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CHARACTERISTICS OF DIFFERENTIAL CHARGING OF ATS-6*

Bruce Johnson and Elden Whipple
University of California, San Diego

Since the launch of the ATS-6 satellite into a geostationary orbit in June of 1974, the UCSD Auroral Particles Experiment has collected an enormous wealth of data. It was not surprising to find these data indicating the ATS-6 satellite was charging to negative potentials of hundreds of volts since ATS-5 charged to such values (DeForest, ref. 1). Since then it has been well established that spacecrafts of varying configurations can frequently charge to hundreds and sometimes thousands of negative volts (DeForest, ref. 2; Reasoner et al., ref. 5). Less well understood is the phenomena of differential charging. Differential charging is simply the charging of different parts of a spacecraft to different values. Clearly this could happen since a typical spacecraft has solar arrays, conducting surfaces, thermal blankets, etc., all of which have different charging properties; but the identification of differential charging as such is not as simple as the idea. Fortunately ATS-6 has some peculiarities in its data that lend well to a differential charging explanation, and that is the topic of this paper.

DESCRIPTION OF THE EXPERIMENT AND DATA

The UCSD Auroral Particles Experiment consists of five particle detectors. There are two rotating heads each containing a positive ion and electron detector. One head rotates in the north-south plane, while the other rotates in the east-west plane. The fifth particle detector is a fixed ion detector pointed eastward in the direction of the spacecraft motion. The rotating heads have a 220° range. Each detector can collect particles at 64 energy steps, ranging from 0 eV to 81 KeV, with the capability of dwelling at one particular energy step or scanning through all 64 steps in 16 seconds. The resolution of the particle analyzers is such that $\Delta E/E$ is approximately 20%. The angular resolution is approximately 2.5° by 6.4° for a flat spectrum. (A more detailed description of this instrument package is given in Mauk and McIlwain, ref. 4.)

Thirteen days of data were analyzed containing peculiarities in the electron data attributed to differential charging. On one of these days the satellite was eclipsed by the earth at local midnight. A useful visual aid for examining the data are spectrograms (fig. 1). A spectrogram plots universal time on the horizontal axis and energy in eV on the vertical axis. Particle count rates are represented by the intensity of the gray scale. The top half of the spectrogram is for electrons; the bottom half is for ions. The ion energy scale is inverted.

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DATA

Referring to figure 1, the particle detectors (i.e. spacecraft) are definitely charged negatively since ion count rates are zero up to a certain energy which defines the potential. Starting at about hour 10 the negative potential increases in magnitude to over 600 volts at about 10:30. Mirroring this ion behavior is the peculiar electron shadow up to a couple hundred eV. Along the boundary of this shadow just after the tenth hour is a 10 minute period of intense count rates. This shadow and intense band are apparently photoelectrons and secondary electrons emitted from the spacecraft and returned to the particle detectors. The electron shadow always appears with the charging event. Its peak energy increases as the charge on the detectors increases. Even when there is no charging there is always a low energy, less than 20 eV, band of electrons. It has been shown that these electrons are photoelectrons and secondary electrons emitted by the spacecraft (ref. 6, Whipple, E. C.). The particle spectra are Maxwellians having temperatures of < 10 eV and densities < 100 per CC. The particles could not be from the ambient plasma since the ambient density is changed by $e^{-V/kT}$ when measured by a negatively charged detector. V is the potential difference between the ambient plasma and the detector. kT is the temperature of the electrons. Even for modest charging of a few times kT, the ambient density would be well over 100/CC which is contrary to observations. Ambient densities are less than 10/CC. Thus the electrons are photo and secondary electrons from the spacecraft, and since they mirror a charging event, the shadow must tell something about the charging characteristics. Further evidence that these particles are photoelectrons comes from eclipse data. Figure 2 shows day 66 of 1976, during which the satellite went into eclipse at about 21:20. Eclipse removes the solar photon flux and thus any photoelectron currents. Removal of this electron current carrying charge away from the spacecraft requires more negative potentials to balance the ambient current to the spacecraft. Thus an increase in charging occurs, to about -10,000 volts. Notice the loss of the shadow when this happens, indicating the electrons are indeed photoelectrons.

But the existence of these peculiar photoelectrons does not necessarily imply differential charging. However, if the spacecraft were uniformly charged to a negative value, a potential barrier would have to exist to return the photo and secondary electrons. Whipple (ref. 6) found that the magnitude of the barrier needed to return tens of eV electrons was too large to be explained by a uniformly charged spacecraft. That the barrier must exist is evidenced by the outline of the photoelectron shadow. Electrons with energies less than the energy outline are barrier-returned photoelectrons, whereas at larger energies are the ambient electrons with enough energy to penetrate the barrier. The only other way to sensibly produce a barrier is differential charging. Information about this barrier can be obtained by analyzing the intense count rates along the boundary of the photoelectrons as seen in figures 1 and 2. These intense count rates are termed spots.

In analyzing the spots, the particle count rates measured need to be clarified. The UCSD particle detectors actually measure the count rate over an energy range E to E + ΔE. This differential count rate for a Maxwellian shifted by a positive potential goes as $E^2e^{-(E-V)/kT}$, where E is the detector energy. V is the potential difference and here taken to be >0. The peak in the differential count rate occurs at 2 kT, assuming the distribution function has not been shifted to energies greater than 2 kT. This is shown in figure 3. So for photoelectrons or secondary electrons originating on a more negatively charged source, the count rate will be enhanced by e(V/kT) for E > V, and the count rate will be zero for E < V.

As mentioned even with no significant charging, there are low energy (< 20 eV) photoelectrons typically having a kT of less than 10 eV, and so peaking at E < 20 eV. Nevertheless even during large charging events a peak in the counting rate at E < 20 eV can still be observed. Thus these electrons must originate on a source with a differential charge of not more than 20 eV. It normally appears that V is approximately 0, so these photoelectrons probably originate from the package on which the detectors are mounted. Conducting materials cover these parts and are connected, so they have the same potential. However, during charging events where the shadow boundary exceeds 80 eV, the electrons at the high energy values also have temperatures less than 10 eV usually, but their count rates are too large to come from a source with V approximately zero. A Maxwellian of kT = 10 eV, N = 100/CC produces only about 400 counts per sec at E = 100 eV. Count rates at 100 eV are often over 1000 counts/sec during charging events. This implies some differential charging. An even stronger indication of differential charging and a potential barrier are the spots.

The spots are generally large count rates, ranging from 300 to 20,000 counts per second, observed at energies from 80 to 150 eV. Seldom does the spot count rate spectrum ever show a peak, but usually shows decreasing count rates with increasing energy for a couple of detector energy steps. This implies that the 2 kT peak of the spot is less than the energy of the first detected spot electrons. This energy of the first detected spot electron is termed the spot energy. Normally kT was around 30 eV for the spots analyzed, with the spots occurring around 100 eV. Figure 4 shows the local time of occurrence of all the spots studied. The local time axis is in half hours, so 12 corresponds to hour 6 which is dawn. Hour 0 is local midnight. This is the same local time distribution reported by Reasoner et al. (ref. 5). Charging, and thus differential charging, occurs around local midnight due to the larger electron fluxes caused by particle injections. Large electron fluxes to the spacecraft imply a large negative current, requiring a negative potential for current balance. Thus the spots are a charging phenomena also, probably related to high electron fluxes. Figure 5 shows the percent number of spots detected at different NS detector positions. 0 implies north, and 90 corresponds to looking away from the earth. The spots appear to come at all different angles, not readily identifying a single source. Likewise the spots occurred over a large pitch angle range for both the NS and EW detectors, so the spots are not always magnetically returned particles. That is, they are not always particles emitted from their source and spiralled around the magnetic field into the detectors. Potential differences are needed to return the electrons, and the spot energies give some insight as to the magnitude of these differences.

Figure 6 shows the spot energy versus the negative potential of the detector; all energies are in eV. First, notice that detector potentials can be over 800 eV, but the spot energies do not exceed about 280 eV. Over 80% of the spots occurred at energies less than 150 eV. It is not unreasonable to assume that the potential difference between the spot source and the particle detectors, V, is equal to the spot energy. This is reasonable since the spots occur very abruptly with large count rates, a behavior typical of the spot energy equalling V as in figure 3. This assumption gives the maximum value V could have, and the actual V is probably not much less than this to produce such enhanced count rates. If this assumption is nearly correct, then the spot energy versus detector potential is bounded by a line of V = .35 (potential), or the spot source charge is 1.35 times the potential. The charging of this source continues up to a maximum of V = 280 eV so it appears that the source of the spots will charge up faster than the detector, and then level off and stay a fixed 280 eV more negative than the detector at higher potentials. Figures 7 and 8 show the spot energy versus the potential for some typical days. They have the same charge up characteristics. Since these spots are always found at the top boundary of the shadow, their source's potential could be the main contributor to developing a potential barrier that returns spacecraft emitted particles.

A detailed study of day 33 (fig. 7) showed that as the detector potential increased the spot energy increased. The count rates increased not only from V increasing, but the temperature of the spot electrons increased from 30 eV to 50 eV. If V was taken as the energy of the spot as before, the densities of the electrons were from 1 to 4 per CC. Also the source potential of the spot increased about two times as fast as the detector potential. Since the electron flux was changing during this time, the changing temperatures and densities along with changing V seem to indicate that spot electrons were secondary emitted electrons. Temperatures of over 30 eV are not characteristic of photoelectrons, and neither is the changing temperatures since the solar photon flux doesn't change. However, as shown in figure 8 the secondary yield of a material is energy dependent. Thus, changing temperatures and larger temperatures (> 10 eV) can be characteristic of secondary electrons (ref. 3, Knott). A strong candidate for the source is the Minnesota experiment which sits protected from the sun on the package containing the particle detectors. Not being able to emit photoelectrons, it could charge faster than the detectors as electron fluxes increased. Covered with a thermal protecting paint it may be ideal for charging and emitting different spectra of photoelectrons in response to changing fluxes. On day 236, 1974, the count rates of the spots were observed to change as the Minnesota experiment rotated into new positions. Only on this day was such an obvious correlation found, but it does indicate that it probably is involved. Being less than a meter from the detectors, this experiment could dominate the local potentials since it is the only insulator so close. Charging to larger negative potentials than the detectors or package, it could produce a barrier. Other possibilities are the solar panels, but they are over 7 meters away, and their effect would be expected to be less.

Further work needs to be done on determining the secondary electron spectrum of the spots. Equations in reference 6 for the yield as a function of energy could be used to calculate temperatures and densities of different materials. Potentials as a function of ambient flux could be calculated to see if the potential of the source would behave as observed. If the calculated values agree with those measured here, the source of the spots will be better understood and simple electric fields could then be modelled around the spacecraft.

CONCLUSION

In conclusion, differential charging seems to be responsible for returning photoelectrons to the spacecraft up to a couple hundred eV, depending on the spacecraft charge. Potential differences of 200 eV can exist between parts of the spacecraft, enhancing the count rates of emitted particles. It is believed that the Minnesota experiment on ATS-6 is largely responsible for producing a potential barrier that returns particles and produces intense spots in the count rates.

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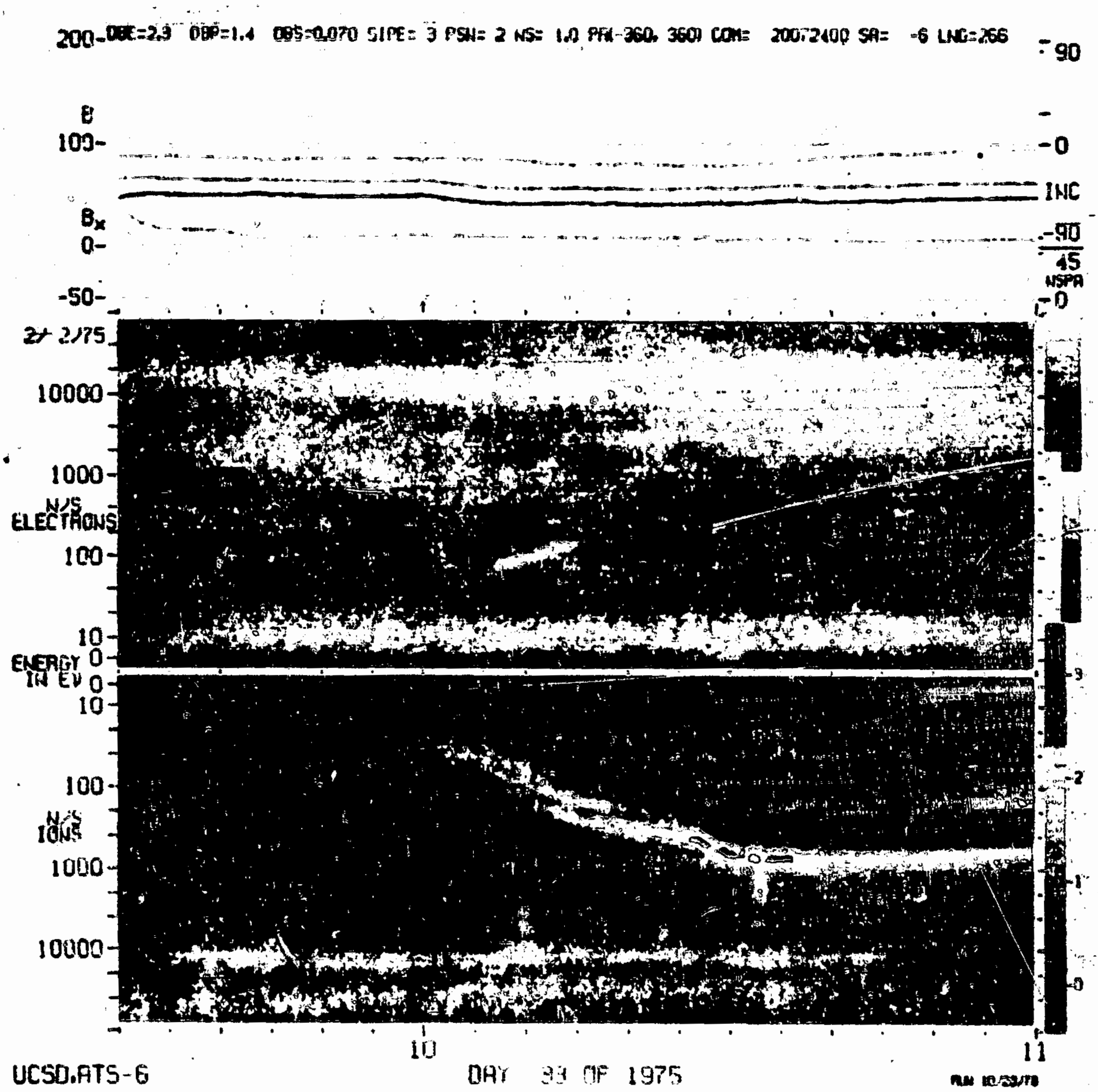

Figure 1. – Intense count rates (spots) along boundary of photoelectrons - Day 33, 1975.

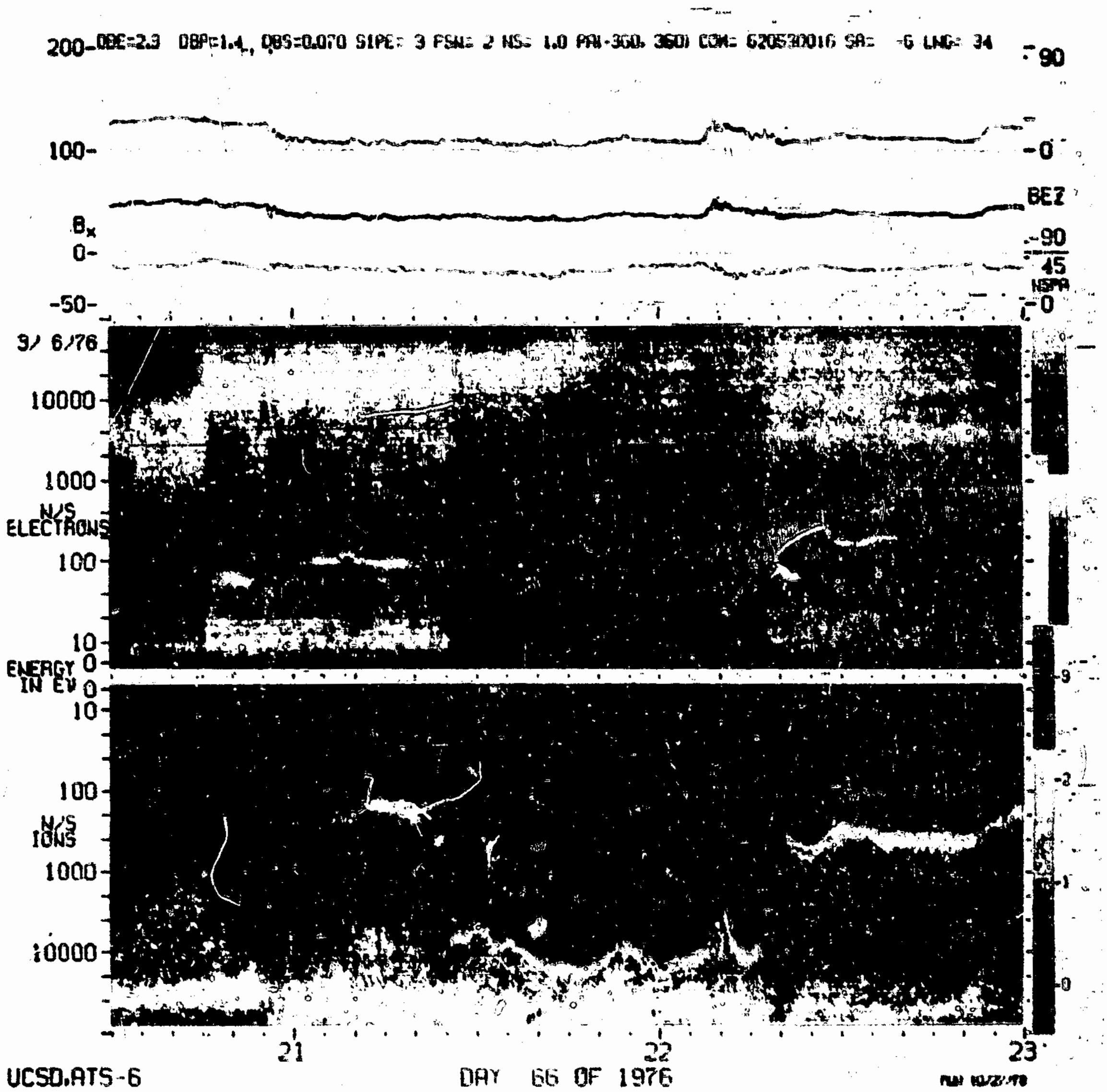

Figure 2. - Intense count rates (spots) along boundary of photoelectrons - Day 66, 1976.

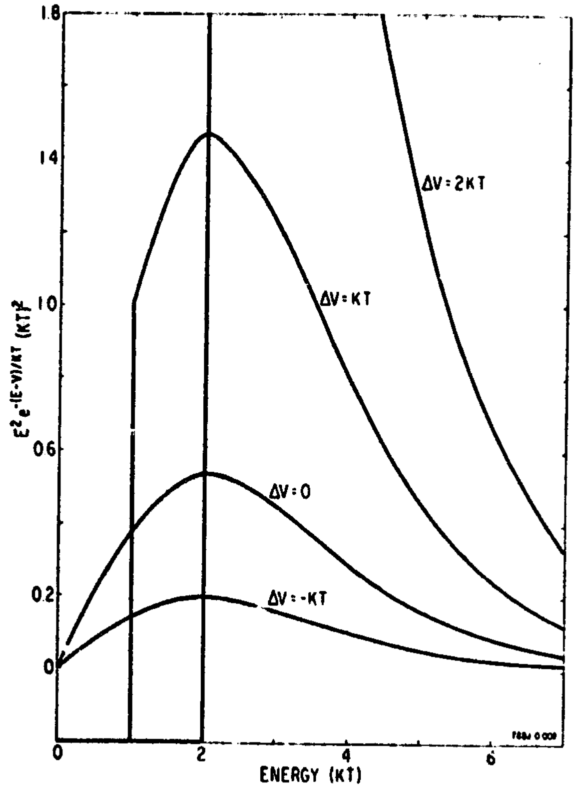

Figure 3. - Differential count rate of Maxwellian shifted by potential V.

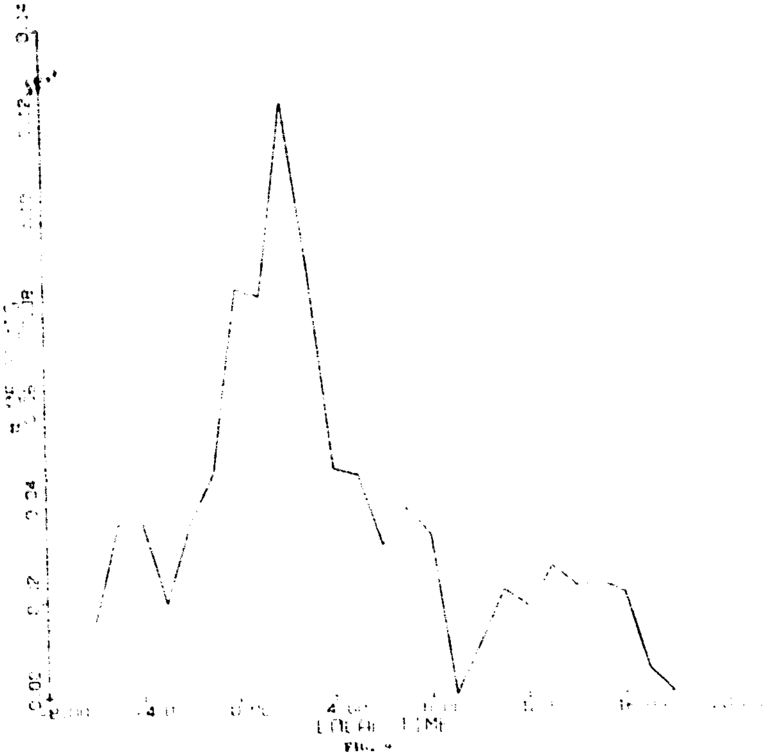

Figure 4. - Local time correspondence of spots.

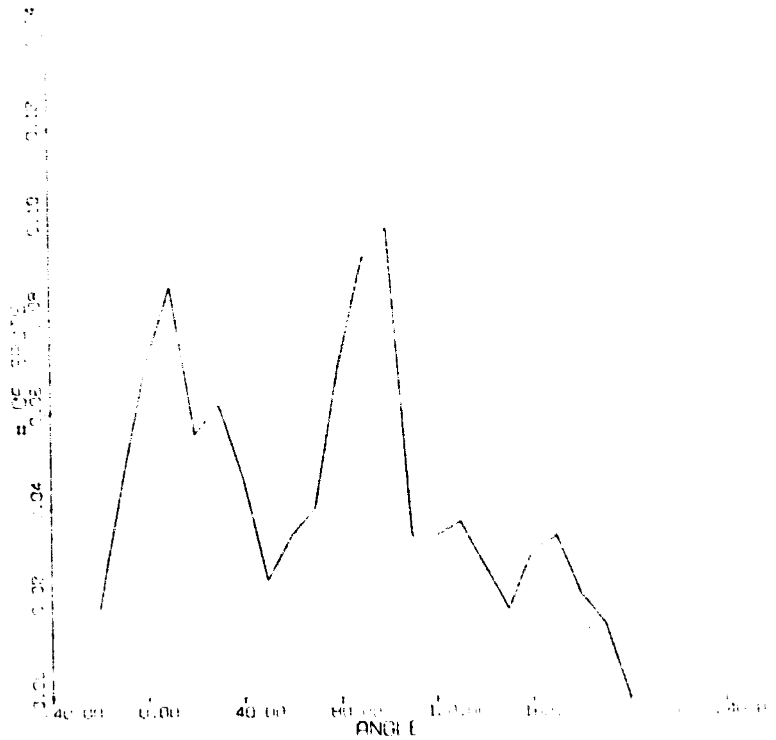

Figure 5. - Number of spots detected as function of angle.

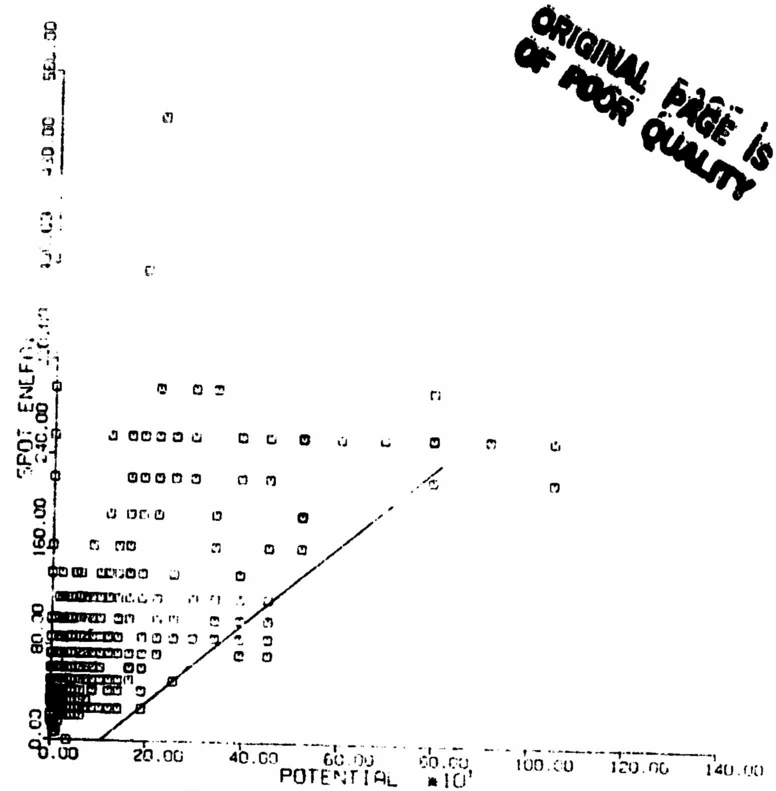

Figure 6. - Spot energy as function of potential.

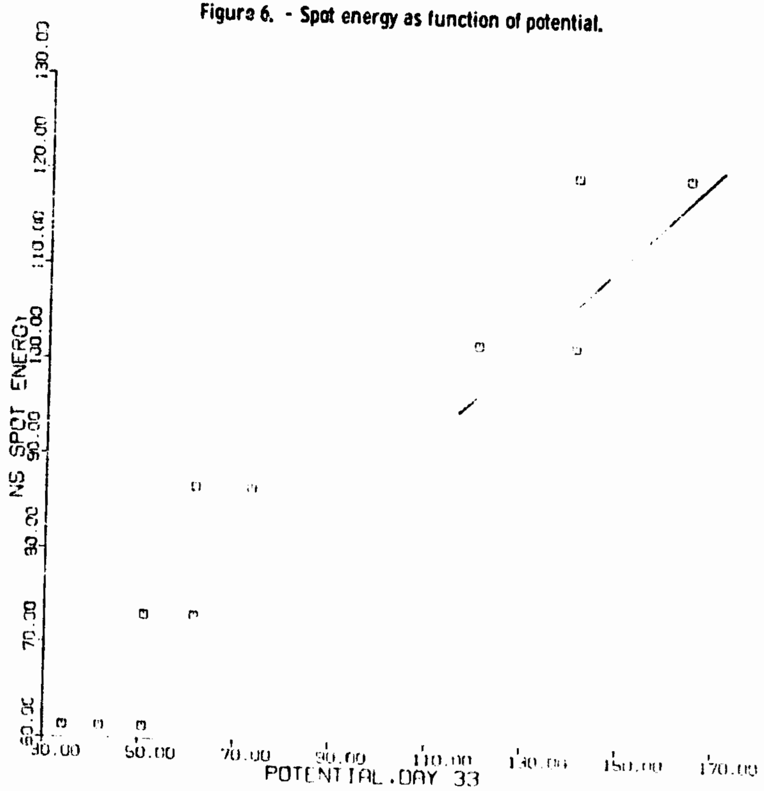

Figure 7. - Spot energy as function of potential - Day 33.

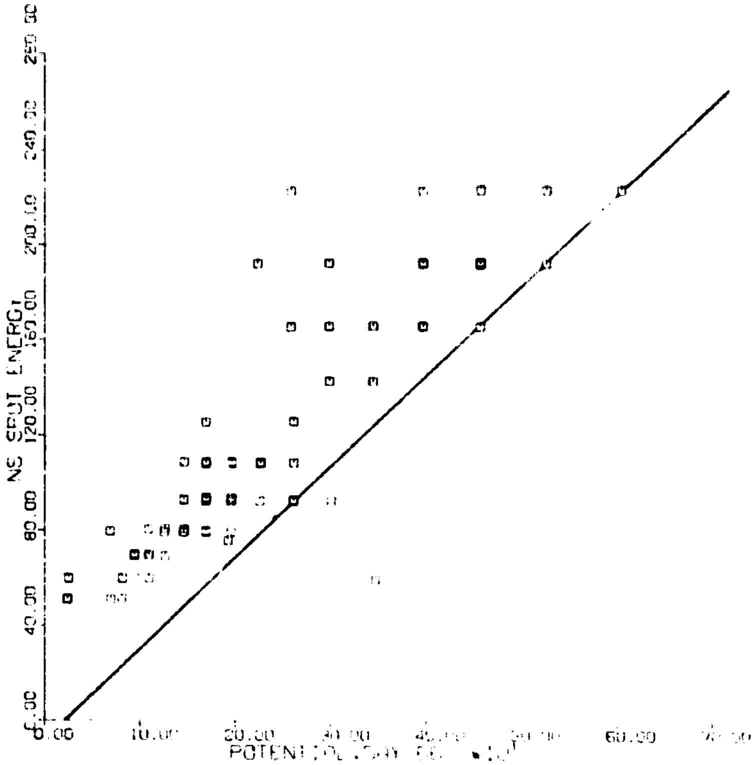

Figure 8. - Spot energy as function of potential - Day 66.

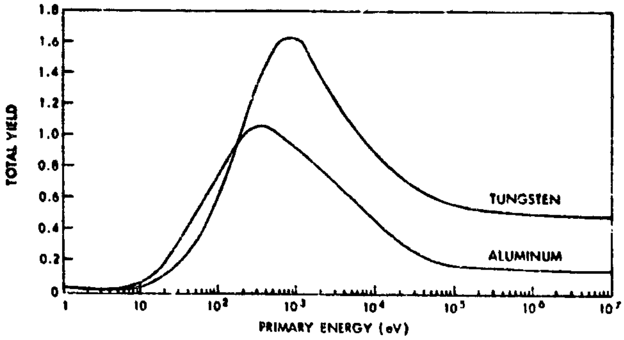

Figure 9. - Total secondary electron yield for tungsten and aluminum.