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PLATED THROUGH-HOLES IN
FLEXCIRCUITS

PDO 6984752, Topical Report

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**Kansas City
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Topical Report

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PLATED THROUGH-HOLES IN FLEXCIRCUITS

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Prepared by R. A. Hile, D/862, under PDO 6984752

A process for electroplating through-hole connections in flexible printed circuitry was established. Evaluation of the plating integrity was accomplished by taking resistance readings before and after exposure to thermal shock, flex testing, and a lamination cycle. It was determined the electrical properties of plated-through holes were not significantly affected by these environments.

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SUMMARY

Processes developed for plating through holes in flexible polyimide circuitry established a manufacturing capability that is useful for many inner-connection applications. The development work centered on establishing a process for sensitizing or electroless-plating polyimide film in drilled holes to achieve good adherence of electroplated copper. A variety of processes were evaluated most of which were a modification of the existing electroless plating process used for rigid printed wiring boards. One process, the use of Shipley 1160 Conditioner followed by the standard process, clearly produced the best results.

A lot of 20 panels was fabricated with this process to test the effect of different environments on the plating integrity. Laminate panels containing various sizes of plated-through holes were subjected to solder dip and level, temperature cycling, flex testing, and lamination cycles. Electrical resistance values of the hole circuits were recorded before and after testing. The electrical testing and visual examination of the plating cross-sections indicated that the plating integrity was unchanged by these environments.

The land diameter or annular ring around the drilled hole had no effect on the plating quality. Using the developed process plated-through holes provide a reliable electrical inner-connection for flexible circuitry.

DISCUSSION

SCOPE AND PURPOSE

The objectives of this project included development of a variety of processes necessary to manufacture flexcircuits for application up to approximately 150°C. This phase was devoted to plated-through holes in flexcircuits. Plated-through holes provide a reliable electrical inner-connection for a variety of flexcable applications.

PRIOR WORK

The previous work of this project, principally devoted to laminated flexcircuits, has been reported in project topical reports listed in the bibliography. The flexcircuit development work has been successfully incorporated into flexcircuits fabricated for specific weapon application.

ACTIVITY

This development work was initiated to establish a through-hole plating process for copper/Kapton/copper flexcircuits. Tests indicated that the existing standard copper plating process used for rigid printed wiring boards would not sensitize the Kapton layer in drilled holes to provide the conductive path necessary for subsequent electroplating operations. The approach of this study was to modify the existing process to obtain good electroless copper adherence to the polyimide surface.

Processes Evaluated

The standard electroless copper plating process is as follows:

- Immerse part in Shipley 1110 Conditioner at 71 to 74°C for 4 to 5 minutes;
- Immerse part in a 2.0 lb/gal (240 kg/m³) solution of ammonium persulfate for 1 to 3 minutes;
- Immerse part in a 10-percent solution of sulfuric acid for 1 to 3 minutes;
- Immerse part in a 25-percent solution of hydrochloric acid for 1 to 3 minutes;
- Immerse part in a 70-percent solution of Catalyst 9F for 1 to 3 minutes;

- Immerse part in a 22 oz/gal (164 kg/m³) solution of Accelerator 19 for 6 to 60 minutes; and
- Immerse part in a 10-percent solution of Cuposit at 44°C for 20 to 30 minutes (the Cuposit consists of 12 oz/gal (90 kg/m³) Shipley 328A, 12 oz/gal (90 kg/m³) Shipley 328B and 1.98 oz/gal (15.85 ml/l) Shipley 328C).

All operations except the hydrochloric acid immersion are followed by a thorough water rinse.

Five different variations of the standard electroless plating process were evaluated.

- Process A consists of the standard process preceded by a conditioning bath of Shipley 1160 for 5 minutes.
- Process B consists of the Shipley 1160 pretreatment from Process A and the replacement of the Shipley 1110 with a 10-percent solution of alchelat at 82°C for 2 to 5 minutes.
- Process C consists of a 2-1/2-percent solution of Shipley 1175 Conditioner at 65°C for 3 to 5 minutes, followed by the standard process.
- Process D consists of the standard process except that the Cuposit is mixed with Shipley 328S replacing the 328B in the last step.
- Process E consists of the following steps:
 1. Immerse part in a 20-percent solution of sodium hydroxide for 3 minutes;
 2. Immerse part in Shipley 1175 at 71°C for 3 minutes;
 3. Immerse part in 2 lb/gal (240 kg/m³) ammonium persulfate for 1/2 minute;
 4. Immerse part in a 10-percent solution of sulfuric acid for 1 minute;
 5. Immerse part in a 20-percent solution of hydrochloric acid for 2 minutes;
 6. Immerse part in Shipley Catalyst 9F for 2 minutes;
 7. Immerse part in Accelerator 9 to 5 minutes; and
 8. Immerse part in Electroless 328S for 7 minutes.

Plated Hole Configuration and Testing

Each of these five processes was used to fabricate a sample lot of eight panels. The material used was 2 oz/1 mil/2 oz (56.6 g/25.4 μm /56.6 g) copper/Kapton/copper laminate bonded together with a thermoset epoxy adhesive. Each test panel contained 120 holes. Four hole diameters were included on each panel: 0.013-, 0.028-, 0.042-, and 0.062-inch (0.340, 0.710, 1.650, and 1.570 mm). All panels on this evaluation were drilled using carbide drill bits. Drill speed was 25000 rpm with 20 inches/minute (508 mm/min) feed rate. The panels were drilled individually using phenolic backup on both sides of the panel. After electroless plating, the panels were electroplated using 30 A/ft² (2.8 A/m²) for 30 minutes to achieve approximately 0.0005 inch (12.7 μm) of plating.

Random holes were selected from each panel and cross sectioned. Results of microscopic examination revealed that Process A produced the best sensitization of the Kapton and thus resulted in the best electroplating. After this initial process screening, it was determined that additional work was needed to prove the repeatability of the process and also to determine the electrical properties of the plating before and after environmental testing. A process lot of 20 test panels (Figure 1) was fabricated using Process A. The panels were then drilled and electroplated using the same methods as the earlier samples. Drilled hole and land diameters (annular ring) were varied to determine the effect on plating quality. The hole and land data as well as the results of the electrical resistance testing is contained in the Appendix.

Testing was performed on eight panels chosen randomly from this lot. Four of these panels were solder dipped and solder leveled to deposit a protective solder layer approximately 0.0001-inch (0.254 μm) thick. The dc resistance of each hole circuit in all test specimens was measured with the use of a micro-ohmmeter and the values were recorded. Resistance values varied with hole diameter, but were generally within 10 percent of the resistance as calculated from the physical parameter of the hole circuits. No significant differences were noted between the measured resistance data of the plated holes which were solder dipped and those which were not.

Extraneous values of resistance were obtained where the annular ring of the hole circuit was too small for the electrode feet of the micro-ohmmeter to make full contact. Other readings, especially those of the smaller diameter holes, showed an open circuit condition caused by photoresist failure during the etching operation. Readings which were relevant for test purposes numbered in excess of 100 per test panel and were used as a criterium for degradation studies in temperature cycling, flexure, and laminating cycle tests.

Figure 1. Plated-Through Hole Test Panel

Temperature Cycling

Two test panels, numbers 11 and 77, the latter being solder dipped, were subjected to 10 cycles of temperature excursion between -35°C and 74°C . Each cycle was comprised of 4 hours minimum exposure at each temperature level with a maximum transfer time of 1 minute. The dc resistances of the hole circuits were measured and compared to the prior test data. Twelve of 264 readings showed an increase of 50 percent or greater. All such increases occurred in the panel which was not solder dipped. Visual examination showed that the copper plating within the periphery of these holes was undamaged. Resistance increases were attributed to changes in surface conditions of the land areas resulting from temperature exposure.

Flexure

Panels number 33 and 55, the latter being solder dipped, were flexed over 0.125-inch-radius (3.18 mm) mandrels in a roller bend test consisting of 25 cycles. Three mandrels were arranged in a triangular configuration (Figure 2) to insure that a consistent tension would be applied to the panel ends as the samples were drawn through by hand. The direction of bending was reversed approximately midway through the cycling. Comparisons of the dc resistance after testing with established data showed a 50 percent or greater increase in 15 of 264 plated-through holes. Fourteen of the higher readings occurred in the non-tinned panels. Since the plating within the holes was visually intact, the resistance change was assigned to variances in the land surface areas and was attributed to contamination or abrasion.

Laminating Cycle

The four remaining panels, 22, 44, and 88, the latter two being solder dipped, were subjected to a press lamination cycle of 20 minutes at 185°C with 500 psi (3.45 MPa) pressure. The lamination cycle is the most severe environment to which a flexcircuit is subjected during manufacture. Testing showed that resistance increased by 50 percent or more in 17 of 528 plated-through holes, with 12 of these on the non-tinned panels. These variations are attributed to surface variations and contamination since the plating integrity was unchanged.

Plating Quality

The resistance measurements and examination under magnification had indicated that the hole plating was of good quality. To verify these results, cross-sections were made of random holes. Representative samples are shown in Figure 3. The plating was satisfactory in all holes; however, there were some irregularities. For example, after drilling holes in Kapton laminate, there is a plastic flow of the Kapton back into the hole, resulting in a slight

Figure 2. Circuit Panel Flex Test Configuration (Side View)

HOLE 1. 0.013-INCH-DIAMETER (0.340 mm) DRILLED HOLE AFTER
SOLDER DIP AND LEVEL AND LAMINATION CYCLE.

HOLE 2. ONE SIDE OF 0.040-INCH-DIAMETER (1.016 mm)
DRILLED HOLE AFTER SOLDER DIP AND LEVEL
AND FLEX TESTING.

Figure 3. Cross-Sections of Plated-Through Holes, Approximately 250X

HOLE 3. ONE SIDE OF 0.040-INCH-DIAMETER
(1.016 mm) DRILLED HOLE AFTER SOLDER
DIP AND LAMINATION CYCLE.

HOLE 4. ONE SIDE OF 0.040-INCH-DIAMETER (1.016 mm)
HOLE AFTER LAMINATION.

Figure 3 Continued. Cross-Sections of Plated-Through Holes, Approximately 250X

bulge in the plating over the Kapton. In addition, plating nodules are common on corners as shown in hole number 3 (Figure 3).

ACCOMPLISHMENTS

The most significant accomplishments from this investigation are:

- An electroless plating process was developed which is suitable for use in electroplating Kapton film:
- Testing of various size plated-through holes revealed that temperature cycling, flexing, solder dipping, or lamination did not significantly affect the plating integrity; and
- Hole size and land diameters had no effect on plating thickness or quality.

FUTURE WORK

No additional work on this project is being performed at the present time.

Appendix

PLATED-THROUGH HOLE
ELECTRICAL RESISTANCE
TEST DATA

Table A-1. Plated-Through Hole Electrical Resistance Test Data

Hole Number	Hole Diameter (Inch)*	Land Diameter (Inch)*	Resistivity ($\mu\Omega$)															
			Panel 11		Panel 22		Panel 33		Panel 44		Panel 55**		Panel 66**		Panel 77**		Panel 88**	
			I†	A††	I	A†	I††	A	I	A†	I	A††	I	A†	I	A††	I	A†
1	0.100	0.175	22	20	21	22	22	22	22	24	22	23	23	23	22	23	22	22
2	0.080	0.125	22	21	20	23	22	22	21	22	-	15	22	23	22	22	23	22
3	0.080	0.125	21	23	20	23	22	22	22	23	22	23	23	23	23	24	23	22
4	0.080	0.125	22	24	22	21	22	21	21	23	22	23	23	24	22	22	23	22
5	0.080	0.125	21	20	22	22	21	22	21	23	22	23	23	23	22	23	23	22
6	0.080	0.125	22	20	21	21	43	47	21	23	22	23	23	23	22	23	23	23
7	0.080	0.125	22	22	21	22	21	22	21	23	22	23	22	23	23	22	23	22
8	0.100	0.175	21	22	21	23	22	23	22	21	22	23	23	24	23	22	24	23
9	0.080	0.175	22	23	21	22	22	23	22	23	22	23	23	23	23	22	23	22
10	0.080	0.175	22	20	21	22	22	22	21	23	22	23	22	23	23	23	23	22
11	0.080	0.175	21	19	21	22	20	22	21	22	22	23	23	24	23	22	22	22
12	0.080	0.175	23	20	21	23	21	23	21	23	22	23	23	23	23	23	23	22
13	0.080	0.175	23	24	21	21	22	23	22	23	20	23	22	23	23	22	22	23
14	0.080	0.175	23	20	21	22	22	23	21	22	21	21	22	23	23	22	23	22
15	0.100	0.175	23	24	20	24	22	22	22	21	22	23	23	23	23	22	23	22
16	0.080	0.100	20	20	21	20	22	23	21	23	22	24	23	23	23	23	23	23
17	0.080	0.100	21	21	21	21	22	22	21	23	22	23	23	23	23	23	23	22
18	0.080	0.100	21	22	21	22	23	23	21	23	22	23	23	24	22	22	-	-
19	0.080	0.100	20	22	21	22	23	23	20	22	22	23	23	24	22	23	23	23
20	0.080	0.100	21	21	20	23	21	23	21	23	22	23	23	23	22	23	23	23
21	0.080	0.100	23	21	21	23	21	23	21	22	22	23	23	23	22	24	22	22
22	0.100	0.175	22	21	20	23	22	23	21	24	22	23	23	23	22	23	23	22
23	0.100	0.175	21	21	20	23	21	23	21	22	21	23	23	23	23	22	22	22
24	0.040	0.075	19	19	18	21	20	19	20	22	21	23	22	23	22	22	21	22
25	0.040	0.075	21	22	19	21	22	20	20	22	21	23	22	22	22	22	22	22
26	0.040	0.075	23	25	20	21	20	21	18	22	23	23	22	22	22	24	20	22
27	0.040	0.075	17	25	18	21	20	22	19	21	24	23	22	22	22	21	19	21
28	0.040	0.075	21	25	20	22	20	22	20	22	22	22	22	23	21	21	21	22
29	0.040	0.075	18	23	20	23	19	21	17	21	21	23	21	22	22	20	21	22

*0.001 inch = 25.4 μm
 **Panels solder dipped and leveled
 †Initial resistance readings
 ††Resistance readings after temperature cycling
 ‡Resistance readings after lamination cycle
 ‡‡Resistance readings after flex test

Table A-1 Continued. Plated-Through Hole Electrical Resistance Test Data

Hole Number	Hole Diameter (Inch)	Land Diameter (Inch)	Resistivity ($\mu\Omega$)											
			Panel 11		Panel 22		Panel 33		Panel 44		Panel 55		Panel 66	
			I	A	I	A	I	A	I	A	I	A	I	A
30	0.100	0.175	22	23	21	23	21	23	21	22	23	24	23	25
31	0.040	0.100	20	18	19	25	19	18	18	19	20	22	21	21
32	0.040	0.100	20	20	20	23	19	21	20	20	19	22	21	23
33	0.040	0.100	20	19	18	23	19	20	21	20	20	22	20	21
34	0.040	0.100	20	18	19	22	19	21	20	19	21	22	21	22
35	0.040	0.100	22	18	20	22	20	20	18	20	20	21	20	22
36	0.040	0.100	18	19	20	21	19	21	18	21	20	21	20	22
37	0.100	0.175	22	20	-	26	22	21	21	21	23	24	22	24
38	0.040	0.062	18	19	19	23	18	23	19	19	20	21	20	21
39	0.040	0.062	21	18	17	24	18	29	19	21	20	21	20	21
40	0.040	0.062	20	18	19	24	18	18	18	20	19	21	19	21
41	0.040	0.062	19	18	19	22	18	26	19	20	20	21	19	21
42	0.040	0.062	18	18	17	21	18	19	22	20	19	21	20	21
43	0.040	0.062	20	18	18	23	22	20	20	19	19	21	20	21
44	0.100	0.175	23	22	21	23	21	23	21	22	21	23	22	23
45	0.100	0.175	22	22	14	25	21	22	21	22	23	23	23	23
46	0.013	0.050	-	16	22	-	19	20	-	15	-	-	-	-
47	0.013	0.050	25	19	20	25	20	20	19	20	19	21	27	21
48	0.013	0.050	19	-	20	22	19	23	18	15	22	17	22	-
49	0.013	0.050	23	-	20	-	20	18	21	15	20	15	-	15
50	0.013	0.050	18	19	20	-	18	15	18	15	17	26	-	16
51	0.013	0.050	23	19	20	21	20	-	19	23	-	-	19	22
52	0.100	0.175	24	21	21	22	22	33	21	22	21	24	23	23
53	0.013	0.075	25	43	20	23	19	33	19	27	28	28	43	61
54	0.013	0.075	32	29	20	35	19	28	31	20	25	31	46	43
55	0.013	0.075	22	34	19	36	20	43	26	25	26	30	51	34
56	0.013	0.075	25	22	20	29	18	29	22	21	26	34	40	43
57	0.013	0.075	20	23	20	27	18	53	44	20	25	36	44	55
58	0.013	0.075	24	40	20	27	18	20	21	28	29	29	38	58
59	0.100	0.175	23	28	21	22	21	23	20	21	23	24	23	23
60	0.013	0.028	20	20	18	-	18	33	18	18	22	25	43	45
61	0.013	0.028	23	38	18	31	18	28	19	29	31	26	22	40
62	0.013	0.028	33	31	17	15	21	23	29	28	22	35	23	15
63	0.013	0.028	19	23	17	19	23	31	50	21	24	22	42	15
64	0.013	0.028	16	27	18	20	18	24	46	19	21	26	34	38
65	0.013	0.028	19	22	19	18	19	24	27	22	21	22	30	32

Table A-1 Continued. Plated-Through Hole Electrical Resistance Test Data

Hole Number	Hole Diameter (Inch)*	Land Diameter (Inch)*	Resistivity (μΩ)															
			Panel 11		Panel 22		Panel 33		Panel 44		Panel 55		Panel 66		Panel 77		Panel 88	
			I	A	I	A	I	A	I	A	I	A	I	A	I	A	I	A
66	0.100	0.175	24	21	20	22	21	24	22	22	21	23	23	23	23	22	23	22
67	0.100	0.175	22	22	20	23	21	21	21	23	21	24	23	23	23	23	23	22
68	0.020	0.062	-	-	23	22	-	15	18	-	-	-	-	-	-	-	-	-
69	0.020	0.062	23	28	20	19	14	24	14	22	-	27	-	-	-	26	-	15
70	0.020	0.062	17	15	20	16	-	15	22	26	14	15	-	-	-	-	-	-
71	0.020	0.062	24	29	19	15	-	-	36	15	14	15	-	-	-	-	-	-
72	0.020	0.062	27	27	20	20	-	15	27	16	14	15	-	15	-	-	-	-
73	0.020	0.062	-	7	21	19	22	16	22	-	14	15	15	24	-	-	21	15
74	0.100	0.175	24	22	21	22	21	22	23	23	21	24	28	22	23	22	24	23
75	0.020	0.086	62	48	20	31	48	86	45	60	53	64	81	89	61	66	64	80
76	0.020	0.086	49	53	20	35	54	66	44	44	53	59	77	71	84	66	67	86
77	0.020	0.086	42	42	19	30	67	65	48	44	58	60	63	65	81	79	-	83
78	0.020	0.086	48	44	18	29	64	62	58	54	56	59	55	74	65	71	66	83
79	0.020	0.086	43	51	19	33	59	71	48	15	47	63	72	86	87	14	-	86
80	0.020	0.086	25	37	19	27	59	67	41	42	57	64	83	-	59	69	63	91
81	0.100	0.175	24	22	21	23	22	25	22	21	22	23	23	23	24	22	23	23
82	0.020	0.040	18	31	29	34	37	42	29	47	39	15	42	44	45	15	45	15
83	0.020	0.040	22	35	24	19	34	14	48	48	53	48	40	15	41	44	67	69
84	0.020	0.040	20	26	20	25	22	49	26	67	18	43	20	15	38	43	-	29
85	0.020	0.040	34	23	20	22	18	-	16	16	15	70	21	15	48	59	40	52
86	0.020	0.040	22	34	22	22	17	73	46	62	-	51	23	15	35	57	-	15
87	0.020	0.040	21	35	20	16	17	40	26	30	30	42	33	47	31	36	15	49
88	0.100	0.175	24	21	22	21	21	24	23	22	22	23	22	23	23	22	23	23
89	0.100	0.175	22	23	21	23	21	23	22	22	22	23	23	23	23	22	22	23
90	0.100	0.125	22	37	18	24	20	23	22	21	22	22	22	21	20	22	22	21
91	0.100	0.125	22	20	-	16	21	23	22	21	22	15	21	22	23	21	23	22
92	0.100	0.125	22	20	19	21	20	22	21	21	21	15	20	22	28	22	22	22
93	0.100	0.125	21	16	17	29	20	22	19	20	22	23	22	22	15	22	15	22
94	0.100	0.125	23	21	20	22	19	23	21	21	22	23	20	22	23	22	15	22
95	0.100	0.125	22	17	19	22	19	22	16	22	22	15	21	15	19	22	-	22
96	0.100	0.175	24	22	21	22	21	24	22	22	22	23	20	23	23	22	23	23
97	0.100	0.150	19	21	19	20	18	25	22	20	20	22	20	21	19	20	19	20
98	0.100	0.150	20	18	17	22	19	21	20	19	21	22	19	21	21	20	19	21
99	0.100	0.150	22	21	17	21	20	20	20	21	21	22	19	21	20	21	20	19

Table A-1 Continued. Plated-Through Hole Electrical Resistance Test Data

Hole Number	Hole Diameter (Inch)	Land Diameter (Inch)	Resistivity ($\mu\Omega$)											
			Panel 11		Panel 22		Panel 33		Panel 44		Panel 55		Panel 66	
			I	A	I	A	I	A	I	A	I	A	I	A
100	0.100	0.150	20	26	18	20	18	21	19	20	21	22	19	21
101	0.100	0.150	18	19	18	20	19	21	20	23	21	21	20	20
102	0.100	0.150	20	20	17	25	18	21	24	20	22	21	20	21
103	0.100	0.175	25	24	21	22	22	22	24	23	22	23	23	23
104	0.040	0.100	24	26	18	22	20	22	21	21	22	22	21	22
105	0.040	0.100	22	23	19	15	20	22	20	22	19	23	21	22
106	0.040	0.100	26	19	20	20	18	20	22	18	22	22	21	22
107	0.040	0.100	23	28	20	22	20	22	21	22	22	23	21	21
108	0.040	0.100	21	23	19	21	20	22	22	21	20	21	21	22
109	0.040	0.100	19	20	19	29	21	23	20	21	22	23	21	22
110	0.100	0.175	24	20	20	24	22	23	22	22	22	23	22	22
111	0.100	0.175	21	22	20	22	21	23	17	21	23	23	24	22
112	0.120	0.150	25	21	22	22	23	23	22	22	23	24	22	48
113	0.120	0.150	25	20	21	21	23	22	22	20	21	23	22	23
114	0.120	0.150	35	20	21	21	23	23	22	21	22	23	22	22
115	0.120	0.150	35	22	20	22	21	23	21	21	22	23	22	22
116	0.120	0.150	-	24	21	22	21	23	21	20	22	23	22	23
117	0.120	0.150	22	20	25	21	21	23	22	21	23	23	22	22
118	0.120	0.150	23	23	22	24	21	23	22	22	23	23	22	23
119	0.120	0.175	22	22	21	22	21	23	22	22	23	23	22	23
120	0.120	0.175	22	38	21	21	21	23	22	21	22	23	22	23
121	0.120	0.175	22	20	21	22	21	23	22	21	20	23	22	24
122	0.120	0.175	29	21	21	23	21	22	22	18	22	23	22	23
123	0.120	0.175	21	22	21	22	21	23	22	20	23	23	22	23
124	0.120	0.175	25	22	21	22	21	23	22	22	22	23	22	24
125	0.100	0.175	22	-	21	21	22	23	22	21	22	23	22	23
126	0.120	0.125	23	24	21	22	23	23	24	22	22	23	22	23
127	0.120	0.125	24	21	20	21	21	23	21	21	22	24	22	23
128	0.120	0.125	26	26	21	21	21	23	25	24	22	23	22	23
129	0.120	0.125	23	23	24	21	21	23	22	22	22	24	22	23
130	0.120	0.125	23	23	21	22	22	23	22	23	22	24	22	23
131	0.120	0.125	22	24	21	21	21	23	20	23	23	24	22	23
132	0.100	0.175	26	22	22	24	21	23	22	23	22	24	23	23

DISTRIBUTION

	Copy
R. Bulcock, AEC-KCAO	1
W. H. Meyers, LASL	2
R. N. McCormick, LASL	3
R. J. Craig, LLL	4
J. Stroud, LLL	5
G. Voids, SLA	6
D. H. Weingarten, SLA	7
R. F. Pippert, D/100	8
J. D. Corey, D/554	9-10
L. Stratton, D/554	11-13
R. P. Frohmberg, D/800	14
D. H. Hax, D/800	15
J. M. Fitzgerald, D/821	16
C. E. Spitzkeit, D/821	17
M. L. Wilson, D/821	18
V. E. Alley, D/862	19
H. F. Darbyshire, D/862	20
J. F. Galbraith, D/862	21
B. T. Gregg, D/862	22
R. A. Hile, D/862	23
J. C. McCoy, D/862	24
J. J. Mosakowski, D/862	25
R. E. Kessler, D/864	26