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# Characterization of Pre-1957 Avionic Scrap for Resource Recovery

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UNITED STATES DEPARTMENT OF THE INTERIOR

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# CHARACTERIZATION OF PRE-1957 AVIONIC SCRAP FOR RESOURCE RECOVERY

by

B. W. Dunning, Jr.,[1] and F. Ambrose[2]

ABSTRACT

This paper describes studies conducted by the Bureau of Mines to achieve its goal of developing methods for increased recovery and utilization of valuable constituents in a wide variety of domestic and industrial wastes. In this particular study, 36 units of obsolete electronic equipment from military aircraft were disassembled into their modular components by hand to determine materials distribution. Further modular disassembly into individual parts was used to identify metal composition. After identifying the metals in some of the more difficult to dismantle modules, similar modules were grouped together, shredded, mechanically separated, and using metal composition data from hand separation, classified along with the hand-separated materials. Although this equipment is normally classified as low-value iron-bearing aluminum, data were obtained that indicated the potential for moderately higher value classification. The electronic units were classified as to precious metals, copper, iron, and aluminum contents, and scrap values were estimated.

## INTRODUCTION

The disposal of obsolete military electronic hardware at a fair value is a pressing problem for the Defense Property Disposal Service (DPDS) of the Department of Defense. Several million pounds of this material, which must be disposed of each year, are avionics from military aircraft. As an example, 12.2 million pounds of electronic units were sold in FY 1976.[3] Each generation of electronic units contains varying amounts of precious-metal-bearing modules, but the outer appearance of each unit (flat black paint) is basically the same whether precious metals are present or not. Therefore, no generalization can be made as to the metal value of an electronic unit since the manufacturer did not indicate by a coding system which metals or materials were used in its construction.

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[3]Government Accounting Office (GAO). Additional Precious Metals Can Be Recovered. Dec. 28, 1977.

Electronic units are enclosed in a boxlike metal casing that serves both to protect fragile components and to make these components inaccessible to foreign objects that might cause discharges or shorts that would render the units inoperable. To a scrapyard hand, one unit looks like the next except for its size, shape, weight, and dial face until the outer casing is removed. Even after removal of the outer casing, an approximate assessment of a unit's scrap value can only be made by a person trained to recognize and know the metal value contained in the different electronic components. This trained person must be able to classify the units into two categories--those that could be economically hand-stripped of precious-metal-bearing components and those that are suitable only for mechanical processing. The remaining materials in hand-stripped units would also be processed mechanically to recover base metal concentrates. Although mechanical processing technology is currently available, there is no known integral system at a single site for dry-separating the conglomerate metals of an electronic unit into salable fractions.

In an effort to better estimate the value of electronic scrap, the Bureau of Mines, under a cooperative agreement with DPDS, is assembling a continuous process research unit (PRU) that involves a series of dry separation techniques. The process includes shredding, followed by wire picking, air classification, screening, magnetic, electrostatic, and eddy-current separation methods. Additional treatments such as roll crushing may be added to upgrade or condition some of the metal fractions. The ultimate goal of the PRU is to obtain clean fractions of magnetic metals, aluminum alloys, copper alloys, nonmagnetic autenitic stainless steel, and nonmetals from shredded electronic scrap in order to assess the marketable value of these fractions. Based on previous laboratory tests, most of the precious metals will be concentrated in the copper alloy fraction. This paper is concerned with the characterization of one type of electronic scrap to be used in the PRU.

## BACKGROUND

In 1977, DPDS initiated a test recovery program for processing a controlled sample lot containing a variety of "black boxes" (surplus electronic units so designated because of the black outer cases). Several identical lots were to be prepared with complete components intact to assure a basis for direct comparison of results. The program was to include determination of base and precious metals content, removal of salable modules, and evaluation of each individual box. The Bureau of Mines' Avondale Research Center received one lot of boxes and agreed to the task of hand-dismantling to determine the potential yield of base and precious metals from each unit.

An identical lot of boxes was placed on display at the Defense Construction Supply Center, Columbus, Ohio, for private industry to bid with respect to the following:

(1) Relative cost-effectiveness, and estimated cost per item, of currently practicable methods for segregation, identification, recovery, and serviceability testing of usable modules.

(2) Reutilization and sale potential of usable modules and components. (Sales potential must be supported by quotations from prospective purchasers.)

(3) Quantity of precious metals and other recyclable materials contained therein.

All interested private industry groups indicated that the sample lot was too low in value to warrant bidding. The Bureau of Mines was well into part 3 of the above program, and its work was continued until the characterization was completed. The sample, with the Defense Logistics Agency's coded Federal stock numbers and unit part numbers, is shown in table 1. More than half of the sample consisted of radio receivers, transmitters, tuners, and power supplies; the remainder consisted of miscellaneous navagation and communication equipment. All units appeared to be produced prior to 1957 and did not contain any printed circuits. The weights for individual units in the sample lot ranged from 2-1/2 to 58 pounds. Total weight of the sample lot was 726.36 pounds.

TABLE 1. - The 36-unit "black box" sample

| Unit | Federal stock No. (FNS) | Unit identification | Part No. | Unit weight, lb[1] |
|---|---|---|---|---|
| 1 | 1280-398-1218 | Storage unit............ | MD2/6107000 | 8.86 |
| 2 | 5821-254-9347 | Receiver trans.......... | RT178/ARC 27 | 56.73 |
| 3 | 5826-241-1011 | Receiver radio.......... | R101A/ARN 6 | 29.13 |
| 4 | 5826-505-0793 | .....do................. | R101B/ARN 6 | 28.49 |
| 5 | 5826-505-0821 | Radio receiver.......... | R322A/ARN | 12.89 |
| 6 | 5826-543-0973 | Receiver trans.......... | RT220B/ARN-21 | 57.74 |
| 7 | 5826-678-6631 | Receiver radio.......... | R625B/ARN-31 | 11.30 |
| 8 | 5841-036-6480 | Indicator............... | ID226B/APR-9B | 9.76 |
| 9 | 5841-036-7088 | Tuner radio............. | TN130/APR 9 | 19.11 |
| 10 | 5841-212-7031 | Amplifier............... | AM291/APN 22 | 16.38 |
| 11 | 5841-305-1057 | Tuner radio............. | TN128/APR 9 | 15.48 |
| 12 | 5841-305-1061 | .....do................. | TN131/APR 9 | 18.13 |
| 13 | 5841-330-5742 | Indicator azim.......... | IP81A/APA 69A | 27.50 |
| 14 | 5841-578-5065 | Converter............... | CV443A/APR 9 | 10.32 |
| 15 | 5841-669-9917 | Tuner radio............. | TN180/APR-13 | 19.39 |
| 16 | 5841-669-9918 | .....do................. | TN179/APR 13 | 15.48 |
| 17 | 5841-669-9920 | .....do................. | TN178/APR 13 | 15.49 |
| 18 | 5867-505-1887 | Indicator azim.......... | IP243/ALA 6 | 22.19 |
| 19 | 5865-518-3144 | Receiver................ | R 467/ALR | 10.62 |
| 20 | 5865-548-0340 | Indicator............... | IP 37/APA 74 | 31.12 |
| 21 | 5865-563-6728 | Amp. video.............. | AM924/APS 54 | 11.57 |
| 22 | 5865-643-4531 | Power supply............ | PP 336/APR 9 | 28.99 |
| 23 | 5865-688-6350 | .....do................. | PP 337/APR 9 | 11.20 |
| 24 | 5865-705-0800 | Tuner radio............. | TN 178/APR-13 | 15.19 |
| 25 | 5895-036-6585 | Keyer................... | KY 84A/APX 7 | 31.31 |
| 26 | 5895-036-6939 | Receiver................ | RT 261/APX 7 | 37.44 |
| 27 | 5895-089-4403 | Control trans........... | C6280/A(P)APX | 2.57 |
| 28 | 5895-304-4736 | Receiver trans.......... | CT 279/APX | 30.44 |
| 29 | 5895-306-4493 | Power supply............ | PP 384/APA-74 | 25.12 |
| 30 | 5895-342-9141 | Coder trans set......... | KY 95A/APX-25 | 7.19 |
| 31 | 5960-511-7182 | Electron tube........... | L 3110A | 11.77 |
| 32 | 5895-538-8317 | Power supply............ | PP384/APA 74 | 26.03 |
| 33 | 5895-852-4237 | Video decoder........... | KY 364/APX | 6.25 |
| 34 | 5895-858-5409 | Coder video............. | KY81C/APA 89 | 5.44 |
| 35 | 6115-527-9281 | N1 compass.............. | 15810-1 | 24.63 |
| 36 | 6125-519-0221 | Inverter................ | SE-16-1 | 15.11 |
| Total | NAp | NAp | NAp | 726.36 |

NAp Not applicable.

[1]Actual weights of as-received units. The unit weights do not agree with DLA's master list, some being heavier and some lighter. This decrepancy must have been due to cannibalization of the units by repairmen.

In order to identify and determine the weight of materials in the individual boxes, it was necessary to hand-dismantle each unit separately.

Figure 1 shows one of the units, a tuner radio, before and after partial hand dismantling. Further hand-processing of some modules shown in figure 1 was necessary to determine the weights of the metals and alloys contained in these items. These modules included metal-encased capacitors and transformers, epoxy-coated transformers, electron tubes, motors, relays, and some small items such as resistors, plastic- and epoxy-encased capacitors, and radio-frequency (RF) coils.

After several boxes had been totally dismantled by hand, it was apparent that an excessive amount of hand labor and time would be required to completely dismantle all 36 units in this manner. The items or modules that were most time and labor intensive to hand dismantle were (1) metal-encased and epoxy-coated transformers; (2) metal-encased capacitors; (3) electron tubes; (4) small motors and relays; and (5) small items like resistors, plastic- and epoxy-coated capacitors, and RF coils. After sufficient identifying spectrochemical data were gathered on the hand-dismantled modules of this labor-intensive type, the rest were weighed, their weight recorded with the respective electronic unit from which it was removed, and then segregated under one of the above five categories. These units were mechanically processed by category and separated into their metal and nonmetal fractions, using the PRU at the Avondale Research Center. These data were then combined with those of the completely hand-dismantled item in the same category for each separate "black box."

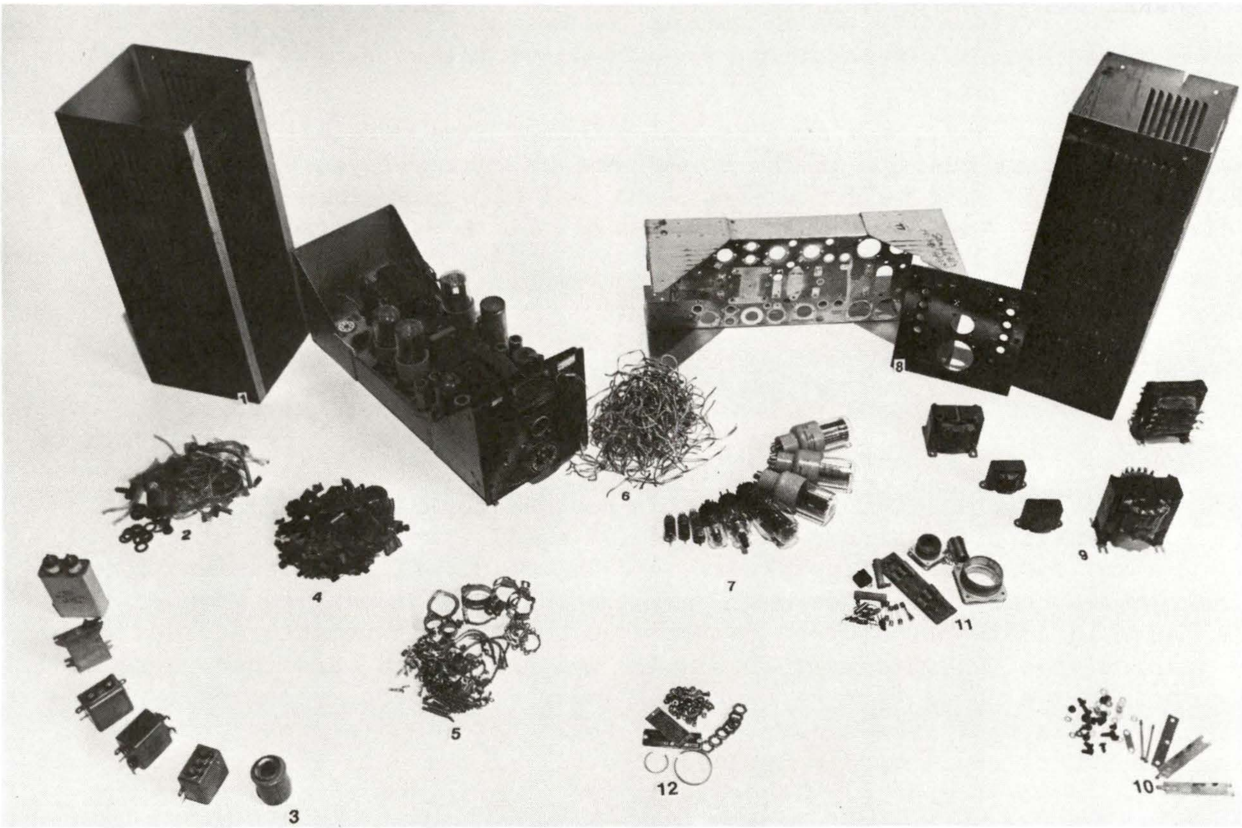


FIGURE 1. - Electronic "black box" with outer cover removed is shown among the dismantled parts of an identical box.

1. *Intact unit with outer wrought aluminum cover removed.*
2. *Thermoplastic plastic and rubber parts.*
3. *Metal-encased capacitors and one transformer.*
4. *Thermosetting plastic and ceramic parts.*
5. *Gold-coated pins, silver-coated connectors, and brass parts.*
6. *Plastic-covered circuitry wire.*
7. *Electron tubes.*
8. *Wrought aluminum front, outer cover, and modular frame.*
9. *Epoxy-coated transformers.*
10. *Magnetic fasteners.*
11. *Resistors, fuses, epoxy-coated capacitors, and miscellaneous parts.*
12. *Nonmagnetic fasteners and two ID plates.*

## CHARACTERIZATION OF MATERIALS FROM THE INDIVIDUALLY DISMANTLED UNITS

### Aluminum Alloys

Wrought, die-cast, and sand-cast aluminum alloys were identified in the sample. The outer casings of the boxes were wrought alloys, and the inner modular framework that held the components was either pressed wrought shapes or die castings. Some of the fasteners were made from aluminum alloys.

### Copper-Base Alloys

A wide variety of copper-base alloys (excluding circuitry wiring) were identified in the sample. Major base-metal alloying elements (equal to or greater than 5 pct) were zinc, tin, and lead. Minor base metal alloying elements (less than 5 pct) were nickel, beryllium, cobalt, antimony, and silicon. Beryllium and cobalt were identified in copper-base alloys where the fabricated part required strength, stiffness, and elastic properties not associated with most copper alloys.

### Magnetic Metals

Most of the magnetic fraction was identified as either plain carbon or silicon steel. However, a minor fraction contained magnetic nickel alloys. In some cases these nickel alloy parts were coated with silver and then gold. To prevent loss of the nickel and precious metals, this magnetic, mostly iron-base fraction could be used for copper cementation. A research study on this concept was conducted at the Bureau of Mines' Salt Lake City Research Center. In this study the residues from a number of cementation tests made with magnetic electronic scrap were combined and melted in an induction furnace. The ingot produced assayed 46.4 pct nickel, 38.7 pct iron, 0.73 pct cobalt, 0.45 pct chromium, 12 oz/ton gold, and 33 oz/ton silver. Results of this study, to be published by the Bureau, will include a section on the copper cementation studies with magnetic electronic scrap.[4]

### Nonmagnetic Stainless Steel

Nonmagnetic stainless steel made up a minor fraction (less than 5 pct) of the total sample. Except for power-transmitting shafts and a few massive rings associated with magnets, most of the stainless steel was in the form of fasteners.

### Nonmetals

The nonmetals have relatively little value and probably would be discarded in a hand-dismantling operation. Nonmetals included waxed cord and tape, chemically treated paper (Aroclor 1254),[5] asbestos cloth, thermoplastic

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[4] Salisbury, H. B., L. J. Duchene, and J. H. Bilbrey, Jr. Recovery of Copper and Associated Precious Metals From Electronic Scrap. BuMines RI 8500 (in press).

[5] Reference to specific brands is made for identification only and does not not imply endorsement by the Bureau of Mines.

and thermosetting plastics, rubber insulation, glass, and ceramics. The non-metals may be disposal problem with the presence of the polychlorinated biphenyl (PCB) Aroclor 1254.

## Precious Metals Coatings

In hand-dismantling, materials that were obviously gold-plated (untarnished gold metallic color) and the less obviously silver-plated items (white metallic with very little luster) were segregated and analyzed spectrographically. Analytical results typical of gold coatings and the host metal alloys are shown in table 2. In table 2 it is noted that the gold plating is very thin and is generally on top of a much heavier plating of silver. The host alloys vary and (copper-tin, copper-zinc-lead, copper-zinc-lead-tin, copper-zinc-nickel-manganese, copper-tin-zinc, and even zinc die cast containing copper and lead) depend upon the necessary physical property requirements of the individual items. Silver-plated parts segregated during hand dismantling were also analyzed spectrographically. Analytical results typical of silver-plated items are shown in table 3. The host alloys for silver-coated items were also mainly copper-base with occasional use of zinc die cast. However, alloying elements found in these items not found in gold-plated parts were beryllium, cobalt, and a much higher iron impurity or deliberate alloying with this element.

TABLE 2. - Composition range of gold-plated items found in a tuner radio (TN 178/APR 13), wt-pct

| Item | Description | >10 | >5 | 1-10 | 0.3-3.0 | 0.1-1.0 | Other |
|---|---|---|---|---|---|---|---|
| 1 | Retaining clips.... | Cu | - | Ag, Sn | - | - | 0.01-0.1 Au |
| 2 | Long round pins.... | Cu, Zn | - | Ag, Pb | - | - | 0.01-0.1 Au |
| 3 | Flat pins.......... | Cu, Zn | Ag | Pb | Sn | Au | - |
| 4 | Female connectors.. | Cu | Ag, Sn | - | Zn | - | 0.03-0.3 Au |
| 5 | Small round pins... | Zn | Cu | Pb | - | Ag | 0.003-0.003 Au |
| 6 | Terminal post...... | Cu, Zn | - | Pb | - | - | 0.01-0.1 Ag, 0.03-0.3 Au |
| 7 | Terminal strip..... | Cu, Zn | Ni | - | - | Mn | 0.003-0.03 Ag, 0.03-0.3 Au |
| 8 | Female connector... | Cu | Ag, Sn | - | Zn | - | 0.03-0.3 Au |

NOTE.--Dash indicates no elements were detected in the weight range.

TABLE 3. - Composition range of silver-plated items found in a power supply (PP 336/APR 9), wt-pct

| Item | Description | >10 | >5 | 1-10 | 0.3-3.0 | 0.1-1.0 | Other |
|---|---|---|---|---|---|---|---|
| 1 | Cylindrical sleeve... | Cu, Ag | - | Be | - | Fe | 0.03-0.3 Co, Ni |
| 2 | Tube pins............ | Cu | Ag, Sn | Pb, Be | - | Fe | 0.03-0.3 Co |
| 3 | Small screws......... | Cu, Zn | - | Pb | - | Fe, Ag | - |
| 4 | Terminal contacts.... | Ag, Cu | - | - | - | - | - |
| 5 | Male pins............ | Ag, Cu | - | Be | - | Co | - |
| 6 | Connector prongs..... | Zn | - | Ag, Cu, Pb | - | - | - |
| 7 | Clip................. | Cu | Zn | Ag | - | - | - |
| 8 | Terminal clip........ | Cu | Zn | Pb | - | Ag | - |
| 9 | Terminal bar......... | Cu, Zn | - | Ag | - | - | - |
| 10 | Flat washer.......... | Cu | - | Sn | Ag | - | - |
| 11 | Forked terminal...... | Ag, Cu | - | - | - | - | - |
| 12 | Flat pins............ | Cu | Ag, Zn | Pb | Fe | - | - |
| 13 | Lock washer.......... | Cu | - | Ag, Sn | - | - | - |

NOTE.--Dash indicates no elements were detected in the weight range.

After precious-metal-coated parts were initially identified spectrographically other items coated with gold and silver were readily discernible from uncoated parts. Approximately 23 lbs of silver-coated and 2 lbs of gold-coated items were hand-picked from the 726.36-lbs sample. About 60 pct of the silver-coated items were fairly large brass sections with a low surface area-to-weight ratio. Melting these items resulted in an ingot assaying 1.78 pct silver. The remaining silver-coated items were small connectors with a large surface area-to-weight ratio. An ingot assaying 4.22 pct silver resulted from melting these connectors. The weighted average of silver in all the silver-coated items was 2.86 pct. Gold-plated items were mainly male or female connectors. Melting these items resulted in a copper-base ingot assaying 3.10 pct silver and 0.263 pct gold.

## Circuitry Wire

The circuitry wire in the sample was both single strand and multistrand covered with various types of insulating material. A wire sample weighing about 2 lbs, and representative of the total lot of 10 lbs removed from all 36 units, was stripped of insulation, melted, and assayed. The unstripped copper-base circuitry wire averaged 58 pct metallic content and assayed 0.14 pct silver and 1.04 pct tin. This is equivalent to 40.8 tr oz/ton silver and 20.8 lbs/ton tin.

## CHARACTERIZATION OF SHREDDED MODULES PROCESSED AS A GROUP

A number of modules were shredded and processed as a group after initially identifying materials in representative modules by complete hand dismantling. Characterizations of both groups are described below.

### Transformers

Nine transformers that were hand-dismantled fit primarily into two categories: metal-encased and epoxy-coated. Tables 4 and 5 list the compositions of the two types.

TABLE 4. - Materials composition of metal-encased transformers

| Transformer | Wt of materials, g | | | Copper base, wt-pct |
|---|---|---|---|---|
| | Copper base | Iron base[1] | Nonmetals | |
| 1.................... | 18.9 | 141.5 | 66.0 | 8.4 |
| 2.................... | 10.0 | 155.3 | 8.0 | 5.8 |
| 3.................... | 43.8 | 225.1 | 61.6 | 13.7 |
| 4.................... | 7.1 | 109.2 | 59.9 | 4.0 |
| 5.................... | 42.5 | 329.1 | 135.8 | 8.4 |
| 6.................... | 245.0 | 1,410.8 | 84.8 | 14.1 |

[1]Outer casing plus silicon steel laminations.

TABLE 5. - Materials composition of epoxy-coated transformers

| Transformer | Wt of materials, g | | | Copper base, wt-pct |
|---|---|---|---|---|
| | Copper base | Iron base | Nonmetals | |
| 1.................... | 222.4 | 335.8 | 166.2 | 30.7 |
| 2.................... | 470.5 | 720.4 | 351.5 | 30.5 |
| 3.................... | 527.5 | 810.3 | 395.4 | 30.4 |

The copper wire in the metal-encased transformers was extremely fine, whereas the epoxy-coated transformers were wound with much coarser wire. Oil was found in most metal-encased transformers. After the oil from the rest of the metal-encased transformers had been drained, all 111 metal-encased and epoxy-coated transformers were combined, weighed, and shredded. Separating materials of the shredded transformers produced 24 lbs of copper-base metals, 68.2 lbs of iron-base metals, and 16 lbs of nonmetals. Gas chromatograph analysis of the transformer oil indicated a PCB content less than 0.0005 pct. This low value for PCB would indicate that the fluid transformer oil was not a PCB but was contaminated with the waxlike PCB Aroclor 1254 when all the metal cases were punctured and drained. Some transformers contained the heavy wax and others contained oil, but all were punctured with the same pointed instrument.

## Metal-Encased Capacitors

Metal-encased capacitors were predominantly composed of paper-backed aluminum foil and paper. The outer metal cases were steel, aluminum, or brass. Some capacitors were oil-filled. Others had a yellowish slimy waxlike material impregnating the paper-foil construction of the capacitors. Contacts, internal wires, and terminals were identified spectrographically as copper alloys containing tin, zinc, and lead. Four capacitor units were hand-dismantled, and the compositions are shown in table 6. The remaining metal-encased capacitors, 503 in all, were drained of oil where required and shredded in the hammer mill. Overall composition of the sample is shown in table 7. The drained capacitor oil and the coarse and fine paper from the shredded capacitors contained 0.25, 1.5, and 6.6 pct of the PCB Aroclor 1254, respectively. No other PCB's were detected. Again, the capacitor oil may have been contaminated with PCB by the instrument used to puncture all the cases.

TABLE 6. - Composition of selected metal-encased capacitors

| Capacitor unit | Outer case | | Terminals, wire, contacts | | Paper-backed foil,[1] wt-pct |
|---|---|---|---|---|---|
| | Material | Wt-pct | Material | Wt-pct | |
| 1 | Aluminum base..... | 12.5 | Copper base... | 11.7 | 75.8 |
| 2 | Copper............ | 41.7 | .....do....... | 14.4 | 43.9 |
| 3 | Galvanized steel.. | 33.5 | .....do....... | 5.4 | 61.2 |
| 4 | Steel............. | 36.0 | .....do....... | 8.6 | 55.4 |

[1]Weight of adhering yellow waxy material included.

TABLE 7. - Composition of metal-encased capacitors

| | Wt, lb | Wt-pct |
|---|---|---|
| Magnetic metal....................... | 5.7 | 13.6 |
| Nonmagnetic metal.................... | 9.2 | 22.0 |
| Paper-backed foil and paper[1].......... | 26.4 | 63.0 |
| Oil.................................. | .6 | 1.4 |

[1]Weight of adhering yellow waxy material included.

## Electron Tubes

Electron tubes were shredded as a group in the hammer mill. Magnetic fractions were recovered first; then pulverized glass, plastics, and ceramics were separated from the nonmagnetic metal fraction using an electrostatic separator. Table 8 shows the distribution of materials. The nonmagnetic metal was melted, cast, and assayed initially by spectrographic analysis. The copper-base ingot contained, 1 to 10 wt-pct Zn, 0.3 to 3.0 wt-pct Ni and Pb, 0.1 to 1.0 wt-pct Ag, Al, Fe, and Sn, and 0.03 to 0.3 wt-pct Mn and Au. Quantitative assay for gold and silver was 0.24 wt-pct Au and 0.12 wt-pct Ag. Metal recovery in ingot form was 635.4 g (1.4 lb) out of 2.8 lbs or 50 pct. Recovery was low because iron-base material and nonmetals were still attached to the coarsely shredded nonmagnetic metal and some high-melting-point nonmagnetic metals or alloys did not dissolve in the molten copper base melt.

TABLE 8. - Shredded electron tubes from 36 electronic black boxes

| Material | Wt, lb | Wt-pct |
|---|---|---|
| Glass, plastic, and ceramics.................... | 15.3 | 67.4 |
| Magnetic metal................................ | 4.6 | 20.3 |
| Nonmagnetic metal............................. | 2.8 | 12.3 |

## Small Motors and Relays

Hand-dismantling small motors indicated that, by weight, the motors were primarily magnetic metals (cases, armatures, and cores), with copper wire, copper alloys in the terminals, and insulation comprising the rest of the contained materials. No evidence of precious metals was noted in the construction materials of small motors. Dismantled relays also were found to be constructed, by weight, mainly of magnetic materials (cases, supports, coils, and fasteners), with copper wire, copper alloy terminal, clips, lever arms, and fasteners plus some nonmetals making up the remainder. Relays do contain precious metals in some contact points, but they only amount to a very minor fraction of the total module weight. To be more exact, points in a relay account for approximately 0.1 pct of the weight in the total relay module. Several relays were hand-dismantled to assess the material contents of the lever arm-contact point combination for precious metals. Metallic points, varying in color and seldom greater than one-sixteenth of an inch in diameter and thickness, were found attached to copper alloy lever arms by either brazing or heading. A qualitative analysis of the metal composition of selected contact points and lever arms was determined and the results recorded in table 9.

TABLE 9. - Spectrographic analysis of selected contact points and lever arms removed from several relay units

| Items | Range, wt-pct | | | | | |
|---|---|---|---|---|---|---|
| | >10 | >5 | 1-10 | 0.3-3.0 | 0.1-1.0 | <0.1 (only precious metals reported here) |
| Points........ | Cu, Pd | - | Sn | Zn | Cr | 0.001-0.01 Ag, 0.03-0.3 Pt |
| Do.......... | Cu, Pd | Ni, Zn | - | - | - | 0.003-0.03 Ag, 0.01-0.1 Pt |
| Do.......... | Cu | Ni, Zn, Pd | - | - | Mn | 0.001-0.01 Ag, 0.003-0.03 Au, 0.03-0.3 Pt |
| Do.......... | Cu | Ni | Zn | - | - | 0.003-0.003 Ag |
| Do.......... | Ag | Cu, Pd | - | - | - | 0.003-0.03 Au, 0.03-0.3 Pt |
| Do.......... | Cu, Sn | Ag, Pd | Zn | - | - | - |
| Do.......... | Be, Cu | - | - | - | Ag | - |
| Do.......... | Cu, Sn | - | Pb, Zn | - | - | 0.001-0.01 Ag |
| Do.......... | Ag, Cu | - | - | - | - | - |
| Lever arms.... | Cu | - | Sn, Zn | - | - | 0.001-0.01 Ag |
| Do.......... | Cu | Ni, Zn | - | - | Mn | 0.003-0.03 Ag |
| Do.......... | Cu | Ni, Zn | - | Mn | - | 0.003-0.03 Ag |
| Do.......... | Cu | Ni | Zn | - | Mn | 0.003-0.003 Ag |
| Do.......... | Cu | - | Sn | - | - | 0.001-0.01 Ag |

NOTE.--Dash indicates no elements were detected in the weight range.

Palladium and/or silver were found to be the major precious metals added in contact point alloys, with trace amounts of gold and somewhat greater-than-trace amounts of platinum sometimes present. Some contact points contained no precious metals in their alloy composition. Alloy combinations of copper-nickel-zinc, beryllium-copper, and copper-tin-lead-zinc were noted in this group. The weight of a contact point was generally less than a tenth of a gram. Lever arms were copper-base alloys containing varying amounts of tin, nickel, and zinc, lesser amounts of manganese, and traces of silver resulting from impurity rather than alloying addition.

There were 20 small motors and 75 relays remaining in the sample after sufficient hand-dismantling was completed to adequately identify the materials makeup of these units. Since the contact points were only 0.1 wt-pct of the relay's materials of construction, and the base-metal composition of small motors and relays were similar, these remaining intact units were combined as a group for mechanical processing. This included shredding and separating into four basic material fractions and removal of the contact points. Table 10 shows the distribution of these materials after shredding and separation.

TABLE 10. - Material composition of small motors and relays

| Material | Wt, lb | Wt-pct |
|---|---|---|
| Magnetic metals............. | 9.0 | 57.7 |
| Copper wire................. | 3.2 | 20.5 |
| Nonmagnetic metals.......... | 1.2 | 7.7 |
| Nonmetals................... | 2.2 | 14.1 |

The total weight of clipped contact points (the contact point plus a small piece of the lever arm) identified in the sample was only 20 g. Although the precious metals value of the points would be high, 20 g in a 726-lbs (330 Kg) sample is a relatively insignificant amount of metal.

## Resistors, Epoxy- and Plastic-Encased Capacitors, and RF Coils

Small items like resistors, capacitors, and RF coils were clipped from the circuit boards and weighed. Several individual items were crushed in a mortar and pestle to establish their composition. The remainder were pulverized in a hammer mill. By air classification, the pulverized material was separated into light (mostly paper-thin mica) and heavy fractions. Magnetic separation removed the magnetic metals from the heavy fraction. The remaining heavy fraction was further processed by roll crushing. This flattened the nonmagnetic metal and crushed the nonmetals into a fine powder. Electrostatic separation of the mixture produced clean nonmagnetic metal and nonmetal fractions. The nonmagnetic metal fraction was melted to homogenize the mixed metals and alloys. The resulting copper base metal assayed, in wt-pct, 0.33 Ag, 0.42 Ni, 16.2 Pb, 6.18 Sn, and 6.55 Zn. Materials distribution is shown in table 11.

TABLE 11. - Composition of combined resistors, capacitors, and RF coils

| Material | Wt, g | Wt-pct |
|---|---|---|
| Lights (mica) | 426.1 | 10.2 |
| Nonmetal from roll crushers | 1,932.5 | 46.0 |
| Nonmagnetic metal | 1,642.6 | 39.1 |
| Magnetic metal | 198.4 | 4.7 |

## ECONOMIC VALUE OF THE ELECTRONIC COMPONENTS

Material weights were recorded for different categories of base and precious metals for each dismantled box. From these data the material compositions were calculated for each individual unit. Results are shown in table 12. For ease of comparison, since individual black box units ranged in weight from 2.5 to 58 lbs, comparative dollar values were based on 100 lbs of each unit. Results are shown in table 13, along with scrap and precious metals values used for calculations.

TABLE 12. - Summary of materials composition

| Unit | Unit identification[1] | Material composition, wt-pct | | | | | Precious metals fraction[2] |
|---|---|---|---|---|---|---|---|
| | | Aluminum base | Copper base | Magnetic metals | Stainless steel | Nonmetals | |
| 1 | Storage unit.... | 58.4 | 14.1 | 15.7 | 0.5 | 11.3 | 0.3 |
| 2 | Receiver trans.. | 56.6 | 17.0 | 13.5 | 1.3 | 11.5 | 2.8 |
| 3 | .....do......... | 36.4 | 18.8 | 23.1 | 3.3 | 18.3 | 1.9 |
| 4 | .....do......... | 32.0 | 17.7 | 21.2 | 3.4 | 25.7 | 1.5 |
| 5 | Radio receiver.. | 28.6 | 25.9 | 23.5 | 1.5 | 20.4 | 3.5 |
| 6 | Receiver trans.. | 20.4 | 35.8 | 19.1 | 4.3 | 20.3 | 14.5 |
| 7 | Receiver radio.. | 25.1 | 28.3 | 29.0 | 2.3 | 15.3 | 11.1 |
| 8 | Indicator....... | 43.9 | 17.0 | 19.6 | 3.0 | 16.5 | 1.4 |
| 9 | Tuner radio..... | 59.6 | 16.5 | 8.3 | 5.5 | 10.1 | 2.5 |
| 10 | Amplifier....... | 32.9 | 22.2 | 23.8 | 2.3 | 18.7 | 5.2 |
| 11 | Tuner radio..... | 51.2 | 17.7 | 14.1 | 7.9 | 9.1 | 2.2 |
| 12 | .....do......... | 62.1 | 12.4 | 8.3 | 8.5 | 8.8 | 2.3 |
| 13 | Indicator azim.. | 40.2 | 17.5 | 20.8 | 4.3 | 17.1 | 1.3 |
| 14 | Converter....... | 47.4 | 23.5 | 11.0 | 3.2 | 14.8 | 8.2 |
| 15 | Tuner radio..... | 54.9 | 17.6 | 10.5 | 7.5 | 9.5 | 11.6 |
| 16 | .....do......... | 57.3 | 20.8 | 9.5 | 4.4 | 7.9 | 13.5 |
| 17 | .....do......... | 56.8 | 20.1 | 9.1 | 5.3 | 8.6 | 13.4 |
| 18 | Indicator azim.. | 36.2 | 19.8 | 21.1 | 4.4 | 18.5 | 1.8 |
| 19 | Receiver........ | 34.5 | 17.4 | 26.7 | 1.7 | 19.6 | 2.2 |
| 20 | Indicator....... | 39.5 | 12.8 | 12.9 | 3.9 | 30.9 | 2.6 |
| 21 | Amp. video...... | 29.4 | 23.5 | 19.3 | 8.9 | 18.9 | 4.7 |
| 22 | Power supply.... | 27.9 | 19.0 | 31.1 | 2.3 | 19.7 | 1.3 |
| 23 | .....do......... | 6.3 | 24.4 | 47.6 | 2.5 | 19.2 | 1.1 |
| 24 | Tuner radio..... | 61.8 | 14.7 | 9.3 | 5.9 | 8.3 | 2.3 |
| 25 | Keyer........... | 28.5 | 23.6 | 21.0 | 5.7 | 21.2 | 5.2 |
| 26 | Receiver........ | 25.9 | 21.7 | 30.1 | 3.4 | 18.9 | 1.8 |
| 27 | Control trans... | 32.1 | 22.4 | 12.9 | 13.7 | 18.9 | 3.8 |
| 28 | Receiver trans.. | 28.8 | 18.1 | 28.6 | 4.0 | 20.5 | 1.2 |
| 29 | Power supply.... | 28.6 | 16.8 | 34.5 | .6 | 19.4 | 1.0 |
| 30 | Coder trans set. | 45.3 | 15.3 | 22.5 | 1.4 | 15.5 | 2.2 |
| 31 | Electron tube... | 14.3 | 8.4 | 69.4 | 5.5 | 2.3 | 0 |
| 32 | Power supply.... | 25.1 | 15.9 | 33.3 | 3.7 | 21.9 | .8 |
| 33 | Video decoder... | 51.6 | 13.3 | 11.5 | 8.5 | 15.1 | 3.6 |
| 34 | Coder video..... | 54.3 | 16.0 | 9.0 | 3.4 | 17.3 | 2.8 |
| 35 | N1 compass...... | 16.1 | 5.1 | 43.8 | 33.3 | 1.7 | .2 |
| 36 | Inverter........ | 32.6 | 19.4 | 41.4 | .8 | 5.8 | .2 |

[1]Unit identifications used by DPDS.
[2]The precious metals fraction represents a percentage of the total black box weight. It was developed by hand-segregating silver- and gold-coated components through visual examination.

TABLE 13. - Base and precious metals value[1] for hand-dismantled black boxes

| Unit[2] | Base and precious metals value (100-lb basis) | | | | | | | Unit value (per lb) |
|---|---|---|---|---|---|---|---|---|
| | Aluminum base | Copper base | Magnetic metals | Stainless steel | Silver | Gold | Total | |
| 1 | $24.24 | $7.68 | $0.63 | $0.14 | $2.01 | $1.66 | $36.36 | $0.36 |
| 2 | 23.49 | 9.26 | .54 | .38 | 15.58 | .78 | 50.03 | .50 |
| 3 | 15.11 | 10.25 | .92 | .96 | 11.13 | .49 | 38.86 | .39 |
| 4 | 13.28 | 9.65 | .85 | .99 | 9.30 | .83 | 34.90 | .35 |
| 5 | 11.87 | 14.11 | .94 | .43 | 24.48 | 2.24 | 54.07 | .54 |
| 6 | 8.47 | 19.51 | .76 | 1.25 | 63.91 | 7.60 | 101.50 | 1.01 |
| 7 | 10.42 | 15.42 | 1.16 | .67 | 65.05 | 12.05 | 12.90 | 1.06 |
| 8 | 18.22 | 9.26 | .78 | .87 | 10.21 | 14.46 | 53.80 | .54 |
| 9 | 24.73 | 8.99 | .33 | 1.59 | 16.35 | .49 | 52.48 | .52 |
| 10 | 13.65 | 12.10 | .95 | .67 | 30.07 | 10.42 | 67.86 | .68 |
| 11 | 21.25 | 9.65 | .56 | 2.29 | 14.70 | 6.62 | 55.07 | .55 |
| 12 | 25.77 | 6.76 | .33 | 2.46 | 13.38 | 5.89 | 54.59 | .55 |
| 13 | 16.68 | 9.54 | .83 | 1.25 | 8.27 | 7.45 | 44.02 | .44 |
| 14 | 19.67 | 12.81 | .44 | .93 | 44.40 | NAp | 78.25 | .78 |
| 15 | 22.78 | 9.59 | .42 | 2.17 | 63.46 | NAp | 98.42 | .98 |
| 16 | 23.77 | 11.34 | .38 | 1.28 | 80.54 | 7.84 | 125.15 | 1.25 |
| 17 | 23.57 | 10.95 | .36 | 1.54 | 80.40 | 6.91 | 123.73 | 1.24 |
| 18 | 15.02 | 10.79 | .84 | 1.28 | 11.40 | 1.95 | 41.28 | .41 |
| 19 | 14.32 | 9.48 | 1.07 | .49 | 13.30 | 8.72 | 47.38 | .47 |
| 20 | 16.39 | 6.98 | .52 | 1.13 | 15.97 | 11.73 | 52.72 | .53 |
| 21 | 12.20 | 12.81 | .77 | 2.58 | 27.65 | 11.35 | 67.36 | .67 |
| 22 | 11.58 | 10.35 | 1.24 | .67 | 7.39 | .49 | 31.72 | .32 |
| 23 | 2.61 | 13.30 | 1.90 | .72 | 9.70 | NAp | 28.23 | .28 |
| 24 | 25.65 | 8.01 | .37 | 1.71 | 14.40 | 4.82 | 54.96 | .55 |
| 25 | 11.83 | 12.86 | .84 | 1.65 | 31.60 | .92 | 59.70 | .60 |
| 26 | 10.75 | 11.83 | 1.20 | .99 | 15.83 | 5.16 | 45.76 | .46 |
| 27 | 13.32 | 12.21 | .52 | 3.97 | 22.01 | 11.34 | 63.37 | .63 |
| 28 | 11.95 | 9.87 | 1.14 | 1.16 | 8.06 | .49 | 32.66 | .33 |
| 29 | 11.87 | 9.16 | 1.38 | .17 | 6.04 | 9.49 | 38.11 | .38 |
| 30 | 18.80 | 8.34 | .90 | .41 | 13.87 | 14.22 | 56.54 | .56 |
| 31 | 5.59 | 4.58 | 2.78 | 1.59 | NAp | NAp | 14.54 | .14 |
| 32 | 10.42 | 8.66 | 1.33 | 1.07 | 4.85 | NAp | 26.33 | .26 |
| 33 | 21.41 | 7.25 | .46 | 2.46 | 21.43 | 34.28 | 87.29 | .87 |
| 34 | 22.53 | 8.72 | .36 | .99 | 16.96 | 15.19 | 64.75 | .65 |
| 35 | 6.68 | 2.78 | 1.75 | 9.66 | 1.58 | NAp | 22.45 | .22 |
| 36 | 13.53 | 10.57 | 1.66 | .23 | 1.58 | NAp | 27.57 | .28 |

NAp Not applicable.

[1]Data based on the following scrap values for base metals taken from Iron Age, April 14, 1980. Data for precious metals were based on primary metals value in the same issue of Iron Age. The precious metal values listed in the table are solely on assay and assuming 100 pct recovery. Scrap refinery charges are not included.

| | | |
|---|---|---|
| Aluminum base | per lb.. | $0.415 |
| Copper base | per lb.. | .545 |
| Magnetic metals | per lb.. | .04 |
| Stainless steel | per lb.. | .29 |
| Gold | per troy oz.. | 486.95 |
| Silver | per troy oz.. | 14.88 |

[2]Corresponds to units listed in table 12.

The total value of each unit was then determined using the actual received weight and the value per material shown in table 14. Results shown in table 14 ranged from $1.62 for the control transformer to $58.32 for the receiver transformer. The average value for the total 36 box unit was $0.55 per lb.

TABLE 14. - Value of units based on as-received units

| Item[1] | Wt, lb | Metals value (per lb) | Value of each unit | Item[1] | Wt, lb | Metals value (per lb) | Value of each unit |
|---|---|---|---|---|---|---|---|
| 1 | 8.86 | $0.36 | $3.19 | 20 | 31.12 | $0.53 | $16.49 |
| 2 | 56.73 | .50 | 28.36 | 21 | 11.57 | .67 | 7.75 |
| 3 | 29.18 | .39 | 11.36 | 22 | 28.99 | .32 | 9.28 |
| 4 | 28.49 | .35 | 9.97 | 23 | 11.20 | .28 | 3.14 |
| 5 | 12.89 | .54 | 6.96 | 24 | 15.19 | .55 | 8.35 |
| 6 | 57.74 | 1.01 | 58.32 | 25 | 31.31 | .60 | 18.79 |
| 7 | 11.30 | 1.06 | 11.98 | 26 | 37.44 | .46 | 17.22 |
| 8 | 9.76 | .54 | 5.27 | 27 | 2.57 | .63 | 1.62 |
| 9 | 19.11 | .52 | 9.94 | 28 | 30.44 | .33 | 10.04 |
| 10 | 16.38 | .68 | 11.14 | 29 | 25.12 | .38 | 9.55 |
| 11 | 15.48 | .55 | 8.51 | 30 | 7.19 | .56 | 4.03 |
| 12 | 18.13 | .55 | 9.97 | 31 | 11.77 | .14 | 1.65 |
| 13 | 27.50 | .44 | 12.10 | 32 | 26.03 | .26 | 6.77 |
| 14 | 10.32 | .78 | 8.05 | 33 | 6.25 | .87 | 5.44 |
| 15 | 19.39 | .98 | 19.00 | 34 | 5.44 | .64 | 3.54 |
| 16 | 15.48 | 1.25 | 19.35 | 35 | 24.63 | .22 | 5.42 |
| 17 | 15.49 | 1.24 | 19.36 | 36 | 15.11 | .28 | 4.23 |
| 18 | 22.19 | .41 | 9.10 | | | | |
| 19 | 10.62 | .47 | 4.99 | Total | 726.36 | NAp | [2]400.23 |

NAp Not applicable.

[1]Corresponds to units listed in tables 1, 12, and 13.

[2]Average values $= \frac{400.23}{726.36} = \$0.55$ per lb.

The precious metals value of this sample is very low. In table 15 the copper-base fraction that contains most of the precious metals is treated as a separate entity. It is the most important and valuable metal fraction recovered from processed electronic units. Results in table 15 show the copper-base fraction made up only 19.3 pct of the 36-box sample and contained a total of about 11 and 0.07 tr oz of silver and gold, respectively. Assuming 80-pct copper recovery, refining this copper-base fraction to anode copper would take about 13,000 lbs of the 36-box sample to produce 1 ton of anodes. In producing the anodes, lead, tin, and zinc would be burned off as oxides and collected in a bag house. A custom melter processing this scrap would probably not give credit for these metals, but would sell the mixed metal oxide dust to another secondary metals refiner. The anodes cast from the copper-base fraction would now assay 193.5 and 1.17 tr oz/ton of silver and gold, respectively. Copper anodes thus produced from the electronic scrap sample compare with anodes produced from copper ore mined at Cerro de

Pasco, Peru, which assay 188 tr oz/ton Ag and 1.2 tr oz/ton Au.[6] An average assay typical of copper anodes produced from U.S. and foreign blister is 44.7 tr oz/ton Ag and 1.51 tr oz/ton Au. From the data developed in table 15, it would take about 13,000 lbs of this electronic scrap sample to produce 1 ton of copper refined as far as the anode stage. The 20 g of contact points in the 36-box sample are now increased by a factor of 18. Therefore, there may be a few troy ounces of palladium and a fraction of a troy ounce of platinum and an additional amount of gold and silver added to the precious metals content of the cast copper anodes. Still, the copper anodes produced from this sample of electronic scrap would be most economically processed by a regular copper refiner rather than a custom precious metals refiner.

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[6]Butts, A. Copper, The Metal. Its Alloys and Compounds. Am. Chem. Soc. Monograph Ser., No. 122, Reinhold Pub. Corp., New York, 1954, pp. 125, 226.

TABLE 15. - Precious metals contained in each individual unit

| Item | Item wt, lb | Wt, pct copper base | Copper base wt, lb | Precious metals in copper base, tr oz | |
|---|---|---|---|---|---|
| | | | | Ag | Au |
| 1 | 8.86 | 14.1 | 1.25 | 0.012 | 0.0003 |
| 2 | 56.73 | 17. | 9.64 | .594 | .0009 |
| 3 | 29.13 | 18.8 | 5.48 | .218 | .0003 |
| 4 | 28.49 | 17.7 | 5.04 | .178 | .0005 |
| 5 | 12.89 | 25.9 | 3.34 | .212 | .0006 |
| 6 | 57.74 | 35.8 | 20.67 | 2.480 | .0090 |
| 7 | 11.30 | 28.3 | 3.20 | .494 | .0030 |
| 8 | 9.76 | 17. | 1.66 | .067 | .0029 |
| 9 | 19.11 | 16.5 | 3.15 | .210 | .0002 |
| 10 | 16.38 | 22.2 | 3.64 | .331 | .0035 |
| 11 | 15.48 | 17.7 | 2.74 | .153 | .0021 |
| 12 | 18.13 | 12.4 | 2.25 | .163 | .0022 |
| 13 | 27.50 | 17.5 | 4.81 | .153 | .0042 |
| 14 | 10.32 | 23.5 | 2.42 | .308 | NAp |
| 15 | 19.39 | 17.6 | 3.41 | .827 | NAp |
| 16 | 15.48 | 20.8 | 3.22 | .838 | .0025 |
| 17 | 15.49 | 20.1 | 3.11 | .837 | .0022 |
| 18 | 22.19 | 19.8 | 4.39 | .170 | .0009 |
| 19 | 10.62 | 17.4 | 1.85 | .095 | .0019 |
| 20 | 31.12 | 12.8 | 3.98 | .334 | .0075 |
| 21 | 11.57 | 23.5 | 2.72 | .215 | .0027 |
| 22 | 28.99 | 19. | 5.51 | .144 | .0003 |
| 23 | 11.20 | 24.4 | 2.73 | .073 | NAp |
| 24 | 15.19 | 14.7 | 2.23 | .147 | .0015 |
| 25 | 31.31 | 23.6 | 7.39 | .665 | .0006 |
| 26 | 27.44 | 21.7 | 8.12 | .292 | .0029 |
| 27 | 2.57 | 22.4 | .58 | .038 | .0006 |
| 28 | 30.44 | 18.1 | 5.51 | .165 | .0003 |
| 29 | 25.12 | 16.8 | 4.22 | .102 | .0049 |
| 30 | 7.19 | 15.3 | 1.10 | .067 | .0021 |
| 31 | 11.77 | 8.4 | .99 | NAp | NAp |
| 32 | 26.03 | 15.9 | 4.14 | .085 | NAp |
| 33 | 6.25 | 13.3 | .83 | .090 | .0044 |
| 34 | 5.44 | 16.0 | .87 | .062 | .0017 |
| 35 | 24.63 | 5.1 | 1.26 | .026 | NAp |
| 36 | 15.11 | 19.4 | 2.93 | .016 | NAp |
| Total | 726.36 | NAp | 140.38 | 10.861 | 0.0667 |

NAp Not applicable.

## CONCLUSION

This paper describes a characterization study conducted for the Defense Property Disposal Service (DPDS) on a sample lot of 36 separate electronic components available for scrap recovery. Using published scrap values for base and precious metals, an estimated average value of $0.55 per pound was calculated. The 36 units described in this study consisted of pre-1957 avionic black boxes. Considerably higher value is expected in more recent generations of avionic scrap. A dry mechanical separation process is currently being tested in a pilot-scale operation of approximately 500 lbs/hr capacity. The data from this test program will be used to estimate processing costs for this method of mechanically processing electronic scrap.

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