ELECTROSTATIC CHARGING CHARACTERISTICS OF THERMAL CONTROL PAINTS AS FUNCTION OF TEMPERATURE*

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SUMMARY

In a study of the charging characteristics of paints for various uses on spacecraft under electron bombardment we have found the following:

There is not a strong temperature dependence of the charging characteristics between -155°C and +30°C.

There is a noticeable hysteresis effect as the electron beam energy is varied.

All of the paints tested exhibit large secondary yields at low ($\sim$ 1 keV) bombarding electron energies.

Surfaces can charge either positively or negatively depending on the conditions and the paint.

Paints are not simple; will require more detailed study; and will probably act differenctly in multiple energy electron tests.

INTRODUCTION

Painted surfaces are common on spacecraft because of their desirable thermal and mechanical properties The concern of spacecraft designers for the electrical properties of spacecraft surfaces underlines the importance of the charging characteristics of spacecraft paints as well, since in some cases partially conductive paints may be used as substitutes for more traditional materials with high resistivities. Spacecraft design requires that the surface charge build-up be less than the material breakdown voltage. For scientific spacecraft, the absolute potential on the spacecraft surface should be small when compared to the electric fields to be measured or the particle spectra to be sampled.

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Even if the spacecraft has an absolute net charge, the differential charging of surfaces should be limited to avoid further disturbance of nearby electrostatic fields; for the Galileo spacecraft, a maximum 10 volt differential surface potential was desired under all environmental conditions. The electrical properties of spacecraft paints (CTL-15, S13G-low)(1) have been of interest to spacecraft for a long period. Normal paints such as S13G low outgasing do charge to some degree[2]. Nonetheless, they do not charge to the high levels observed for Teflon^R, and Kapton^R surfaces. In this report, we will begin by discussing our results on standard spacecraft paint, and then on several conductive paints.

STANDARD CHEMGLAZE PAINT

The surface potential versus electron beam energy for standard Chemglaze paint is shown in Figure 1. In this experiment, the incident electron flux was kept at about 1 nanoamp/cm^2 and the sample at room temperature. The surface potential builds up almost linearly with the accelerating beam voltage until the beam energy reaches about 10 keV. At that point the surface voltage saturates at just over 400 volts even though the beam energy increases to 20 keV.

After exposure to the 20 keV beam, the beam energy was reduced to 5 keV, and the sample was cooled. The surface voltage did not return to its previous value at 5 keV, but remained at the voltage it had reached in the 20 keV beam. This effect may be important in situations where the environment is changing rapidly.

As the temperature of the sample falls (as seen in Figure 2) the surface potential raises at a rate of approximately 1 volt/degree Kelvin, reaching its highest value near the coldest temperature. These hysteresis effects may be due to the heterogeneous nature of paints. Suppose that part of the paint is a very good insulator, charges to high voltages and has a long decay constant, but that the remainder of the paint is relatively conductive, does not charge to high voltage and tends to bleed charge off rapidly. This material will then behave in a manner similar to that observed. Some electrons will happen to penetrate into regions of high resistance and become trapped. Because these regions have long decay times, varying the incident beam energy will not cause a readjustment of this charge. This will produce the effect seen when the sample was first exposed to a 20 keV beam and then returned to a 5 keV beam without a significant change in the surface voltage.

The second feature of paints observed, namely the increase in surface voltage as the temperature decreases, can be explained by the characteristics of the relatively conductive part of the paint. In most non-metallic materials, the resistance of the material increases as the temperature decreases. In the case of a two-resistivity material, such as the one we have postulated for paints, this means that the ability of the material to bleed charge from the insulating areas is now reduced, and the material will charge to a higher levels as the material is cooled.

Figure 3 shows the increase in surface voltage as the sample is cooled and warmed during exposure to a 20 keV electron beam. The cooling and warming curves are separated by as much as 100 volts. The cooling curve voltage lags while the warming curve leads the straight line fit to both curves. This could well be due to the difference in temperature between the surface of the paint, and the point of temperature measurement, or it could be due to the fact that all of the surface voltage measurements were made while the temperature of the sample was charging.

CONDUCTIVE PAINTS

Four paints, 2 black and 2 white, modified to be conductive, have been tested in the experimental facility described in another paper(3). For these tests the paint samples were mounted so as to be in good thermal contact with the liquid nitrogen plate, but electrically isolated from it. The experiment was carried out in the same manner as the tests described above, except that data was taken during both warming and cooling in 1, 5, 10, and 20 keV. The test matrix is shown in Table I. Typical cooling and warming curves are shown in Figures 4 and 5. The rate of cooling (or warming) depends strongly on the rate at which LN_2 (or room temperature air) is pushed into the cooling fixture. These were adjusted by hand to allow the maximum time to be spent at each temperature data point. Table II shows the paint samples tested. The results of extensive testing are shown in the next four figures (6,7,8,and 9). These show the surface potential as measured by a Monroe electrostatic non-contacting voltage probe. The electron beam was removed by closing a mechanical valve between the electron source and the sample during surface voltage measurements. The beam current was adjusted to remain at approximately 1 nanoamp/cm^2. The temperature was varied using the low temperature fixture described earlier.

These results show there is no strong temperature dependence in the electrical characterization of these paint samples, but the surface potential was in excess of the 10 V differential desired by the Galileo project for science considerations.

One notable result is that there is no apparent temperature dependence to the surface potential, which is at variance with expectations based on resistance measurements. Resistance measurements vs temperature at JPL (not published) show a 10^5 change in resistance over the same temperature range. There is no ready explanation for this apparent discrepancy, but it indicates that conductive paints cannot be analyzed in terms of a simple $E = IR$ model.

Another of the interesting questions raised by these tests is the apparent non-repeatability of the test results at 1 keV. After exercising the sample in the 5, 10 and 20 keV beams, and throughout the temperature range, the sample was returned to room temperature and exposed to a 1 keV beam. Generally, the results of the last measurement at 1 keV disagreed with the initial data taken at room temperature and 1 keV. This effect could be the same effect we first noticed in testing the regular Chemglaze samples, except that these samples are much more conductive, and so the effect is not as pronounced, however, our experiments with secondary emission described below suggest a more subtle explanation.

The total back current measured in a 1 keV beam is grossly different from the expected beam current even though the surface potential is approximately zero. This is due to high secondary emission at 1 keV. In separate experiments on selected samples a small bias was applied to the sample to verify that secondary electrons were indeed responsible for the low observed back current. In these experiments the current collected by the wall of the chamber, as well as the current through the sample were measured. The wall current should increase as more secondaries are emitted. The current through the sample with and without a bias applied to the back of the sample were also measured. During these experiments the temperature and electron flux were varied. However, the temperature and flux variations did not have as significant an effect as the time. Figure 10 shows the gradual increase in the secondary emission coefficient as a function of time as measured during these experiments. During this time a cooling and warming cycle took place with little apparent effect. The long time constant observed is apparently due to the nature of secondary emission itself. For this paint, the secondary emission process takes a considerable period of time to become established when exposed to beams which cause high secondary emission. This effect undoubtedly plays a role in the observed discrepancy between samples exposed to 1 keV electrons before and after exposure to other energy electrons.

The most puzzling result of this study is the occasional measured positive surface potentials at high beam energies. Surface contamination causing a very thin insulating surface (perhaps caused by cyro-pumping of outgassed products on the sample) could be responsible, since 20 keV electrons from a thin insulating surface has been suggested as a possible mechanism. Another possibility is the inaccuracy of the voltage probe at such low potentials, or in the presence of the plasma produced by the high energy electron beam.

CONCLUSION

Conductive paints are not simple. They will require more detailed study to understand their behavior under electron bombardment. Although they do not charge to any significant degree, they do have very interesting properties.

REFERENCES

1. J.E. Gilligan, R.E. Wolf, and C. Ray, "Electrically Conductive Paints for Satellites", p. 593, Proc. of the Spacecraft Charging Technology Conference, 1976, AFGL TR-77-0051, and NASA TMX-73537, C.P. Pike, R.R Lovell, editors.

2. N. John Stevens, F.D. Berkopec, J.V. Staskus, R.A. Blech, S.J. Narciso, "Testing of Typical Spacecraft Materials in a Simulated Substorm Environment" p. 431 (especially pp 434-435) Proc, of Spacecraft Charging Technology Conference, 1976, AFGL TR-77-0051 or NASA TMX-73537, C P. Pike, and R.R. Lovell, editors.

3. P. Robinson, E. Brown, et al., "Evaluation of Charge Control Techniques on Spacecraft Thermal Surfaces", Paper II 11 Spacecraft Charging Technology Conference, 1980.

TABLE I. TABULAR LISTING OF MEASUREMENT CONDITIONS, TEMPS vs. KeV

	ACCELERATING VOLTAGE, KeV					
	1	2	5	10	15	20
(Room Temp) 23°C	X	X	X	X	X	X
-10	X		X	X		X
-45	X		X	X		X
-88	X		X	X		X
-127	X		X	X		X
-155	X	X	X	X	X	X

TABLE II. ESD-CONDUCTIVE PAINTS TESTED

PAINT	COLOR	METHOD USED TO MAKE CONDUCTIVE
Chemglaze, modified Z004 over 9922 primer with 2% carbon black	Black	Carbon Filler
Bostic Finch 463-14	Black	Carbon Filler
Zinc Orthotitanate	White	Unknown
Goddard NS43C	White	Unknown

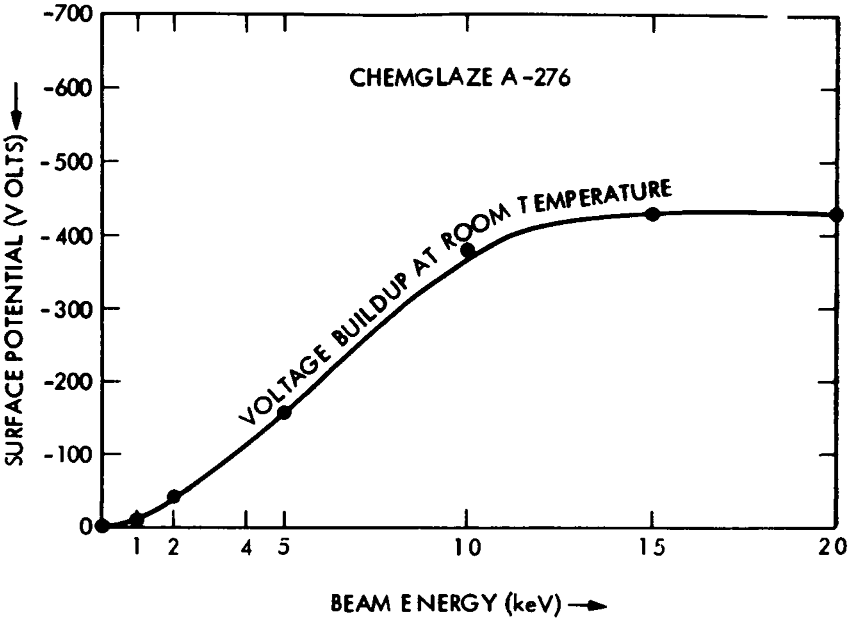

FIGURE 1

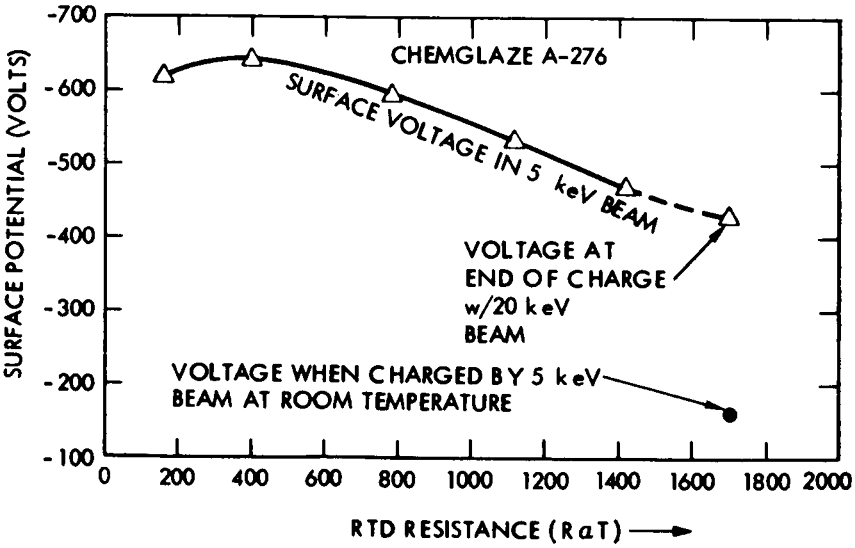

FIGURE 2

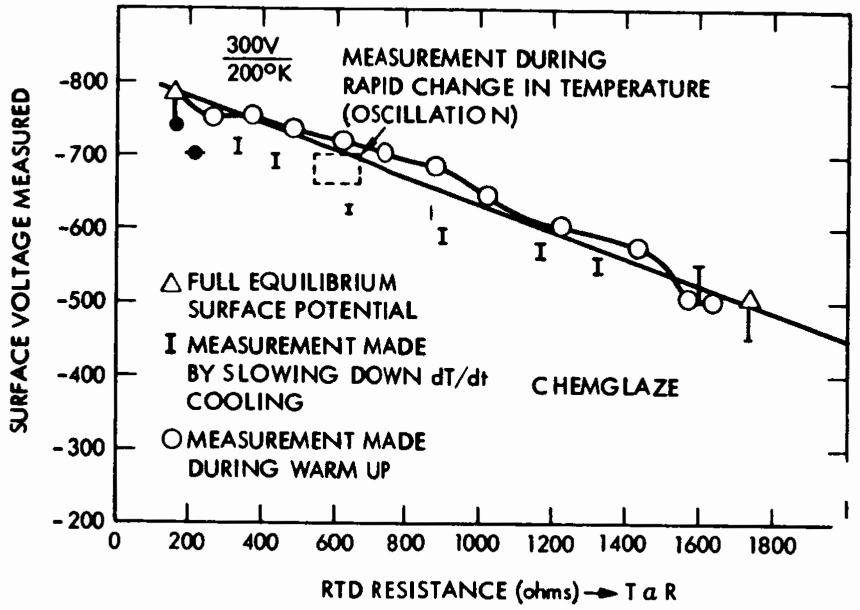

FIGURE 3

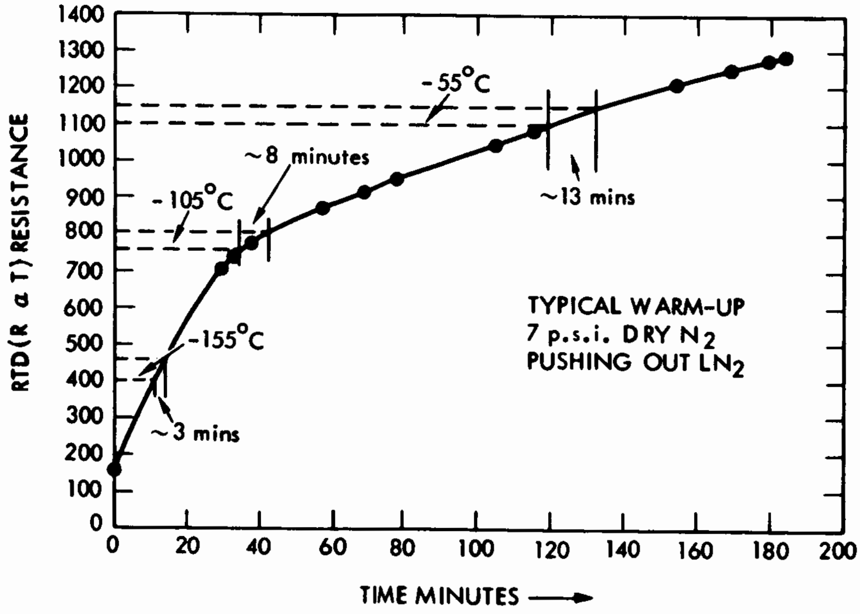

FIGURE 4

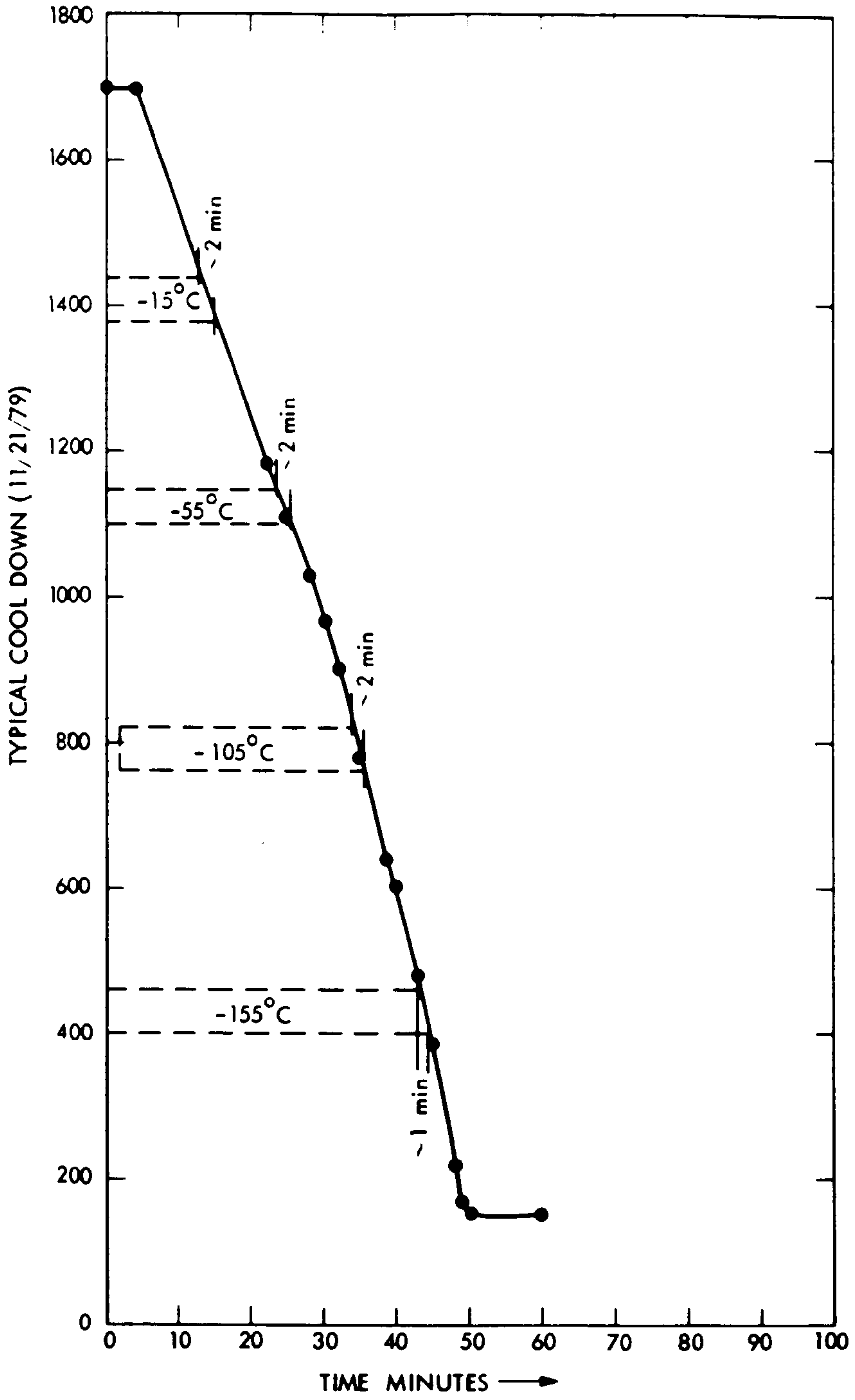
TYPICAL COOL DOWN (11/21/79)
TIME MINUTES
0
200
400
600
800
1000
1200
1400
1600
1800
0
10
20
30
40
50
60
70
80
90
100
-15°C
-55°C
-105°C
-155°C
~2 min
~2 min
~2 min
~1 min

FIGURE 5

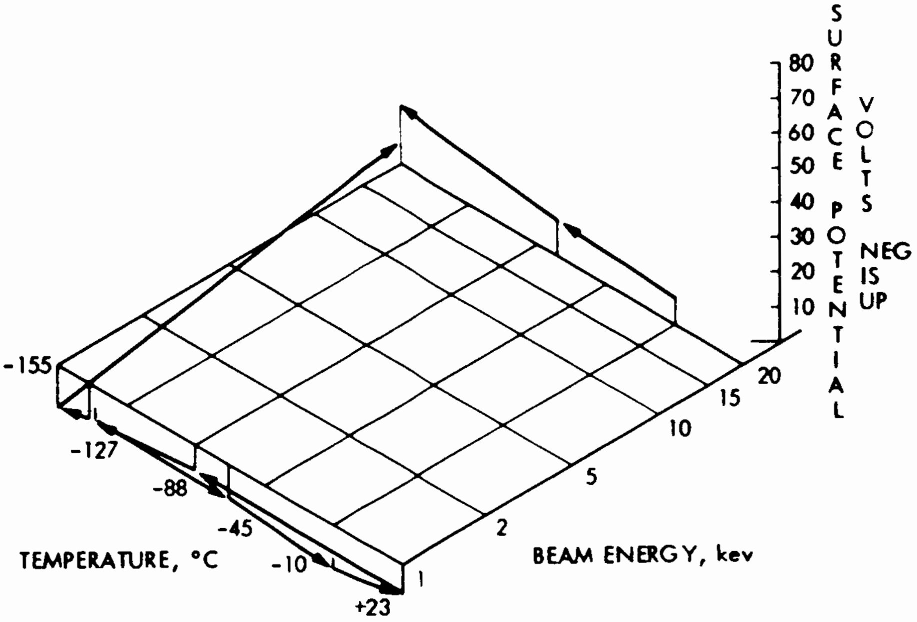

FIGURE 6. SURFACE POTENTIAL CHEMGLAZE BLACK SAMPLE 2-4

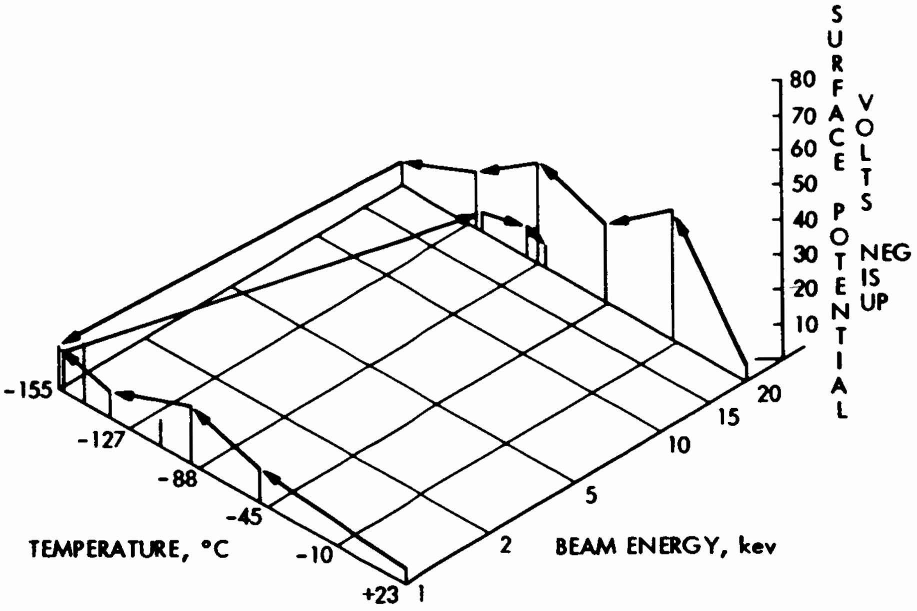

FIGURE 7. SURFACE POTENTIAL BOSTIC-FINCH SAMPLE 3-1

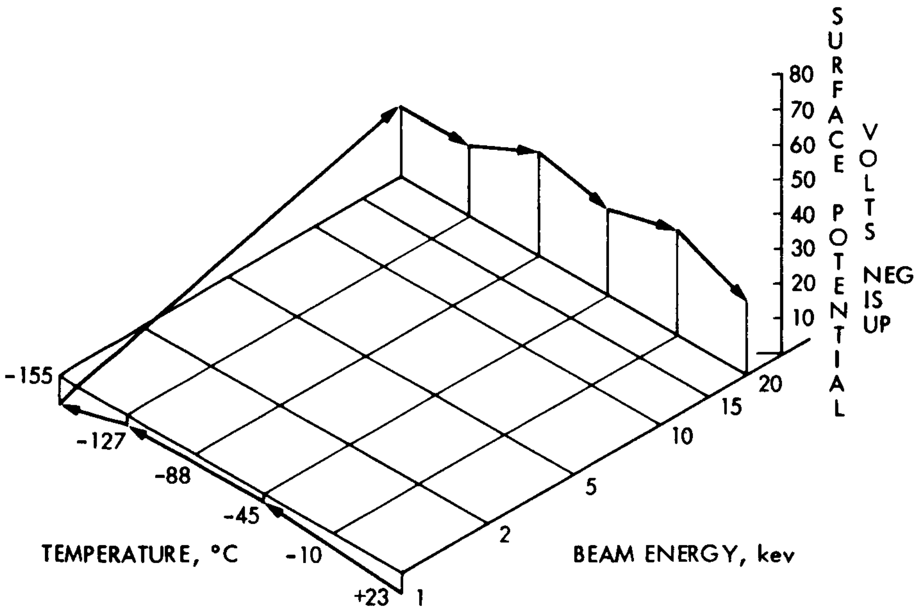

FIGURE 8. SURFACE POTENTIAL ZOT PS7

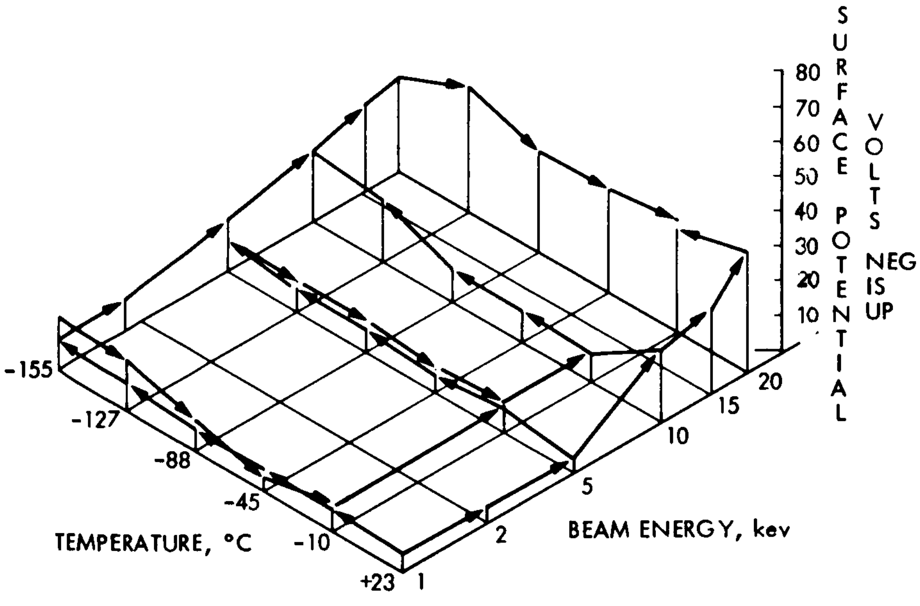

FIGURE 9. SURFACE POTENTIAL GODDARD WHITE NS43C SAMPLE 1-1

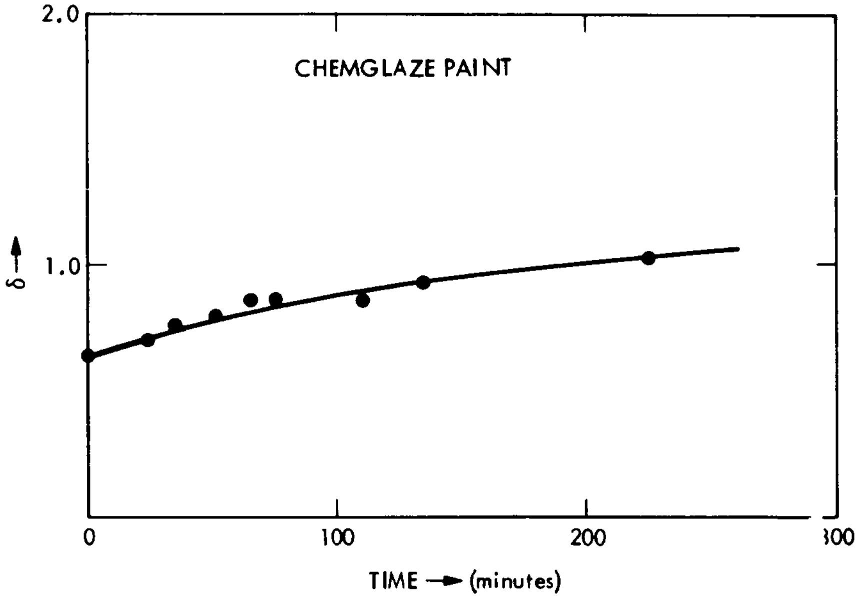

FIGURE 10