal occurred and resulted in a poor surface condition and fracture.

To prevent the formation of surface irregularities resulting from swaging small diameter rod (and because swaging long lengths of rod is both tedious and time consuming), it was decided to perform the first reductions by swaging and to begin the wire drawing operations using the largest size die feasible with the available equipment. Thus, it was standard practice to swage from 0.500 inch diameter rod to 0.042 inch diameter rod, then to complete the further reduction by wire drawing.

A few preliminary tests (described later) were made to establish a satisfactory annealing temperature for cold reduced metal. From the data thus acquired and from other sources (4, 5), an annealing temperature of 400° C was selected for wire reduced 75 percent in area. This quantity (75%) of cold work left a small margin of safety over the 80% noted above (at which flashing occurred) and did not consume too much time for intermediate anneals; so it was chosen for the experimental work.

Pointing of wire in order to thread the drawing die was readily accomplished for dies 0.014 inch or larger. The wire was swaged for several inches to a size which would

pass through the selected die opening. Swaging gave a work hardened point which had sufficient strength to resist fracture of the point when the drawing operation was started. The swaging procedure was satisfactory for the die sizes noted above, but could not be used for smaller sizes, as the smallest swaging die obtainable (0.012 inch) produced wire about 0.013 inch in diameter. In order to point wire for threading into dies less than 0.014 inch diameter, it was necessary to select a method other than swaging.

Electro-etching as a means to secure a point was prone to form pits during metal removal. Failure of the point occurred because of reduced cross section and stress concentration caused by the pitting. Also, removal of metal by electrolytic attack removed the protective silver coating and permitted metal seizure between the tuballoy point and the die. The method did not prove satisfactory.

Pointing the wire by grinding roughened the surface and removed the silver coat. This procedure also introduced the possibility of point failure by notch effects and metal seizure between die and wire.

To prevent the uneven removal of metal, which resulted in the formation of a flat, thin point susceptible to fracture, considerable care was required in the grinding operation. By clamping the wire about one inch from the end and

using care, uniform removal of metal sufficient to accommodate threading of the wire in the die could be obtained by sanding with No. 2 emery cloth. This length of point (about one inch) was sufficient to thread the die so that the point could be grasped with a pair of needle nose pliers and the drawing started. By hand starting, a length of wire could be drawn which would enable clamping the wire in the drawing block.

Rolling wire between two hardened steel plates was considered as a means of pointing, and preliminary tests indicated that the method would be suitable for tuballoy wire. However, because of the hardness of the tuballoy metal, a jig would have had to be made wherein pressure could be applied to the rolling plates and, since sanding was found satisfactory, the rolling method was not used.

The wire drawing machine (Figure 1A) was remodeled (Figure 1B) so that the force required to draw the wire could be calculated from a measure of the extension of a calibrated spring. Table II presents the results of the tests made to determine the force required for drawing. A wide variation of results was obtained and no attempt was made to correlate these results except as to the relative merit of lubrication, and to compare the drawing force for coated versus bare wire, Table III.

Aquadag (a colloidal suspension of graphite in water) was selected as the best lubricant because a small amount could be placed in the die throat and would lubricate several hundred inches of wire. Although soapy mixtures reduced the drawing force to about the same value as aquadag, it was less convenient to provide constant application of the soap mixture. Thus recourse was had to the more readily applied aquadag.

The drawing of lubricated bare tuballoy wire gave irregular and uncertain results. There was a tendency for the wire to seize to the die until the spring attached to the die holder was well extended. The wire then drew with a resulting contraction of the spring until seizure again occurred. This action repeated itself and frequently resulted in fracture of the wire. It is probable that the irregular drawing gave maximum forces which did not truly represent the force required for smooth drawing.

In certain of the tests an anomalous behavior was encountered during drawing. It was general practice to draw a fully coated wire to a desired diameter, then strip the silver coat from a portion of the wire to compare the drawing forces for coated and bare wire which had essentially the same prior treatment. It was found that where a tendency existed for the silver to spall off during drawing,

the remaining portion of bare wire drew better than when the silver coat did not spall.* A satisfactory explanation for this behavior has not been obtained. It may be that small particles of silver from spalled wire were caught in the die throat and smeared on the bare wire, thus easing its passage through the die. The values in Table III marked (a) result from the condition noted above and are therefore subject to questionable accuracy.

Neglecting the values marked (x) (which refer to those cases where fracture occurred) and marked (a), the average force required to draw dry silver coated wire was 18.6 percent less than the average force needed to draw lubricated bare wire. The average force for the lubricated silver coated wire was 23.5 percent less than for dry silver coated wire. The most favorable condition (silver coated, lubricated wire) compared to the less favorable condition (lubricated, bare wire) resulted in a total reduction in the drawing force amounting to 37.8 percent.

The annealing of rod or wire was performed in an induction heated vacuum furnace, Figure 2, at an absolute pressure of about 15 microns. The metal was charged to the

*Where a single wire was partly coated and partly bare, the coated portion was always drawn first.

furnace at room temperature. The furnace was evacuated, then heated to the 400°C annealing temperature. Charge and furnace were then allowed to cool to room temperature. Holding the metal at the annealing temperature for a period of time (from $1/2$ to 12 hours) did not seem to help nor hinder subsequent working.

Annealing at 600°C , a procedure used in previous drawing projects (2) (3), was satisfactory for metal which had been lightly cold worked (10-15 percent reduction of area). However, such a procedure tended to embrittle metal which had been extensively cold worked (75 percent reduction of area). No investigation was made to determine the cause of embrittlement.

Tensile and hardness tests were made on wire swaged from $7/16$ inch diameter rod to 0.117 inch diameter wire (93 percent reduction of area) and annealed at several temperatures, Table IV. The data thus acquired, together with data secured from consulted references, were used to aid in the selection of an annealing temperature. Based upon cold reduction of 75 percent in area by either swaging or drawing, an annealing temperature of 400°C was chosen. Although complete recrystallization of cold worked metal is considered to take place at a higher temperature, it was thought advisable to use the 400° temperature. At

the temperature concerned, the metal softening would be largely due to the relief of internal stresses. It was felt that the use of higher temperatures, say 500-600° C, might promote grain growth and embrittlement.

The use of high speed drawing for uranium wire was found to be unsatisfactory. At a drawing rate of 900 inches per minute, the friction between the wire and die created considerable heat. It was felt that the heat generated contributed to a tendency to rupture the silver plate with subsequent seizure of the uranium metal to the die. The low speed machine, Figure 1, which drew at a rate of 40 inches per minute, allowed the heat generated to be dissipated and injury to the wire was not encountered.

In one instance during the series of drawing steps, the silver coat on sections of the wire became quite thin and ultimately disappeared. At the time the silver coating disappeared, the wire diameter was 0.016 inch. Drawing was continued until the diameter had been reduced to 0.008 inch, equivalent to a reduction of 75 percent in area in the bare condition.

The wire from which the silver coating was removed in processing was obtained from stock which had been warm swaged.. The procedure also differed from the usual practice in that drawing was started using a 0.101 inch die, whereas it was

a general procedure to start the drawing through a 0.0403 inch die. It may be that these two conditions (warm swaged stock and greater total reduction by drawing) were effective in causing total removal of the silver during drawing.

Wire from which the silver coat had been chemically stripped could be drawn; but fracture resulted in the majority of cases. It did not appear that such a method held much promise. In those instances where the silver coat gradually disappeared during several drawing reductions, continuous drawing of the (apparently) bare wire was possible. It is probable that the chemically stripped wire presented an irregular, etched surface susceptible to seizure in the die during drawing, whereas the surface of the denuded wire was smooth, thus reducing the possibility of seizure.

Although tuballoy wire smaller than the 0.0033 inch diameter material produced could very probably be drawn, the present investigation did not carry the experimental work beyond the 0.0033 inch size. The most serious difficulty to be overcome, in trying to produce smaller wire, would appear to be concerned with a means to point the wire for threading through the dies. Hand sanding wire of the above diameter is both tedious and uncertain in its results. Elongating the wire by tension to form a pointed break is not feasible, as uranium does not possess sufficient ductility

for this method to succeed. In view of seeming difficulties and time limitation, the investigative work in respect to minimum size was concluded with the production of 0.0033 inch diameter wire.

No tests were made to draw wire of "25" metal less than 0.010 inch diameter. There were several reasons why further drawing of "25" was not done. First, it was felt that the performance of "25" and tuballoy would be practically identical insofar as plastic deformation was concerned. As it had been shown that tuballoy could be reduced to diameters less than 0.010 inch, it was assumed that "25" could likewise be made in diameters less than 0.010 inch. Second, the original request specified 0.010 inch diameter "25" wire, and it was not considered as pertinent to carry out an investigation on "25" parallel with that of tuballoy for the production of smaller wire. Third, the accountability required for "25" metal was not conducive to experimental work beyond that required.

Based on the work thus far performed, the procedure outlined below has proved successful in producing uranium wire 0.0005 inch in diameter.

1. The uranium metal rod stock should be machined to provide a surface free from oxide and smooth in contour, then electroplated with silver to a thickness of about 0.003

inch. The plated bar is heated at 600° C in vacuum to "set" the plate and prevent spalling during fabrication.

2. Reduction of the rod can be accomplished by swaging, with intermittent anneals at 400° C in vacuum recommended when a 75 percent reduction of area has been achieved. (It is only necessary to heat the metal to the annealing temperature and furnace cool.) Successive reductions by swaging and drawing, with intermittent anneals as required, can be employed to fabricate wire to 0.005 inch in diameter. It is suggested that the reduction of area made in any single pass be not more than 35 percent for swaging and not more than 20 percent in drawing.

3. For purposes of lubrication in drawing, aquadag of a paste consistency has been found suitable. The paste is introduced in the die throat before threading the wire.

4. A slow drawing speed is recommended to prevent separation of the silver coat from the wire and to prevent detriment to the coat itself. A drawing rate of 40 inches per minute has been found satisfactory.

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Fig. 1A--Wire drawing apparatus.

Fig. 1B--Wire drawing apparatus set up to measure drawing force.

Fig. 2--Vacuum anhealing furnaces.

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Fig. 3--M.I.T. curve.

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Fig. 4--Sample of wire showing end splitting.

TABLE IAnalyses of Metal Stock*

(Values are in parts per million)

	High Purity Cast Tuballoy Metal	Extruded Tuballoy Metal	Cast U-235
Carbon	120-110	900	150
Silicon	60	150	100
Iron	25	100	70
Manganese	20	10	70
Magnesium	10	10	10
Cobalt	10	-	5
Nickel	10	10	5
Calcium	10	-	5
Copper	5	20	5
Aluminum	5	-	5

* All other elements for which values were obtained in spectroscopic analysis showed less than 5 ppm.

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TABLE II

Drawing Forces Encountered in Wire Drawing -- Pounds

Die Size In.	Dry Ag Coated Wire				Ag Coated - Aquadag Lubricated				Bare Tu - Aquadag Lubricated			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
0.0243			41				27.5				72	
0.0226			70				53				75 (x)	
0.021			—				35				45	
0.0201			50				31.5				50	
0.019	20		20		15		13		45 (x)		26.5	
0.017	33		'34		'26		'28		'38 (x)		'39	
0.016	24		31.5	25.5	19		21.5	20	35 (x)		33 (x)	33 (x)
0.015	22		26.5	21.5	17		20	16	35 (x)		33 (x)	33 (x)
0.014	20	22	21.5	20.5	14.5	17	18	16.5	17	15	30	29.5 (x)
0.013	18.5	17	14.5	18	11.5	13.5	12	15	15 (x)	12.5	15	26 (x)
0.012		12	10.5	14		9	8	10		10	14.5	— (x)
0.011		'13.5	'12	'14.5		'11.5	'10	'12		'10	'14.5 (x)	18 (x)
0.010			13.5	16		12.5	11.5	12.5			14.5 (x)	17.5

- (1) Annealed (400° C) at 0.0213 inch diameter
 (2) Annealed (400° C) at 0.0153 inch diameter
 (3) Annealed (400° C) at 0.0285 and 0.0142
 (4) Annealed at 0.0173 inch diameter.
 (x) Denotes force at fracture

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TABLE III

Percent Reduction in Drawing Force

Die Size In.	From Lubricated Bare Wire to Dry Silver Coated Wire				From Dry Silver Coated Wire to Lubricated Silver Coated Wire			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
0.0243			43				33	
0.0226			6.7 (x)				24.3	
0.0201			0				37	
0.019	55.5 (x)		25.5		25		35	
0.017	13.2 (x)		12.8		21.2		17.2	
0.016	31.4 (x)		4.5 (x)	22.8 (x)	20.8		31.8	21.6
0.015	37.2 (x)		19.5 (x)	34.8 (x)	22.7		24.5	25.6
0.014	-15 (a)	-31.8 (a)	28.3	30.5 (x)	27.5	22.7	16.3	19.5
0.013	-18.9 (a)	-33.4 (a)	3.3	30.8 (x)	37.8	20.6	17.2	16.7
0.012		-16.7 (a)	27.5	(x)		25	23.8	28.6
0.011		-25.9 (a)	17 (x)	19.5 (x)		14.8	16.7	17.2
0.010			6.9 (x)	8.5			14.8	21.8

- (1) Annealed 400° C at 0.0213 inch diameter
 (2) Annealed 400° C at 0.0153 inch diameter
 (3) Annealed 400° C at 0.0285 and 0.0142 inch diameter
 (4) Annealed 400° C at 0.0173 inch diameter

(x) Denotes fracture

(a) The drawing force for bare wire was less than the force required to draw silver coated wire. This behavior is discussed on pages 15 and 16.

Tensile and Hardness Tests

TABLE IV

0.117" wire. Last pass through 1/8" swaging die.

Reduction from 7/16" bar - (93% reduction in area)

	Ultimate Tensile (P.S.I.)	Hardness (Rockwell C)
#1 as worked	183,000	34
2 Annealed at 250° C	195,000 (?)	24
3 Annealed at 400° C	163,000	19
4 Annealed at 500° C	134,000	5
5 Annealed at 600° C	109,000	7

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TABLE V

Swaging Dies and Reductions in Area

Waterbury Farrel Foundry
and Machine Co.
Swaging Machine #3

<u>Die Sizes Used</u>	<u>% Reduction from Last Die</u>
7/16"	-
3/8"	- 26.5
11/32"	- 16.0
5/16"	- 17.4
9/32"	- 19.0
1/4"	- 21.0 - From 1/2" = 75%
7/32"	- 23.4
3/16"	- 26.5
5/32"	- 30.5
1/8"	- 36.0 - From 1/4" = 75%

Other dies on hand are:
3/4"; 11/16"; 5/8"; 9/16"; 1/2"; 3/32"

The Torrington Co.
Swaging Machine #2

<u>Die Sizes Used</u>	<u>% Reduction from Last Die</u>
0.102"	- 33.3
0.081"	- 36.0
0.064"	- 37.4 - From 1/8" = 73.7
0.051"	- 36.6
0.040"	- 38.5 - From 0.064 = 61.0
Other dies on hand are:	
0.162"; 0.0201"; 0.020"; 0.019";	
0.018"; 0.017"; 0.016"; 0.015";	
0.014"; 0.013"; 0.012".	

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Swaging Machine #1

<u>Die Sizes Used for Pointing</u>	<u>% Reduction from Last Die</u>
0.032"	- 37.2 From .064 = 75
0.0253"	- 36.3
0.0201"	- 36.7
0.018"	- 20.0
0.016"	- 21.0 From .037 = 75
0.014"	- 23.4
0.012"	- 26.5 From .016 = 44
Other dies on hand are:	
0.204"; 0.162"; 0.102"; 0.081"; 0.064";	
0.051"; 0.040"; 0.020"; 0.019"; 0.017";	
0.015"; 0.013";	

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TABLE VIWire Drawing Dies and Reductions

<u>Die Sizes</u>	<u>% Reduction in Area from Previous Die</u>	<u>Die Sizes</u>	<u>% Reduction in Area from Previous Die</u>
.1010	-	.0084	-
.0907	-	.0079	-
.080	-	.0075	-
.070	-	.007	-
.065	-	.0065	-
.060	-	.006	-
.0535	-	.0055	-
.0453	-	.005	-
.0425	-	.0045	-
.0403	-	.0042	-
.0375	-	.00385	-
.035	-	.0035	-
.0319	-	.00325	-
.0285	-	.003	-
.0255	-	.0028	-
.0243	-	.0026	-
.0226	-	.0024	-
.021	-	.0022	-
.019	-	.002	-
.017	-	.0018	-
.016	-	.00165	-
.015	-	.0015	-
.014	-	.0014	-
.013	-	.0013	-
.012	-	.0012	-
.011	-	.0011	-
.010	-	.0010	-
.0095	-	.0009	-
.0089	-	.0008	-
		.0007	-
			10.7
			11.7
			9.9
			12.9
			13.8
			14.8
			16.0
			17.3
			19.0
			12.9
			15.8
			17.5
			13.8
			14.8
			12.9
			13.8
			14.6
			15.8
			17.4
			19.0
			16.0
			17.4
			12.9
			13.8
			14.8
			16.0
			17.4
			19.0
			21.0
			23.4

Procedure: Ag Plating U Bars

The method used to electroplate the uranium bars with silver gives a mechanical bond between the base and plated metals. Prior to plating, the machined bars were cleaned in an organic solvent such as trichloroethylene or acetone to remove cutting oils. The bars were rinsed in cold water; then immersed in concentrated nitric acid for four minutes to remove uranium oxide. From the nitric acid bath, the bars were rinsed in cold water, then made the anode in a bath consisting of 10 cc per liter of hydrochloric acid, 125 grams per liter of trichloroacetic acid, and balance water. The anode current density was 0.5 amperes per square inch and time of treatment was 15 minutes. The stainless steel container holding the bath was the cathode. The electrolytic activation treatment was followed by a cold water rinse, then four minutes in concentrated nitric acid with a subsequent cold water rinse.

The prepared rods were made the cathode and plated in a silver cyanide plating solution consisting of 31 grams per liter of silver cyanide, 40 grams per liter of potassium cyanide, 70 grams per liter of potassium carbonate, and the balance water. The anode was silver (99.99%) and the bath container stainless steel. The cathode current density was

0.1 ampere per square inch of area to be plated. The bath was operated at room temperature with a constant 0.0431 ampere hour per square inch input which produced a one mil deposit of silver. The rods were plated with three mils of silver (holding contacts were moved at regular intervals to insure maximum plating at contact points).

The trichloroacetic acid treatment attacks the uranium and forms a deeply etched surface. This irregular surface provides the "hill and valley" effect needed to bond the silver to the uranium.

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