8265 F.J. Cupps
For: TIC

(2)

SAND76-8023
Unlimited Release

Electroplating U-0.75 Ti, 105-mm, XM774 Penetrators With Nickel and Zinc

J. W. Dini, H. R. Johnson

Sandia Laboratories

SF 2900 Q(7-73)

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SAND76-8023
Unlimited Release
Printed June 1976

ELECTROPLATING U-0.75 Ti, 105-mm, XM774 PENETRATORS WITH NICKEL AND ZINC

J. W. Dini
H. R. Johnson
Metallurgy and Electroplating Division 8312
Sandia Laboratories

ABSTRACT

Procedures were developed and utilized whereby 105-mm U-Ti penetrators were plated with 1.0 mil of nickel and 0.2 mil of zinc and then chromated. Twenty-three full-size penetrators were coated to demonstrate the feasibility of the system and to provide parts for ballistic tests. Dimensional inspection of the parts before and after etching and plating revealed the coating process to be viable and repeatable.

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ACKNOWLEDGMENTS

The authors would like to acknowledge J. R. Helms for plating support, T. L. Bryant for metallographic support, and P. Dean for technical writing support. Helpful conversations and dialogue were provided by R. S. Kemper, K. Sump, and G. Zima of Battelle Northwest.

CONTENTS

ILLUSTRATIONS

TABLES

ELECTROPLATING U-0.75 Ti, 105mm, XM774 PENETRATORS WITH NICKEL AND ZINC

Introduction

Sandia Laboratories, Livermore, is active in the development of a protective coating for a 105-mm uranium alloy projectile. The request by the U.S. Army[1] to develop this coating was based upon our recent experience in designing a similar protective coating for a 30-mm uranium alloy penetrator,[2] as well as our overall expertise with respect to corrosion and protection of uranium alloys. This report covers the initial phase of corrosion study in support of Picatinny Arsenal's development program for the projectile 105-mm APF SDS-T, XM774.

Specifically, SLL's task was to develop methods for protecting the 105-mm penetrators from corrosion and to use these methods for coating parts for testing. The penetrators, fabricated from U-0.75 Ti, have two different threaded portions and several other unattractive features from a coating viewpoint over their 13-inch length (Figure 1). The threaded sections clearly constituted the major challenge; it was felt that if these areas could be coated to meet tolerance requirements, the remaining recesses and protuberances could also be successfully coated. Earlier work showed two viable systems which afford excellent corrosion protection for U-Ti: (1) plating with 1.0 mil of nickel (Ni) and 0.2 mil of zinc (Zn), and then chromating; and (2) hot-dip galvanizing (Zn plus chromate).[2] Either of these systems was a logical candidate for the 105-mm penetrators.

Figure 1. Sections of a Penetrator

Selection of Coating Technique

As the following discussion will show, the Ni plating method was chosen over galvanizing because of the need to coat the penetrators within tight dimensional tolerances. A 2-mil tolerance band is specified on BNW drawing GPΔ24-1 for the shank portion of the penetrators, a 6-mil band for the outer diameter of the buttress grooves, and a 6-mil band for a section on the tip end. In addition, the small threaded section on one end of the penetrators and the buttress grooves must also meet specific thread requirements. All of these dimensions include machining tolerance; there are no added tolerances for coatings. This is a very important point because all of the tolerance band had been used up during the machining of many of the penetrators. Therefore, the coating system to be used had to be capable of producing a coating within very tight tolerances.

Because of the necessity for close tolerances, any coating buildup, particularly on threaded sections, became critical. For standard threads (60° angle) such as those on the end of the penetrators, a coating on the wall or shank of the thread increases the pitch diameter by four times the thickness; e.g., 0.0012 inch of plating (0.001 Ni plus 0.0002 Zn) would increase the pitch diameter by 0.0048 inch. For a 45° thread such as that on the buttress grooves, a plating thickness of 0.0012 inch would increase the pitch diameter by 0.0034 inch. Figures 2 and 3 pictorially show this increase in pitch for both types of threads. Depending on the coating system used for the 105-mm penetrators, the pitch diameter change could or could not be as great as the above information indicates. For example, if a plating process is used, the problem would be noticeably minimized because the parts would have to be etched prior to plating. The etching operation removes approximately 1.0 mil of material from each etched surface, which is then replaced with a nominal plating thickness of 1.2 mil; thus there is very little change in pitch diameter. Conversely, if galvanizing were used, no etching step would be needed, and the buildup depicted in Figures 2 and 3 could be expected.

The data obtained on galvanized parts (see Appendix A) showed that although the hot-dipped coatings are fairly uniform, the buildup on the threads would indeed be too great for the penetrators to be coated in this program. If thinner, more uniform coatings could be achieved through alloying and fusing, hot-dip coatings could become a viable, cheap alternative to electroplating. For that matter, hot-dip Zn coatings could be an alternative to electroplating in this program if the tolerances on the finished parts were to be relaxed.

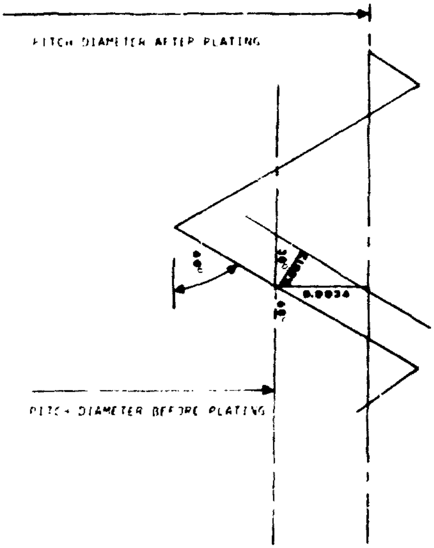


Figure 2. Influence of Plating Build-Up on a 60° Thread

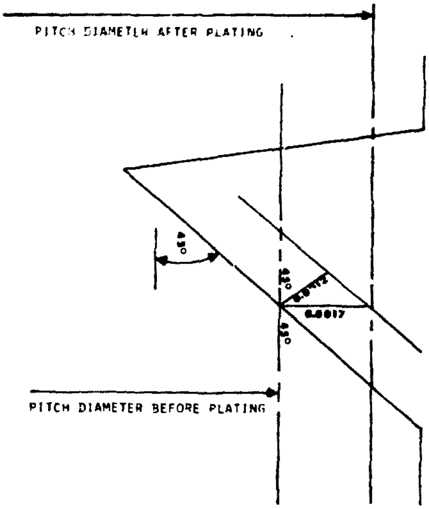


Figure 3. Influence of Plating Build-Up on a 45° Thread

Preliminary Etching and Plating Studies

General

Uranium is one of the more difficult metals to plate upon because its surface has a tendency to become passive. If the proper procedures are used, however, it is possible to obtain suitable mechanical adhesion between uranium and electrodeposited coatings. The most successful techniques involve chemical or electrolytic treatment of the uranium in acid solutions containing chloride ions, followed by removal of the chloride reaction products in nitric acid before plating. Uranium alloys are even more difficult than uranium to plate upon because the alloying elements (Ti, Mo, Zr, Nb) make the substrate material more resistant to the etchants used for preparing unalloyed uranium for plating.

Extensive work at SLL prior to the granting of this contract has resulted in procedures for etching and plating U-0.75 Ti. This work[3] basically shows that solutions containing either ferric chloride or zinc chloride provide good results. The ferric chloride etchant results in a relatively smooth etch (~100 μin, CLA), whereas the zinc chloride etchant provides extremely rough surfaces (<400 μin, CLA) and offers more promise for applications in which joining dissimilar metal by plating is a consideration. For the penetrator work, the ferric chloride etchant was the obvious candidate for preparing the substrates to be plated. Earlier efforts had shown the efficiency of using this etching system prior to plating for corrosion protection.[4]

Etching Studies

The etchant used for U-Ti is a solution containing 1400 g/l ferric chloride. The operating parameters for this solution have previously been defined and documented in the literature.[3] To ensure that the etchant would work suitably for the U-Ti provided by BNW, one U-Ti rod was machined with the buttress grooves and one with the small thread configuration. These two specimens, which were duplicates in size of the stainless steel mandrels shown in Figure 4 on page 19, were measured on an optical comparator, etched, and then re-checked for change in dimensions.

The buttress grooves etched quite uniformly over their entire threaded section. Metal removal varied from 2.0 to 2.9 mils on the diameter and was quite consistent from peak to valley (Table I). In the case of the part with the small threads, the etching process was not acceptably uniform over the entire six inches of threads (approximately 60 threads). However, there are only 10 threads of the configuration on the actual penetrator. When the threads were examined in 20-thread segments, the etching uniformity was

TABLE I
ETCHING RESULTS FOR BUTTRESS GROOVES(1)

Thread Location(2)	Diameter (in.)(3)		
	Before Etching	After Etching	Difference (mils)
1	1.2952	1.2923	2.9
1-V	1.1832	1.1809	2.3
5	1.2954	1.2933	2.1
5-V	1.1848	1.1827	2.1
10	1.2952	1.2932	2.0
10-V	1.1854	1.1839	1.5
15	1.2925	1.2903	2.2
15-V	1.1872	1.1857	1.5
20	1.2947	1.2926	2.1
20-V	1.1885	1.1863	2.2
25	1.2959	1.2942	1.7
25-V	1.1912	1.1891	2.1
30	1.2963	1.2943	2.0
30-V	1.1900	1.1877	2.3
32	1.2966	1.2942	2.4

(1) Etched in 1400 g/l $FeCl_3 \cdot 6H_2O$ solution at 120°F for 3 minutes, followed by a second 2-minute etch.

(2) The numbers refer to the location on the part, with number 1 being the bottom groove on the part. The numbers followed by a "V" represent valleys; the numbers without a "V" represent peaks.

(3) Measured on optical comparator.

found to be acceptable. The part was not etched as long as the buttress groove part discussed above, and therefore less metal was removed. As shown in Table II, metal removal varied from 0.9 to 1.6 mil and was slightly less in the valleys than on the corresponding peaks.

The data from this set of tests showed that the ferric chloride etchant worked quite well on the U-Ti received from BNW, and that the threaded sections etched uniformly enough so that no problems were anticipated with the full-size parts.

TABLE II

ETCHING RESULTS FOR SMALL THREADS(1)

Thread Location(2)	Diameter (in.)(3)		
	Before Etching	After Etching	Difference (mils)
2	0.8727	0.8718	0.9
2-V	0.7963	0.7955	0.8
5	0.8733	0.8717	1.6
5-V	0.7961	0.7954	0.7
10	0.8740	0.8727	1.3
10-V	0.7955	0.7940	1.5
15	0.8751	0.8737	1.4
20	0.8757	0.8741	1.6
20-V	0.8737	0.7926	1.1

(1) Etched in 1400 g/l $FeCl_3 \cdot 6H_2O$ solution at 120°F for 3 minutes.

(2) The numbers refer to the location on the part, with number 1 being the bottom groove on the part. The numbers followed by a "V" represent valleys; the numbers without a "V" represent peaks.

(3) Measured with an optical comparator.

Plating of Threaded Sections

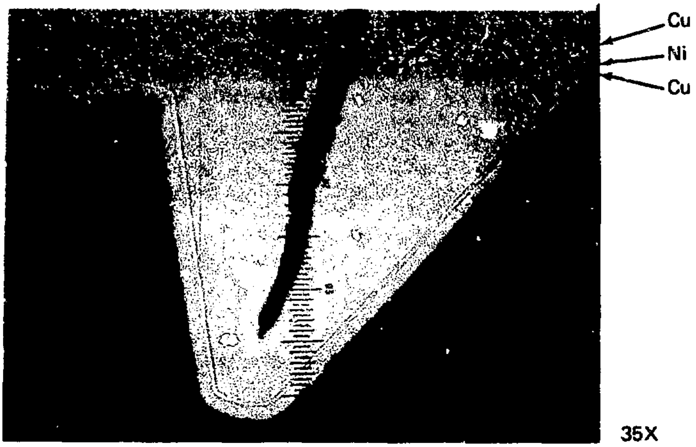
Earlier work had shown that good corrosion protection is obtained with a combination of 1.0 mil of Ni and 0.2 mil of Zn which was then chromated.[2] Because Ni comprises the bulk of this Ni/Zn coating system, efforts in the present program were directed toward evaluating the uniformity obtainable with Ni. The first task was to evaluate procedures for providing the best uniformity possible on the plated threaded sections.

Stainless steel mandrels of the buttress and end threads were fabricated. (Stainless steel mandrels allowed many subsequent parts to be readily separated without damaging the mandrel; therefore many experiments could be run at low cost and very quickly.) These mandrels, approximately six inches long, were plated with nickel* using the operating conditions that were of interest and then overplated with thick copper. Two cuts 180° apart were then made along the entire length of the plated section composite, and the composite was separated from the stainless steel by mechanical force. The electroformed threaded section was again overplated with thick copper to protect the underside of the nickel threads, and the parts were cross sectioned for metallographic inspection. The mandrels and some electroformed sections are shown in Figure 4, and some metallographic cross sections in Figure 5.

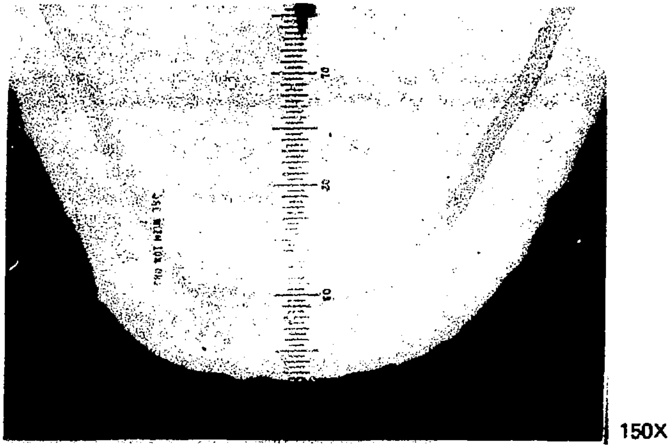
Figure 4. Mandrels of Threaded Section and Buttress Grooves With Some Electroformed Sections

---

*The nickel plating formulation is included in Appendix B.

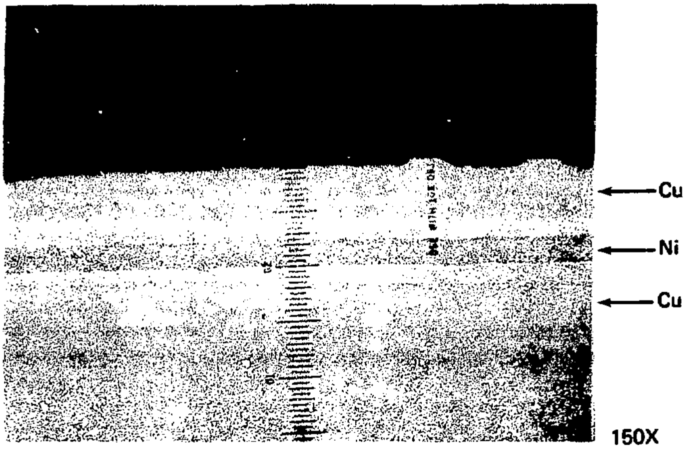


a. Overview showing Ni plated threads overplated on both sides with Cu



b. Higher magnification of plating in a valley

Figure 5. Cross Sections of Buttress Grooves Plated at 10 asf



c. Higher magnification of plating on a peak

Figure 5. (Continued)

Plating current densities of 5, 10, and 20 asf were used. The results, shown in Table III, clearly reveal that the better plating distributions were obtained with the lower current densities, regardless of the size of the threaded sections.

Full-Size Ni Plating Studies

Based on the results obtained with the threaded sections, full-size penetrators machined from stainless steel were plated with Ni at current densities of 5 and 10 asf. Stainless steel was again used because the plating could be stripped from these parts without damaging the substrate, and the penetrators could be used for additional plating experiments. All parts were checked at 50X magnification with an optical comparator before and after plating. For Ni plating, two variations in anode arrangement were used; one with no shield and another with the anode in a lucite box that had a 2 1/4-inch opening in the region of the center of the buttress grooves. During plating, the penetrators were rotated at approximately 30 rpm.

The data for the Ni plating studies are shown in Table IV. Plating uniformity was clearly better from end to end on the parts when the shield was used on the anode. Maximum plating thickness was lower for both current densities when the shield was used; e.g., at 5 asf, 1.35 versus 1.6 mils and at 10 asf, 1.4 versus 1.95 mils. This finding led to the obvious

TABLE III

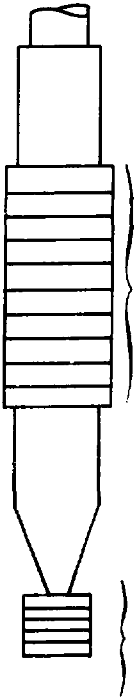
Ni PLATING* DISTRIBUTION ON SMALL THREADS AND ON BUTTRESS GROOVES

	Current Density (asf)	Thickness (mils)	
		Peak	**Valley**
Small Threads	5	1.0	0.85
	10	1.0	0.85
	20	1.0	0.55
Buttress Grooves	5	1.0	0.76
	10	1.0	0.60
	20	1.0	0.50

*Ni sulfamate solution

TABLE IV

INFLUENCE OF CURRENT DENSITY AND SHIELDING ON NICKEL PLATING THICKNESS(1)



	5 asf - No Shielding (mils)	5 asf - Shielding(2) (mils)	10 asf - No Shielding (mils)	10 asf - Shielding(2) (mils)
	1.6	1.35	1.75	1.4
	1.25	1.15	1.35	1.25
	0.75	1.0	1.1	0.8
	1.0	1.1	0.65	1.2
	1.3	0.9	0.95	1.05
	1.2	0.85	0.95	0.95
40	0.95	0.8	1.6	0.9
40V	0.85	0.85	-	0.55
30	0.85	1.05	0.95	1.1
30V	0.7	0.9	0.55	0.55
20	1.15	0.95	1.0	1.5
20V	0.9	0.6	0.7	0.8
10	1.25	0.5	1.15	1.1
10V	1.25	0.9	0.95	0.9
1	1.35	1.25	1.6	1.45
1V	1.3	1.05	0.95	0.95
	1.2	1.0	1.1	1.15
	1.2	1.2	1.25	1.2
	0.95	1.0	0.85	0.9
9	1.15	0.9	1.2	1.1
9V	0.7	0.8	0.7	0.65
5	1.1	1.05	0.95	1.4
5V	0.6	1.05	0.55	0.8
1	1.25	0.95	1.95	1.2
1V	0.95	0.85	1.2	1.0

(1) Parts were full-size penetrators fabricated from stainless steel. Plating was determined by using an optical comparator at 50X magnification.

(2) The shield consisted of a lucite box with a 2 1/4-inch opening in the region of the center of the buttress grooves. The anode was positioned inside this box.

conclusion that the shielding arrangement should be used for plating of penetrators. The results also showed that a current density of 10 asf could be used for Ni plating, which would shorten the plating time considerably (2 hours to plate one mil of Ni at 10 asf compared to four hours when using 5 asf).

Etching and Plating of Full-Size U-Ti Penetrators

Twenty-seven penetrators were received from BNW; of these, three (#28, 31, and 41) were known rejects intended only for experimental purposes. The remaining twenty-four penetrators were to be plated and returned to BNW.

To ensure that the exact dimensions of the parts were known before and after etching and plating, the inspections described in Table V were performed.* These inspections revealed that seven of the remaining twenty-four parts were out of tolerance. Five of these (#50, 55, 62, 69, and 90) were under-size on the buttress groove outer diameter; e.g., they were less than 1.266 in. The remaining two out-of-tolerance parts were #83, which was less than 1.100 in. on the shank position B, and #85, which was thin in position B and passed the no-go gage on its threaded end. Part #62, which was undersize on the buttress groove, also passed the no-go gage on its threaded end.

The data in Table VI also reveal that a number of the penetrators were at the upper end of the tolerance band at positions C and D, e.g., close to 1.1020 for position C and 0.960 for position D. Plating generally results in an increase in thickness for uranium parts, even though they are etched prior to plating; therefore, concern existed at SLL about meeting finished dimension requirements on these parts where the tolerance band had been used up by machining. This situation was discussed with Ken Sump on March 16; he stated that an upper tolerance band of 1.1030 for positions A, B, and C, and 0.961 for position D would be acceptable.

---

*In addition to these preliminary inspections, a 10-32 hole was drilled and threaded 1/4 inch deep on the rear surface of each penetrator to provide for an electrical contact.

TABLE V

INSPECTION OPERATIONS

<table>
<tr><th>Measurement</th><th>Description</th></tr>
<tr><td>Dimensional Measurements</td><td>Micrometer measurements were made at six different locations (see Table VI for location of these measurements</td></tr>
<tr><td>Buttress Grooves</td><td>The buttress grooves were gaged with an optical comparator. Charts were made on a Gerber plotter machine and used to check two conditions for each buttress groove:
a. The tolerance band for the grooves
b. The tolerance band for the sabot
The charts were designed for use at 20X with an optical comparator; they are shown in Figures 6 and 7.</td></tr>
<tr><td>Threaded Section</td><td>The threaded end section was certified, using a set of go/no-go gages fabricated to the following requirements:*
<table>
<tr><th></th><th>Basic Dimension (in.)</th><th>To Clear (in.)</th><th>Clears</th></tr>
<tr><td>Pitch Diameter -</td><td>0.8280</td><td>+0.0003
-0.0</td><td>Set and sealed</td></tr>
<tr><td>Minor Diameter -</td><td>0.8145</td><td>+0.0006
-0.0</td><td>0.8149</td></tr>
</table>
These gages were certified by SLL meterology personnel before and after the inspections steps described in this report. Figure 8 shows the gages.</td></tr>
</table>

*Ponam LTD, Inc., Glendale, CA 91201

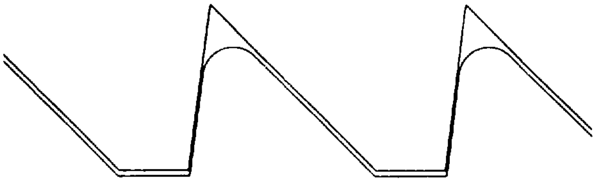


Figure 6. Section From a Comparator Chart for Sabot Grooves (Mag. 15X)

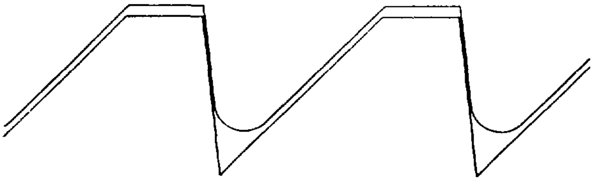
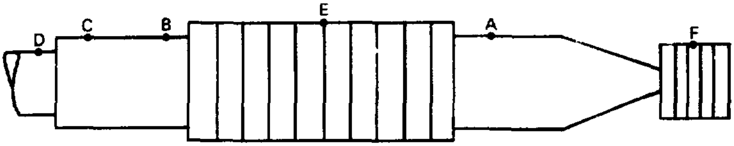


Figure 7. Section From a Comparator Chart for Penetrator Grooves (Mag. 15X)

Figure 8. Gages Used for Certifying Threaded End of Penetrators

TABLE VI
AS-RECEIVED INSPECTION DATA FOR PENETRATORS(1)



	A	B	C	D	E	F	
	(Diameter, inches)						
Part No.	1.100/1.1030†	1.100/1.1030†	1.100/1.1030†	0.955/0.961†	1.266/1.271†	-	Comments
28*	1.0985	1.1015	1.1015	0.959	1.265/1.266	0.867	Known reject
31*	1.1015	1.0960	1.0965	0.954	1.266/1.269	0.869	Known reject
41*	1.099	1.098	1.0985	0.957	-	-	Known reject
49	1.101	1.1015	1.1015	0.9595	1.269*	0.871	
50*	1.100	1.100	1.101	0.9585	1.265	0.871	Buttress too thin
51	1.1015	1.1005	1.1015	0.960	1.269*	0.872	
52	1.1005	1.1015	1.1015	0.960	1.267/1.268	0.870	
53	1.1015	1.1015	1.1020	0.9595	1.266/1.267	0.871	
55*	1.100	1.101	1.1015	0.960	1.265/1.2665	-	Buttress too thin
56	1.1015	1.100	1.1005	0.9585	1.267/1.268	0.871	
57	1.1015	1.100	1.101	0.960	1.267	0.872	
58	1.101	1.101	1.1015	0.960	1.267	0.871	
59	1.1005	1.101	1.1015	0.9595	1.269	0.870	
62**	1.1005	1.1005	1.101	0.960	1.265	0.865	Buttress too thin Threaded end passed no-go gage
67	1.1005	1.100	1.100	0.958	1.267	0.871	
69*	1.1015	1.1005	1.101	0.9595	1.264/1.265	0.871	Buttress too thin
80	1.102	1.101	1.101	0.959	1.266	0.871	
81	1.1005	1.100	1.1005	0.959	1.268	0.870	
82	1.1005	1.1015	1.1015	0.960	1.267	0.871	
83*	1.100	1.099	1.100	0.958	1.267	0.872	Thin in position B
84	1.101	1.1015	1.1015	0.959	1.268	0.871	
85**	1.102	1.0995	1.1005	0.959	1.271	0.866	Threaded end passed no-go gage Thin in position B
86	1.101	1.100	1.1005	0.959	1.267	0.870	
87	1.101	1.101	1.1015	0.960	1.270	0.871	
88	1.101	1.1015	1.1015	0.9595	1.268	0.870	
89	1.1005	1.100	1.1005	0.959	1.267	0.871	
90*	1.100	1.1005	1.101	0.9595	1.263	0.869	Buttress too thin

(1) Determined by micrometer measurement

*Refers to out-of-tolerance parts

†Tolerance Band

Tolerance Control Through Etching and Plating

The plating procedures and solution formulations used in etching and plating the penetrators are described in Appendix B. The metal removed as a result of etching was generally in the range of 1 to 2 mils on the diameter regardless of location on the penetrator. Data for four positions on each part measured with a micrometer before and after etching are included in Table VII. Uniformity from one end to the other and from part to part is quite evident. On five of the seven parts that were out of tolerance in the as-received condition (#50, 55, 62, 83, and 90), metal removal was deliberately kept on the low side, e.g. around 1.0 mil in an effort to keep the parts from getting further out of tolerance. This selective etching, combined with the plating process, resulted in all of these parts except #90 meeting tolerances after plating.

Final Inspection Data

The final inspection data are included in Table VIII. Seven parts were out of tolerance after plating and etching; however, none of them were very seriously out in our opinion. Three of these parts (#69, 85, and 90) had been out of tolerance in the as-received condition. The buttress diameters of parts #69 and 90 were too thin as-received and were still too thin after plating. Part #85 was thin by 0.0005 inch in postiion B after plating; it had also been thin in position B when received, and its threaded end passed the no-go gage. Part #85 is a good example of a penetrator that was in effect brought into tolerance by plating.

The other four out-of-tolerance parts included:

#52 - One section of the buttress diameter was thin by 0.0015 inch. This part had been plated, stripped, and then replated. During the stripping operation, the U-Ti was attacked.

#58 - The buttress diameter was thin by 0.0015 inch in one area. This part had been deliberately etched to remove more metal because it was one of the first parts plated and was done before Ken Sump relaxed the tolerance band. In the as-received condition, it was at maximum diameter at position D, and an attempt was made to reduce this dimension by overetching.

#80 - This part passed the no-go gage on its threaded end; no explanation is available.

#82 - This part was on the high side when received; after etching and plating, the part was oversize by only 0.0005 inch.

TABLE VII

METAL REMOVED BY ETCHING IN FERRIC CHLORIDE SOLUTION(1)

Part No.	A(2)	B	C	D
	Diameter (inches)			
28	0.0022	0.002	0.0017	0.002
31	0.0013	0.002	0.002	0.0015
41	0.002	0.0022	0.0025	0.002
49	0.0023	0.0022	0.0023	0.0025
50	0.0012	0.0010	0.0010	0.002
51	0.002	0.0027	0.0025	0.0022
52	0.002	0.002	0.0017	0.002
53	0.002	0.0016	0.0017	0.0018
55	0.001	0.0009	0.0013	0.001
56	0.0015	0.0024	0.0024	0.0029
57	0.0017	0.0017	0.0020	0.0023
58	0.002	0.003	0.0025	0.002
59	0.0019	0.0016	0.0020	0.0022
62	0.001	0.0009	0.001	0.001
67	0.0015	0.0015	0.0015	0.0015
69	0.0025	0.0025	0.0025	0.0030
80	0.0028	0.0021	0.0020	0.0020
81	0.0016	0.0019	0.0020	0.0020
82	0.0014	0.0018	0.0016	0.0015
83	0.001	0.0015	0.0015	0.0012
84	0.002	0.0024	0.0025	0.002
85	0.0019	0.0024	0.0024	0.0028
86	0.0015	0.0015	0.0015	0.0015
87	0.0017	0.0025	0.002	0.0022
88	0.0017	0.0018	0.0013	0.0015
89	0.0010	0.0017	0.0013	0.0014
90	0.0010	0.0015	0.001	0.0013

---

(1) Etched in 1400 g/l($FeCl_3 \cdot 6H_2$) solution at about 100°F. Metal removal was approximately 0.001 inch per 10 minutes of etching. All measurements were made with a micrometer.

(2) See illustration on Table VI for positions A, B, C, D.

TABLE VIII

FINAL INSPECTION DATA

Part No.	A(2)	B	C	D	Buttress Grooves		Gages		Comments
	(Diameter, inches) 1.100/1.1030†	1.1000/1.1030†	1.1000/1.1030†	0.955/0.961†	1.2660/1.2710†		No-Go	Go	
49	1.1015	1.1015	1.1015	0.9595	1.269	1.2685	No	Yes	
50	1.101	1.101	1.102	0.9595	1.267	1.265	No	Yes	
51	1.102	1.101	1.102	0.9605	1.2685	1.268	No	Yes	
52	1.100	1.101	1.102	0.9605	1.267	1.2645	No	Yes	Buttress too thin
53	1.102	1.102	1.1025	0.9595	1.2665	1.267	No	Yes	
55	1.1015	1.102	1.102	0.9585	1.2675	1.2665	No	Yes	
56	1.1025	1.100	1.1005	0.9585	1.2665	1.2660	No	Yes	
57	1.1025	1.101	1.102	0.9605	1.267	1.2675	No	Yes	
58	1.1025	1.1015	1.1025	0.961	1.2665	1.2645	No	Yes	Buttress too thin
59	1.1015	1.1025	1.103	0.961	1.269	1.2692	No	Yes	
62	1.102	1.1015	1.1015	0.959	1.2655	1.266	No	Yes	
67	1.1015	1.1005	1.1015	0.9595	1.267	1.2665	No	Yes	
69	1.1015	1.1005	1.1015	0.9605	1.264	1.2635	No	Yes	Buttress too thin
80	1.1025	1.1015	1.1025	0.960	1.2665	1.2665	Yes	Yes	Threaded end passed no-go gage
81	1.101	1.101	1.1015	0.9595	1.2675	1.267	No	Yes	
82	1.1015	1.102	1.103	0.9615	1.2675	1.267	No	Yes	High in position D
83	1.102	1.1005	1.101	0.9595	1.267	1.267	No	Yes	
84	1.102	1.1015	1.1015	0.9585	1.267	1.2675	No	Yes	
85	1.1025	1.0995	1.100	0.9585	1.270	1.270	No	Yes	Thin in position B
87	1.1015	1.101	1.102	0.961	1.2685	1.269	No	Yes	
88	1.102	1.102	1.103	0.961	1.2675	1.2675	No	Yes	
89	1.1015	1.101	1.1015	0.9595	1.2675	1.2675	No	Yes	
90	1.1005	1.1015	1.1025	0.961	1.264	1.264	No	Yes	Buttress too thin

(1) Except for the gages for the threaded ends, all data are micrometer measurements.

(2) See illustration on Table VI for positions A, B, C, D.

† Tolerance Band

As can be seen from this information, the parts were out of tolerance because they were used as experimental guinea pigs; however, they are all probably still acceptable for testing.

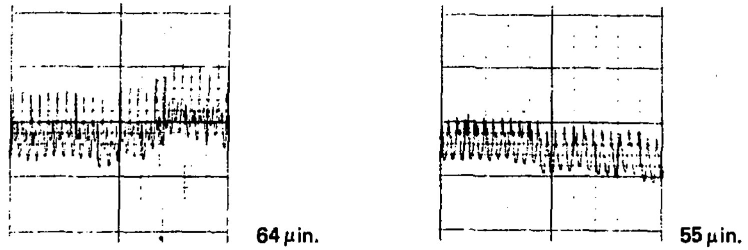
These results show that the etching and plating operation is a repeatable process and can even be used to salvage parts. For example, of the seven parts that were out of tolerance in the as-received condition, four were in tolerance after etching and plating.

Surface Finish

The surface finish of four penetrators was checked at various stages of the etching/plating cycle. In the as-received condition, parts exhibited finishes in the range of 23 to 83 μin, CLA (Table IX). After etching, finishes were in the range of 100 to 200 μin. For most surfaces, final plating provided some leveling or smoothing and resulted in finishes in the range of 70 to 115 μin. Surface finish scans for one of the penetrators are shown in Figure 9. The data in Table IX show, however, that the penetrators did not always etch uniformly and consistently. Part #62 ranged from 90 to 200 μin. after etching and 75-193 μin. after plating. This same type of phenomenon was seen on Part #31, which was more severely etched on one section of the long shank than nearby regions, as shown in Figure 10. The reasons for this type of response during etching are not known; however, the variations in surface finish are believed to be linked to variations in the U-Ti. This behavior is not an atypical experience for uranium alloys.

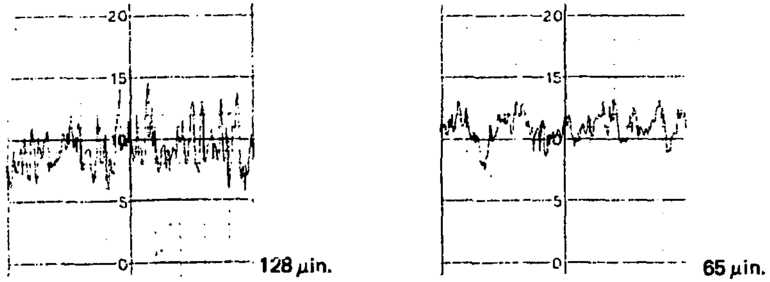
Chromate Finish

The chromate finish is a conversion coating applied to Zn to further enhance its corrosion resistance. It is applied by immersing the part in a solution containing either chromic acid or dichromates in combination with certain inorganic compounds which function as catalysts. When Zn-plated parts are immersed in the solutions, an amorphous chromate film less than 0.02 mil thick is precipitated on the surface. The film can vary from a virtually undetectable, colorless coating to a heavy olive drab, depending on the amount of chromate in the film. Because of the color variations and thinness of the film, the finish of chromated parts can vary somewhat between different areas on a part or from part to part. The slight variations in appearance on the 105-mm parts are probably related to the fact that the parts were awkward to handle in a laboratory situation and therefore the chromating, rinsing, and drying operations were difficult to perform without having some stains form on the parts. Consequently, any variations were primarily due to staining and not to actual variations in thickness of the chromated film. The chromated film applied to the 105-mm penetrators should be equivalent to that applied to 30-mm penetrators on an earlier program because the same procedures were used. It should be noted that those 30-mm penetrators performed quite satisfactorily in salt spray tests.[2]



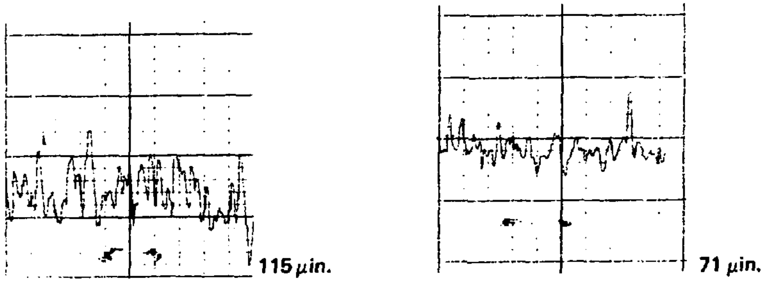
a. Long End, As-Received

d. Short End, As-Received



b. Long End, After Etching

e. Short End, After Etching



c. Long End, After Plating

f. Short End, After Plating

Figure 9. Surface Finish Scans for Penetrator #82

TABLE IX

SURFACE FINISH DATA FOR SOME PENETRATORS

Code	As-Received (μin., CLA)	Etched (μin., CLA)	Plated (μin., CLA)
56 - Long End	64	115	103
- Small End[1]	34	130	82
62	72-83	90-200	75-193
82 - Long End	64	128	115
- Small End	55	65	71
31	23-64	60-190	-

[1] Small end is the shank section by small threads.

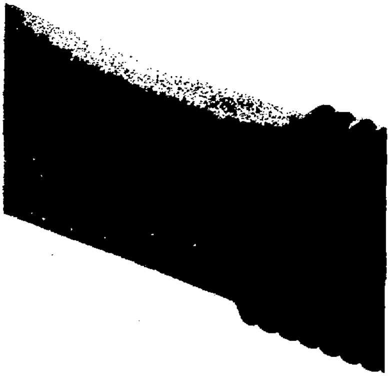


Figure 10. Etch Variation on a Penetrator (*31)

There are perhaps other chromating solutions available which would give a more pleasing appearance and less staining; however, within the scope of this contract, funds and time were not available for evaluating such products. Another possibility would be to use a Zn plating solution with additives to refine the grain size. Finer grained deposits reportedly chromate more uniformly.

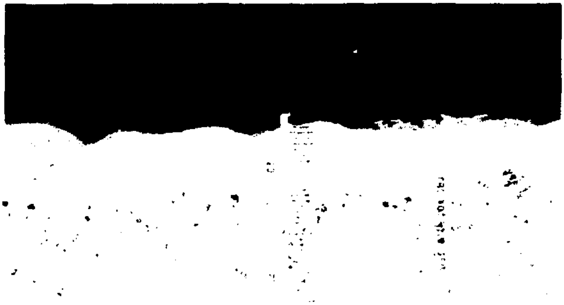
Metallography

A penetrator which had been etched and nickel plated was cross sectioned for metallographic inspection. The zinc plating step was omitted for this part in order to simplify the metallography operation. Cross sections taken from sections along the length of the penetrator are shown in Figure 11. The etched uranium surface is typical of that normally obtained with uranium and uranium alloys. Many sites for mechanical interlocking or "interfingering" of the Ni deposit are clearly evident in all the photomicrographs. Ni plating thickness was somewhat greater on the shank sections of the part than on the threaded regions. This is not an unexpected finding because of the large surface area in the threaded sections. However, the threaded end and buttress grooves had approximately the same thickness of plating on the peaks as in the valleys.

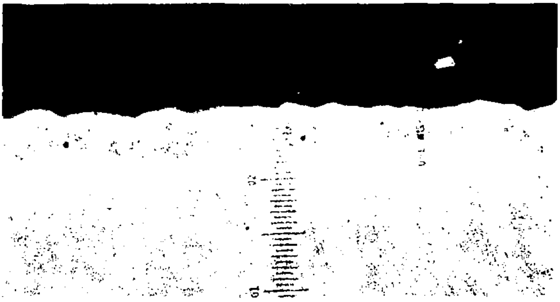
Threaded End Peak (150X)

Cross Sections of an Etched and Plated Penetrator

Threaded End Valley (150X)



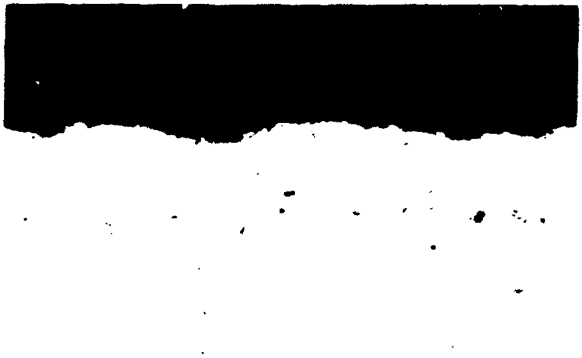
Shank Section Between Threaded End and Buttress Grooves (300X)



Top of a Buttress Groove (150X)

Figure 11. (Continued)

Bottom of a Buttress Groove (150X)



Shank Section Between Buttress Groove and Tip (300X)

Figure 11. (Continued)

Summary

Procedures were developed and utilized for plating 105-mm U-Ti penetrators with Ni and Zn. Twenty-four penetrators were coated to demonstrate the feasibility of the system and provide parts for ballistic tests. Dimensional inspection of the parts before and after etching and plating revealed the process to be viable and repeatable.

The penetrators were etched in ferric chloride solution, plated with Ni and Zn, and then chromated. Nominally, about 50 μm of metal was removed from the diameter of each part during etching except for some parts that were out of tolerance as-received or on the low side of the tolerance band. With these, only approximately 25 μm of metal was etched from the diameter to avoid making the parts more out of tolerance. This selective etching, combined with the plating process, resulted in some of the out-of-tolerance parts being in tolerance after plating.

A considerable amount of inspection was included during this work to ensure that the exact dimensions of the parts were known before and after etching and plating. Outer diameters were checked in six different locations by micrometer on each part before etching, after etching, and after plating. Additional inspection included use of comparator charts with a shadowgraph for checking the buttress grooves and a set of go, no-go gages for the threads on the small end of the parts.

The results clearly indicate that the process is capable of use in a production type operation.

REFERENCES

1. G. E. Zima, Technical Assessment of Potential Corrosion or Component Interactions During Handling or Long-Term Storage of 105-mm Projectiles Utilizing Depleted Uranium Components, Battelle Northwest, Richland, Washington, June 1975.

2. L. J. Weirick, H. R. Johnson, and J. W. Dini, Corrosion and Protection of Uranium Alloy Penetrators, Sandia Laboratories, Livermore, SAND75-8243, June 1975.

3. H. R. Johnson and J. W. Dini, Metal Finishing 74, 37 (March 1976), 38 (April 1976).

4. L. J. Weirick and D. L. Douglas, The Effect of Thin Electrodeposited Nickel Coatings on the Corrosion Behavior of U-0.75, Sandia Laboratories, Livermore, SLL 74-5010, June 1974.

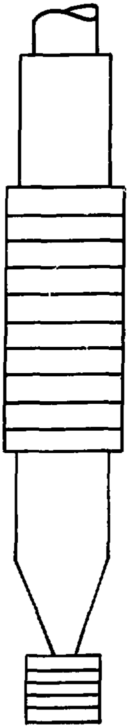
APPENDIX A--GALVANIZING

Galvanizing is the practice of coating iron or steel parts with a thin layer of Zn to protect the surface against corrosion. An earlier report[2] reviewed the literature on using this process to coat uranium and also provided information on uniformity obtainable on 30-mm penetrators. For this present contract, it was decided to cursorily examine galvanizing to determine the uniformity obtainable on the 105-mm penetrators.

Steel parts identical in shape to the 105-mm penetrators except for the tip end were galvanized using industrial procedures developed for coating small parts uniformly. This procedure involves fluxing the parts both before and during their removal from the molten Zn bath, centrifuging the parts while the Zn is still molten, and quenching the parts in water to freeze the coating. Thickness data obtained by micrometer measurements are shown for several locations on the parts in Table A-I. One part was cross sectioned into quarters and then examined microscopically for Zn thicknesses at key locations; the results are shown in Table A-II.

TABLE A-I

ZINC THICKNESS ON PENETRATORS[a]



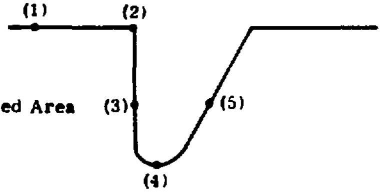
Thickness (mils/per surface)		
Sample 1	Sample 2	Sample 3
3	3	2.5
2.5	2	2
2.5	3.0	2
2	2.5	2.5
3	2.5	3

(a) Determined by micrometer measurement.

TABLE A-II

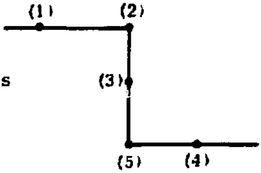
ZINC THICKNESS ON PENETRATORS[a]

(A) Buttress Threaded Area



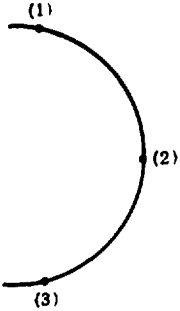
(1)	2-2.3
(2)	1.201.5
(3)	1.2-3.1
(4)	1-1.5
(5)	1.2-2.4

(B) Right Angle Areas



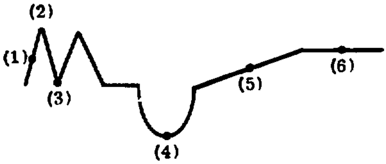
(1)	1.9-2.7
(2)	1.1-1.3
(3)	1.9-2.7
(4)	1.5-2.5
(5)	1.0-1.2

(C) Tip Area



(1)	1.2-3.2
(2)	1.4-2.9
(3)	0.4-3.0

(D) Threaded Area



(1)	1.3-2.4
(2)	1.2-3.3
(3)	1-1.2
(4)	1.2-2.4
(5)	1.2-2.4
(6)	1.6-2.4

(a) Determined by metallographic measurement.

APPENDIX B

ETCHING AND PLATING PROCEDURES FOR PENETRATORS

Plating System

1. Vapor degrease in trichloroethylene
2. Pickle in 8M nitric acid at room temperature for 2 to 5 minutes
3. Rinse
4. *Etch in 1400 g/l ferric chloride* ($FeCl_3 \cdot 6H_2O$) solution for about 20 minutes at 38°C
5. Rinse
6. Pickle in 8M nitric acid at room temperature for 2 to 5 minutes
7. Rinse
8. Repeat step 6
9. Rinse
10. Plate in nickel sulfamate solution for 2 hours at 4 amps
11. Rinse
12. Plate in Zn cyanide solution for 12 minutes at 8 amps
13. Rinse
14. Immerse in 25 ml/l nitric acid solution for 5 seconds
15. Chromate in Granodine 90 for 10 seconds at 24°C
16. Rinse and dry

Nickel Plating Solution

Nickel	80 g/l
Nickel sulfamate(a)	450 g/l
Nickel chloride	<1.0 g/l
Boric acid	38 g/l
Temperature	54°C
Current density	107 A/m^2
pH	3.8
Surface tension	38 dyne/cm
Anodes	SD nickel

(a) The Richardson Co., Allied-Kelite Division, Los Angeles, CA

Zinc Plating Solution

Zinc	22.5 g/l (28 g/l zinc oxide)
Sodium cyanide	56.5 g/l
Sodium hydroxide	80.0 g/l
Cyanide/zinc ratio	2.5:1
Temperature	24°C
Current density	214 A/m^2

Chromate Solution

Granodine 90(a)	15% by volume
Temperature	*24°C*
Immersion time	*10 seconds, with agitation*

(a) Amchem Products, Inc., Amsler, PA