UTD

THE UNIVERSITY OF TEXAS AT DALLAS

October 9, 1973

W. F. Eichelman
National Aeronautics and
Space Administration
L. B. Johnson Space Center
Houston, Texas 77058

Reference: TN3-73-6-04

Subject: NASA Contract NAS 9-5964
UTD Account E1473

Dear Sir:

The Cold Cathode Gauge Experiment Data requested in the referenced letter is enclosed.

If you have any additional questions or requirements, please don't hesitate to contact us.

Sincerely,

Francis S. Johnson
Executive Director
Center for Advanced Studies

FSJ/skg
Enclosure

214 231-1471 BOX 30365 DALLAS, TEXAS 75230

Apollo Cold Cathode Gauge Experiment

The cold cathode gauge experiment (CCGE) was included in the ALSEP on the Apollo 12, 13, 14 and 15 missions. The Apollo 12 instrument experienced a failure after only a few hours of operation and the Apollo 13 package was not deployed due to spacecraft problems and the cancellation of the landing.

The purpose of the CCGE was to evaluate the amount of gas present on the lunar surface. The CCGE indications can be expressed as concentration of particles per unit volume or as pressure, which depends on the ambient temperature in addition to the concentration.

Instrumentation

The vacuum gauge that was included in the Apollo Lunar Surface Experiment Package (ALSEP) is a cold cathode ionization gauge built by Norton Research Corporation. The general configuration is shown in Figure 1. The envelope and electrodes are of stainless steel. An axial magnetic field of about 900 gauss is provided by a permanent magnet. The orfice was closed but not sealed with a spring loaded cover that was released by an electrical impulse to a squib motor. To reduce the possible effects of the magnet on other instruments, a magnetic shield can was mounted around the gauge and its magnet.

10/9/73

The response of the gauge in terms of cathode current versus pressure is shown in Figure 2. The gauge of course is really sensitive to gas density rather than pressure, and the response curve shown in Figure 2 is for room temperature. A temperature sensor was attached to the gauge envelope so as to permit corrections to be made to the gauge response based on the wide variations in temperature encountered on the lunar surface, about 100 to 400°K. The gauge response is also somewhat dependent upon gas composition, and the calibration was for nitrogen. As the composition of lunar atmospheric gases is not known, a fundamental uncertainty is introduced into the interpretation of the data, and the results are presented as if the gas on the lunar surface were nitrogen. The difference between the nitrogen equivalent pressure and the true pressure is probably less than a factor of two.

The gauge anode is connected to a +4500 ± 200-volt power supply, which is shown diagrammatically in Figure 3. The supply consists basically of a regulator, converter, voltage-multiplier network, and a feedback network to the low-voltage supply. The regulator furnishes 24-volt output for conversion to a 5-kHz squarewave that is applied to the converter transformer. The output of the transformer goes to a voltage-multiplier network consisting of stacked standard doublers. The output is filtered and applied to the gauge anode and also divided down in order to provide a monitor signal. A high resistance in the connection to the gauge anode provides overload protection for the gauge and power supply, limiting the maximum current to about 2 microamperes. The output regulation is within 2% for load currents up to 1 microampere.

The gauge cathode is connected to an auto-ranging, auto-zeroing electrometer that measures currents in the range 10^{-13} to 10^{-6} ampere with an output of -15 millivolts to -15 volts. The output goes to an analog-to-digital converter for transmission over the ALSEP data link to earth. The electrometer consists of a high-gain, low-leakage, differential amplifier with switched high impedance feed-back resistors for range changes. The output voltage and input current are related by

$$E = R_f(I_i + I_l)$$

where E is the electrometer output, I_i the input current, I_l the leakage current, and R_f the feedback resistance. When the input current is zero, the output voltage does not go to zero because of leakage and other factors, and the output voltage can be expressed as $R_f I_l$; this voltage is the zero offset voltage, and it is cancelled by introducing a compensating error voltage from the auto-zeroing network into a second grid in the electrometer tube, as indicated in Figure 4. Auto zeroing is accomplished by disconnecting the sensor by opening relay S1 and switching in the auto-zeroing amplifier in a feedback network to the second grid by closing S3 for a short interval; capacitor C1 holds the zero-correcting potential until the next auto-zeroing cycle. Relay S2 connects the sensor to ground during the interval that it is disconnected from the electrometer.

The electrometer operates in three automatically selected overlapping ranges: (1) 10^{-13} to 9×10^{-11} amp, (2) 3.3×10^{-12} to 3.2×10^{-9} amp, and (3) 10^{-9} to 9.3×10^{-7} amp. The electrometer has strong feedback to maintain the input grid potential at nearly zero. Automatic range switching is accomplished by the switching of two feedback resistors R_1 and R_2 across permanent feedback resistor R_3, as indicated in Figure 4. To control the range changes, the electrometer output is compared against -15 mV and -15 V references by means of comparators. The output of these comparators pass to a logic circuit that drives relays S4 and S5 and generates a range signal for transmission to earth; a signal is also generated to select the proper current generators for calibration by closing S6, S7, or S8 and S9, S10, or S11.

The normal operating sequence of the electrometer circuit includes a 16-second calibrate function, including auto-zeroing, at approximately 2 1/2-minute intervals. The first operation is the zero check and correction; S1 is opened and S2 is closed to disconnect the gauge and then after about 9 seconds the output of the electrometer is sampled, followed by a closing of S3 for about 2 seconds to accomplish the auto-zeroing. This is followed by the first step of the calibration cycle, accomplished by closing S13, and then by the second step, accomplished by opening S13 and closing S12. Following the calibrate cycle, the gauge is reconnected to the electrometer. The electrometer output is then sampled five times at 2.4 second intervals and 3 times at 40 second intervals. The cycle of operation can be altered by ground command to provide readings every 2.4 seconds without any calibration or zero correction. The zero correction drifts only slightly over a period of an hour, as its time constant was about 6 hours.

The method chosen for presentation of the data is a microfilm plot with concentration on the bottom of the frame and the gauge temperature at the top of the frame, as shown in Figure 5. The times used on all of the frames are GMT. In the normal operating mode of the instrument an average of four data points are obtained each minute. The data are recorded on 35 mm film with approximately 15 hours of data on each frame. The range of concentration is plotted logarithmically from 10^5 to 10^{11} particles/cm^3, and the range of temperature is linear from 0^oK to 400^oK. The values shown on the plots have been computed using the calibration curves of the appropriate gauge and temperature sensor.

A brief description of the data for each of the experiments follows.

APOLLO 14

The Apollo 14 instrument was first activated on February 6, 1971 while the astronauts were still on the lunar surface. The unit was operated for short periods of time (approximately 30 minutes) during the LM venting for the 2nd and 3rd EVA. The experiment was then turned off until lunar sunset.

During the following months the instrument was not activated during the lunar daytime except for brief periods in order to allow the package to outgass and minimize the possibility of high voltage arcing. Chart A shows the approximate time of operation. The period of operation was increased each month until complete operation was obtained during the daytime in November 1971.

Data are available for all periods of operation except during periods when problems occurred.

The first problem occurred in April 1971 when the +A to D converter became eratic. This problem was not serious as far as the CCGE data were concerned, since it affected only the temperature and housekeeping data.

No additional problems other than occasionally noisy data were encountered with the CCGE until the nighttime operation in February of 1972. At that point the CCGE data dropped out for about four days at the end of the lunar night but came back at sunrise. This problem occurred intermittently until the nighttime operation in late November 1972 at which time all nighttime data were lost. This complete loss of nighttime data lasted for two months followed by one month of complete data in late March 1973 and then two more months of no nighttime data.

The start of the lunar day on April 15, 1973 produced the third and the most serious problem to date. At this time the SIDE/CCGE went into the standby condition and no data were available from either the SIDE or CCGE. Attempts to restore the experiment to normal operation were unsuccessful until the following lunar night, at which time the CCGE high voltage was restored but the SIDE high voltage had to be left off. In this condition, the CCGE nighttime data were again good and remained good until an unsuccessful attempt was made about sunrise to restore the SIDE high voltage. After sunrise it was not possible to obtain operation with either of the high voltages on and the experiment was left in standby until sunset. According to the Flight Control Division, no daytime operation has been successful since about April 15, 1973. The nighttime operation is reported to be normal with both high voltages operating. Tapes for this period show intermittent operation.

If the situation continues unchanged, it appears that no daytime CCGE or SIDE data will be obtainable in the future from Apollo 14 and the nighttime CCGE data will probably be intermittent.

APOLLO 15

The Apollo 15 gauge was operated only for short time periods after deployment and original turn-on on July 30, 1971. The data shown in Figure 6 represent this mode of operation. The operating times coincided with the depressurization of the LM for the various EVA's and for the lift-off of the LM. Following lift-off, the unit was turned on at about 215/02/53 for another short period. The instrument amplifier was left on in order to monitor temperature but the high-voltage supply was off to prevent the possibility of arcing within the package as it heated up and degassed. Chart B shows the approximate times of operation of the Apollo 15 instrument.

The high voltage supply was turned on at approximately 225/01/30 and remained on until about 242/09/52. During this period of time several changes in concentration were observed apparently due to release of gas from various hardware items left on the lunar surface. The high voltage was turned off during most of the lunar day time for the first few months to minimize the possibility of arcing. However, when the voltage was turned off at about 271/05/00, a low value of leakage current appeared and continued to be present from that point on. This leakage current appears on the plot as a very low concentration.

Several anomalies appearing in the plots generally have been traced to noisy data which appears to be originating in the gauge or its associated electronics. The noise is worse near sunrise or sunset when the package temperature is changing. One example is shown in Figure 7 where the scattered points above and below the main plot are caused by range changes in the instrument. The range change is automatic and normally there is no problem except when the noise factor becomes large enough so that unrepeated range changes occur.

Since the range data are not updated just prior to converting the concentration data, the computer occasionally produces a bad point on the plot due to use of the incorrect range. The double traces that appear from 271/02/52 to 271/05/52 of 1971 appears to be an instrument problem involving cross talk in certain words of the SIDE frame.

The abrupt concentration changes which occasionally appear, such as at 333/00/52 (Figure 8) are due to the operating characteristics of the Cold Cathode Gauge and are identified as mode changes. Oscillation between the upper and lower levels of the mode sometime occur if the concentration is changing slowly.

A definite increase in concentration occurred at sunset during the early months of operation. The amount of gas released decreased with each sunset and eventually disappeared thus indicating that the gas was associated with hardware left on the surface.

The Apollo 15 CCGE operation was good until February 1973 at which time the nighttime data became eratic. During the problem periods the data are very noisy and the automatic zero and calibration functions do not appear to be operating. This problem has persisted during all nighttime operations through July 1973 with only occasional periods of proper operation. Tapes have not been received past July 1973.

In summary, it appears that nighttime data from the Apollo 15 CCGE are now sporadic but the daytime data are complete.

Data Sets and Availability Through NSSDC

The data listed in Charts A & B are available at NSSDC on 35 mm film in the form shown in Figure 5. Data for 1973 will be available at NSSDC in early 1974 and is available at UTD at the present time with an approximate three months lag depending upon receipt of tapes from JSC.

CHART A

Apollo 14

Data Available at NSSDC

From Day/Hour/Minute/GMT			TO
<u>1971</u>			
	37/00/51	Spot Operation	37/13/40
	50/16/30		66/21/00
	77/14/00		97/10/44
	107/12/15		128/14/15
	135/13/00		157/23/40
	159/12/00		159/14/00
	165/13/00		187/19/10
	194/14/44		217/10/44
	217/21/00	Spot Operation	219/09/00
	223/21/00		232/17/46
	236/17/44		246/05/44
	253/22/15		275/20/30
	276/16/30	Spot Operation	281/19/55
	282/15/45		311/00/44
	312/17/44		365/23/59
<u>1972</u>			
	000/00/08		009/00/00
	009/17/44		068/17/44
	069/17/44		177/06/44
	179/17/44		205/06/30
	207/14/44		271/12/50
	275/17/44		307/17/44
	311/17/44		346/22/50
	351/17/44		365/23/59

CHART B

Apollo 15

Data Available at NSSDC

1971

212/18/56	Original turn on and spot operation	215/02/53
225/01/30		242/09/52
253/16/30		271/05/40
271/05/40	Spot Operation	282/15/53
282/15/53		302/23/20
302/23/20	Spot Operation	312/13/02
312/13/02		336/13/10
341/16/52		352/18/52
356/18/52		364/15/30

1972

004/18/52		030/13/52
034/14/00		057/18/52
058/12/52	Spot Operation	063/14/00
063/14/00		006/18/52
087/18/52		088/16/10
092/14/52		118/01/20
122/21/40		148/04/10
149/05/00		190/02/30
191/18/52		194/03/00
195/18/52		263/23/52
267/18/52		365/23/59

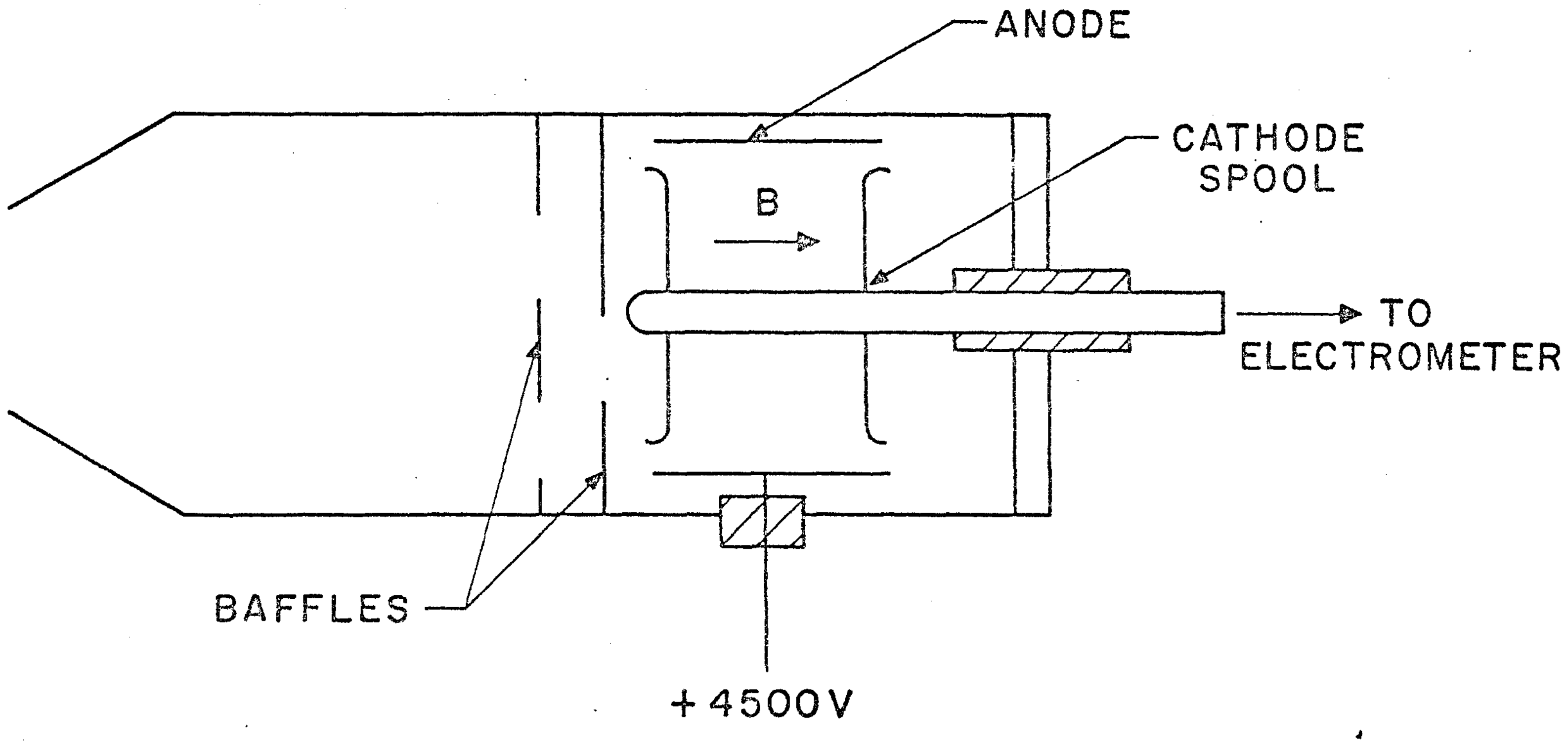

FIGURE 1

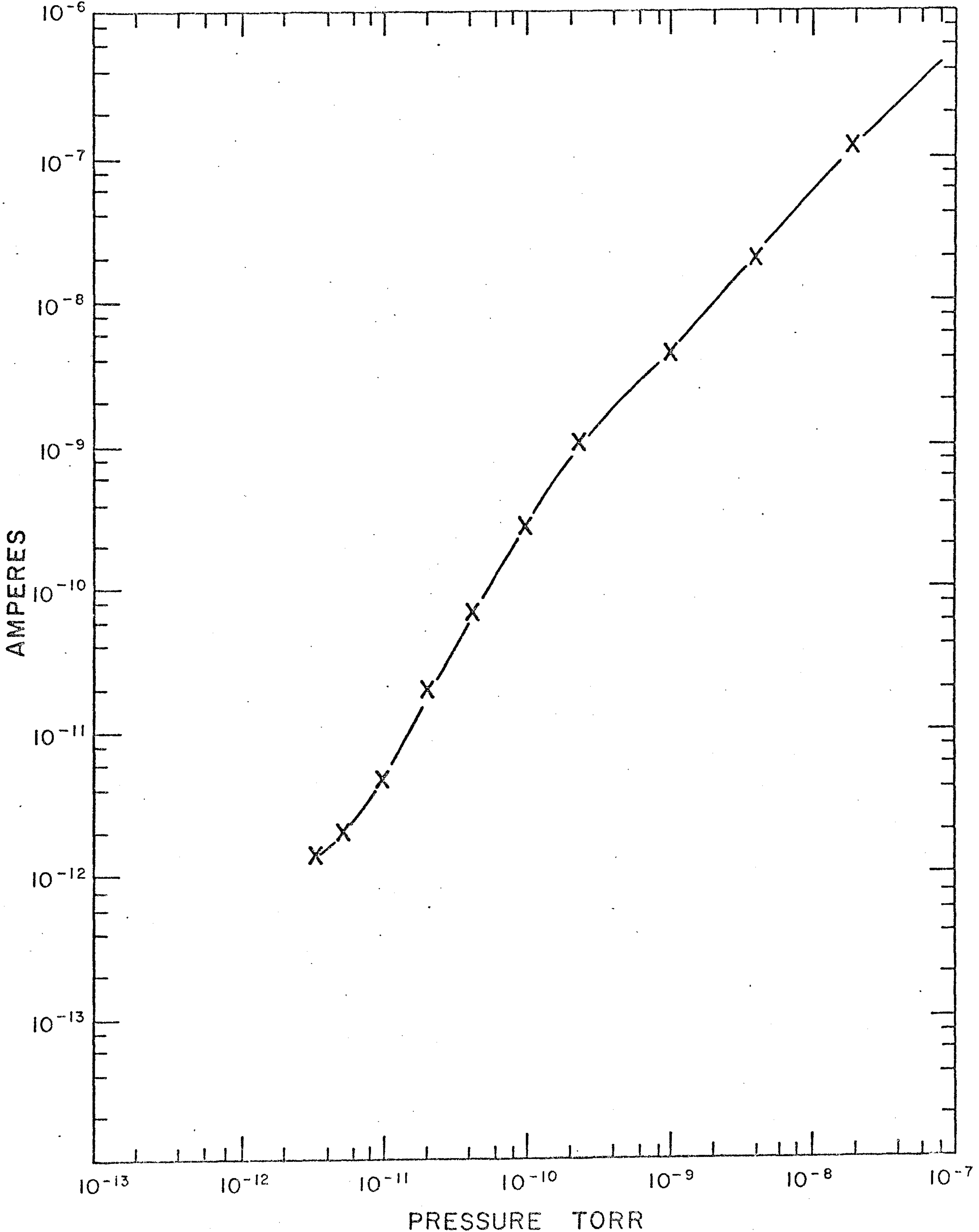
AMPERES
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-13}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
PRESSURE TORR

FIGURE 2

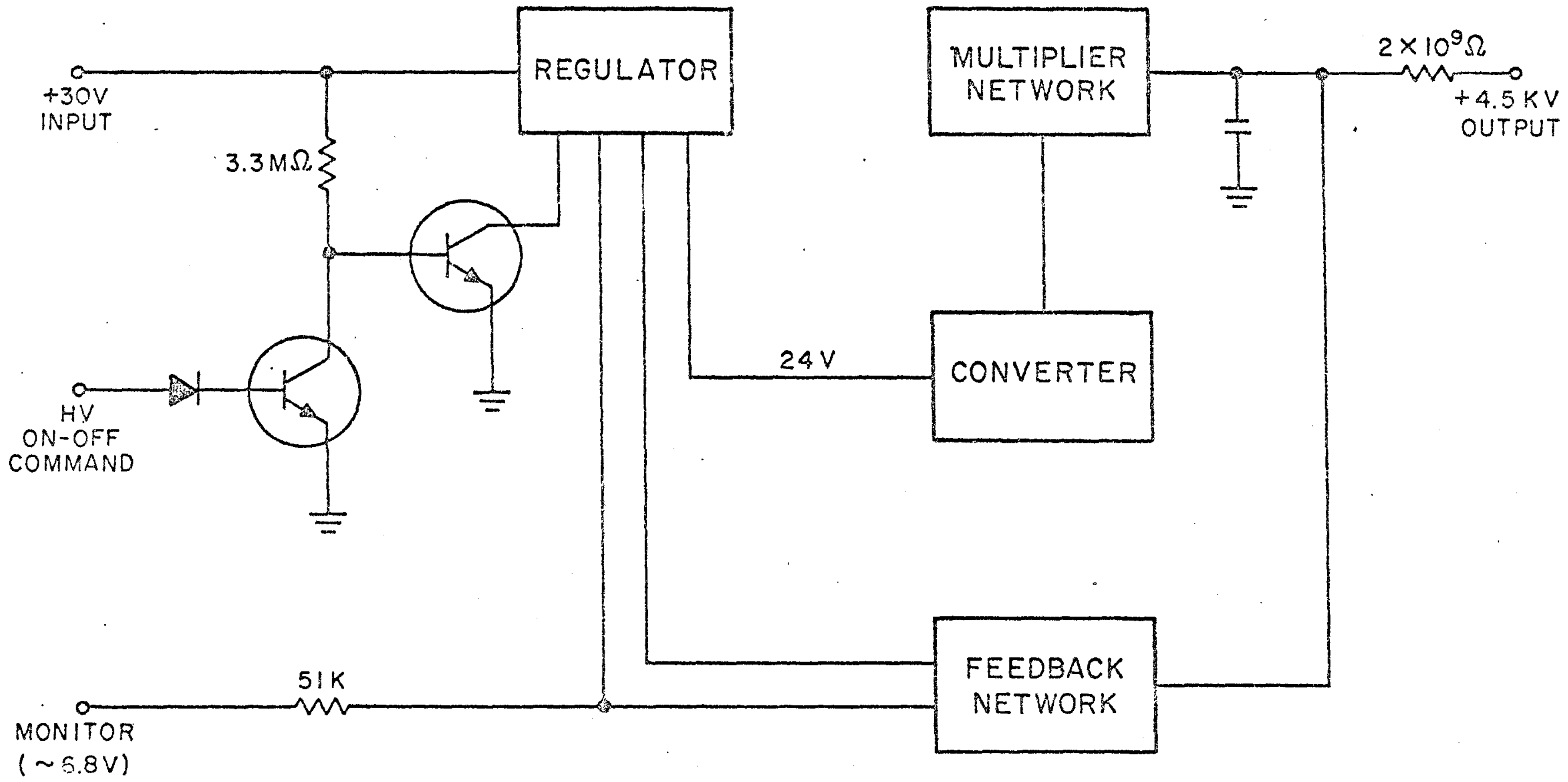
+30V INPUT
3.3MΩ
REGULATOR
MULTIPLIER NETWORK
2×10⁹Ω
+4.5 KV OUTPUT
HV ON-OFF COMMAND
24V
CONVERTER
51K
FEEDBACK NETWORK
MONITOR (~6.8V)

FIGURE 3

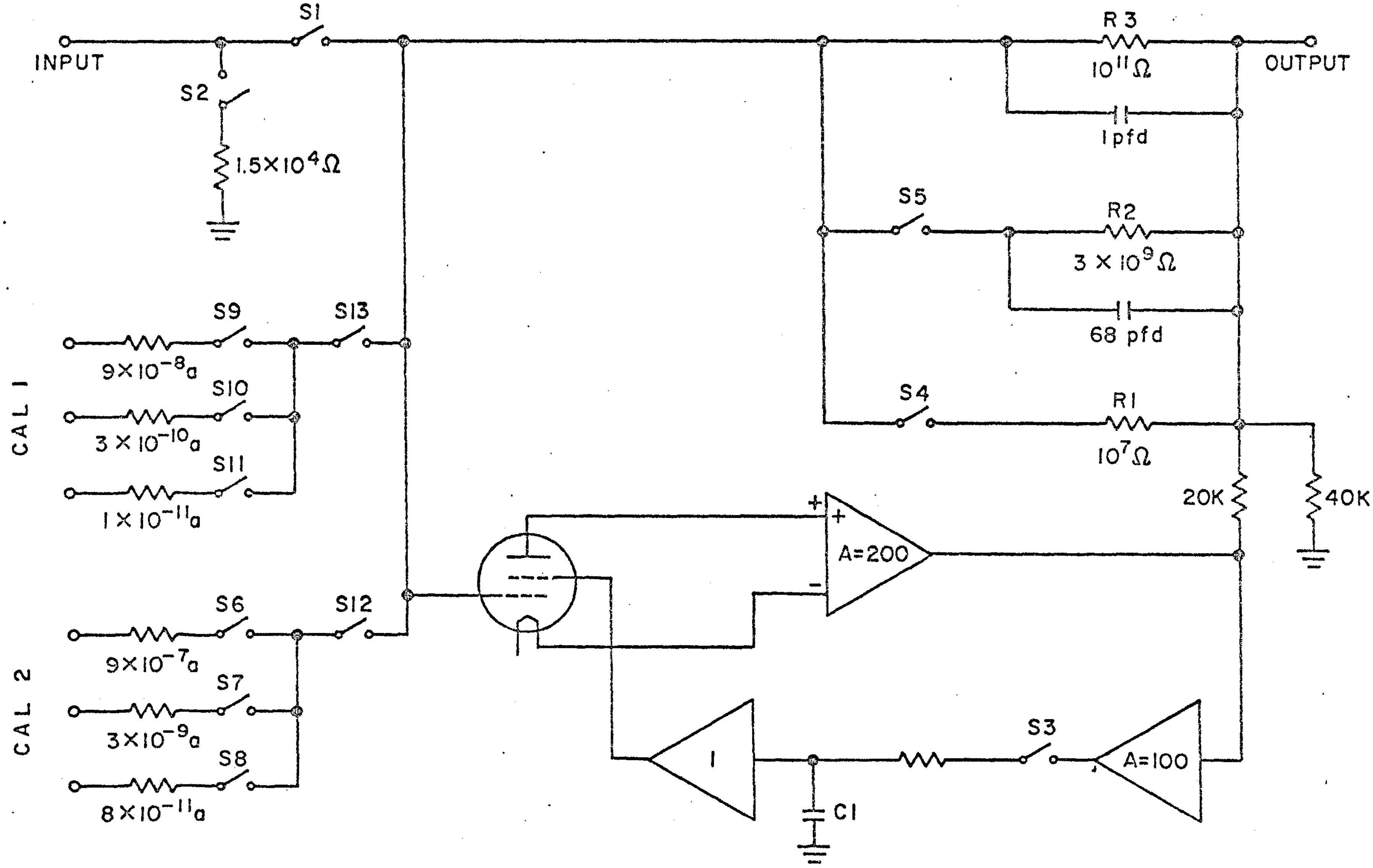
S1
INPUT
S2
1.5×10⁴Ω
R3
10¹¹Ω
OUTPUT
1pfd
S5
R2
3×10⁹Ω
68 pfd
S4
R1
10⁷Ω
20K
40K
S9
S13
9×10⁻⁸a
S10
CAL 1
3×10⁻¹⁰a
S11
1×10⁻¹¹a
A=200
+
−
S6
S12
9×10⁻⁷a
S7
CAL 2
3×10⁻⁹a
S8
8×10⁻¹¹a
1
S3
A=100
C1

FIGURE 4

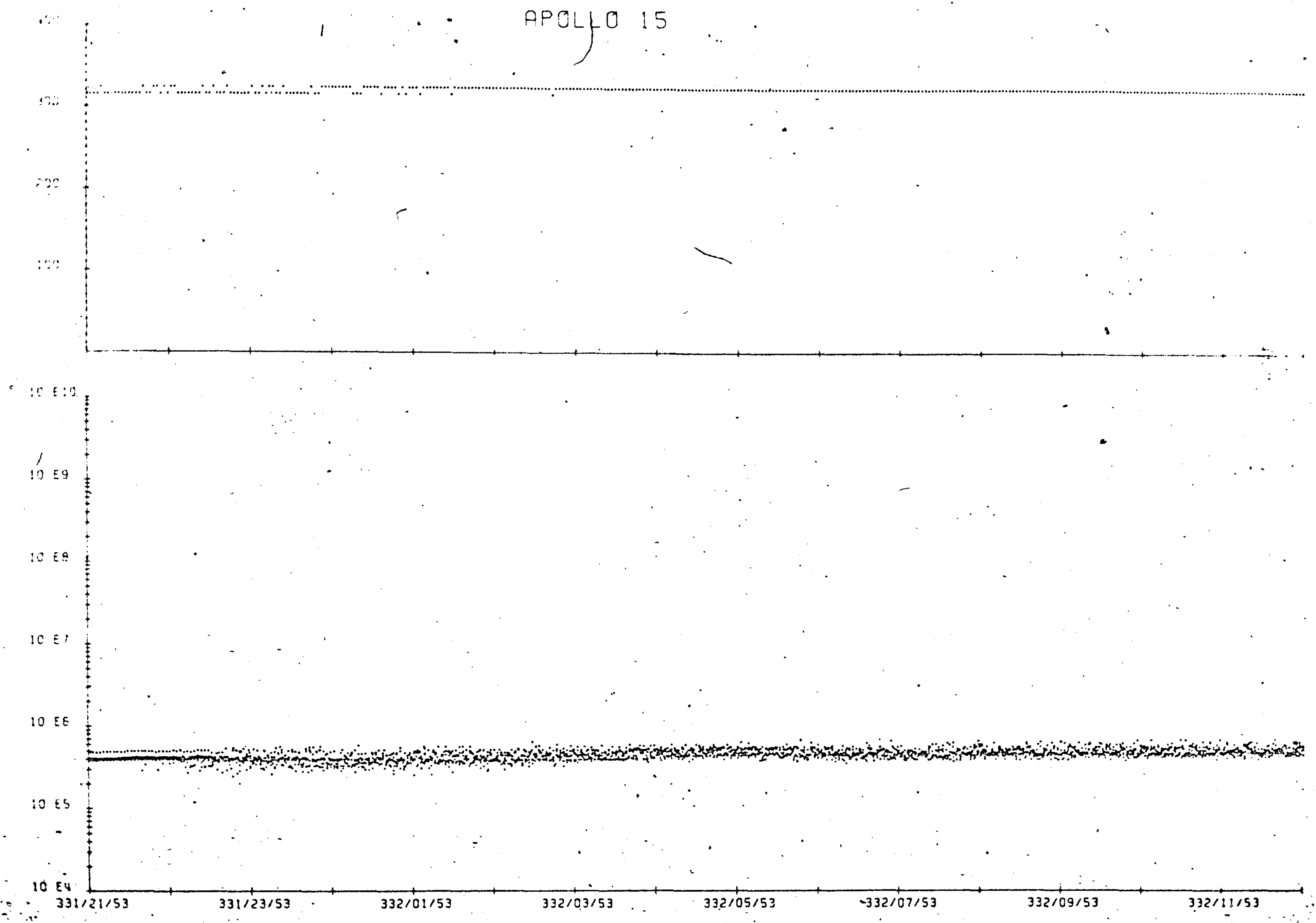
APOLLO 15
400
300
200
100
10 E10
10 E9
10 E8
10 E7
10 E6
10 E5
10 E4
331/21/53
331/23/53
332/01/53
332/03/53
332/05/53
332/07/53
332/09/53
332/11/53

FIGURE 5

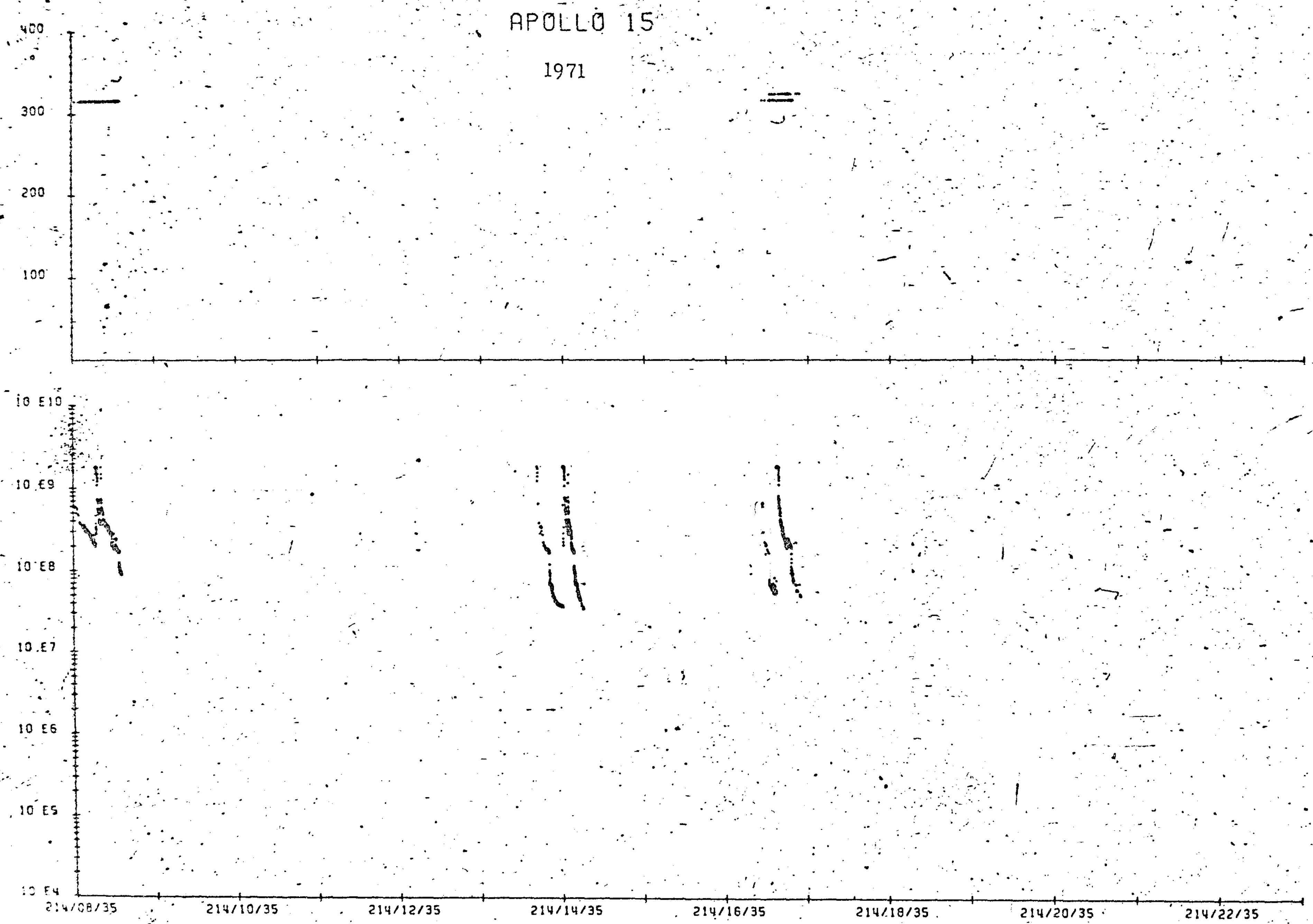
APOLLO 15
1971
400
300
200
100
10 E10
10 E9
10 E8
10 E7
10 E6
10 E5
10 E4
214/08/35
214/10/35
214/12/35
214/14/35
214/16/35
214/18/35
214/20/35
214/22/35

FIGURE 6

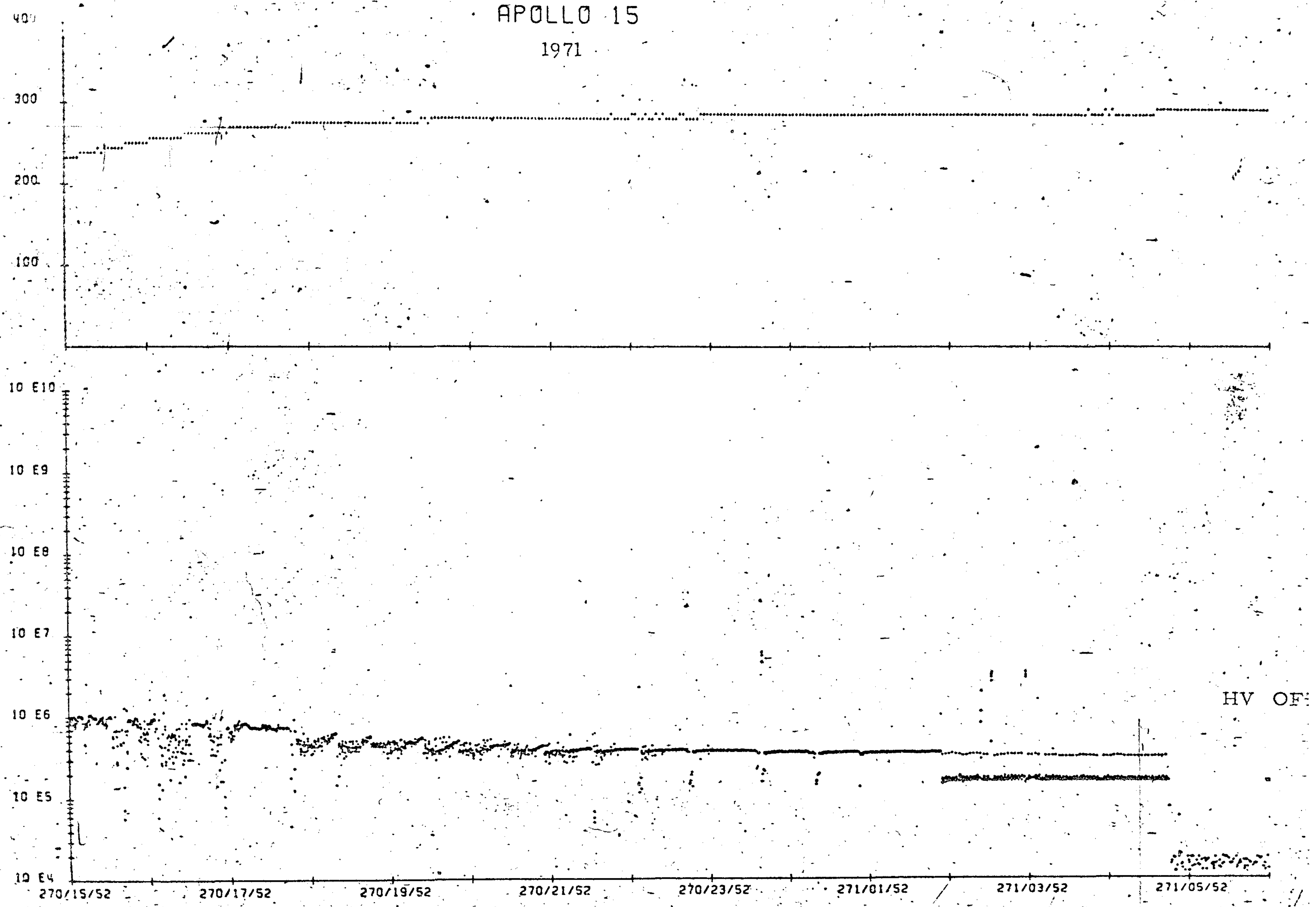
APOLLO 15
1971
400
300
200
100
10 E10
10 E9
10 E8
10 E7
10 E6
10 E5
10 E4
270/15/52
270/17/52
270/19/52
270/21/52
270/23/52
271/01/52
271/03/52
271/05/52
HV OF

FIGURE 7

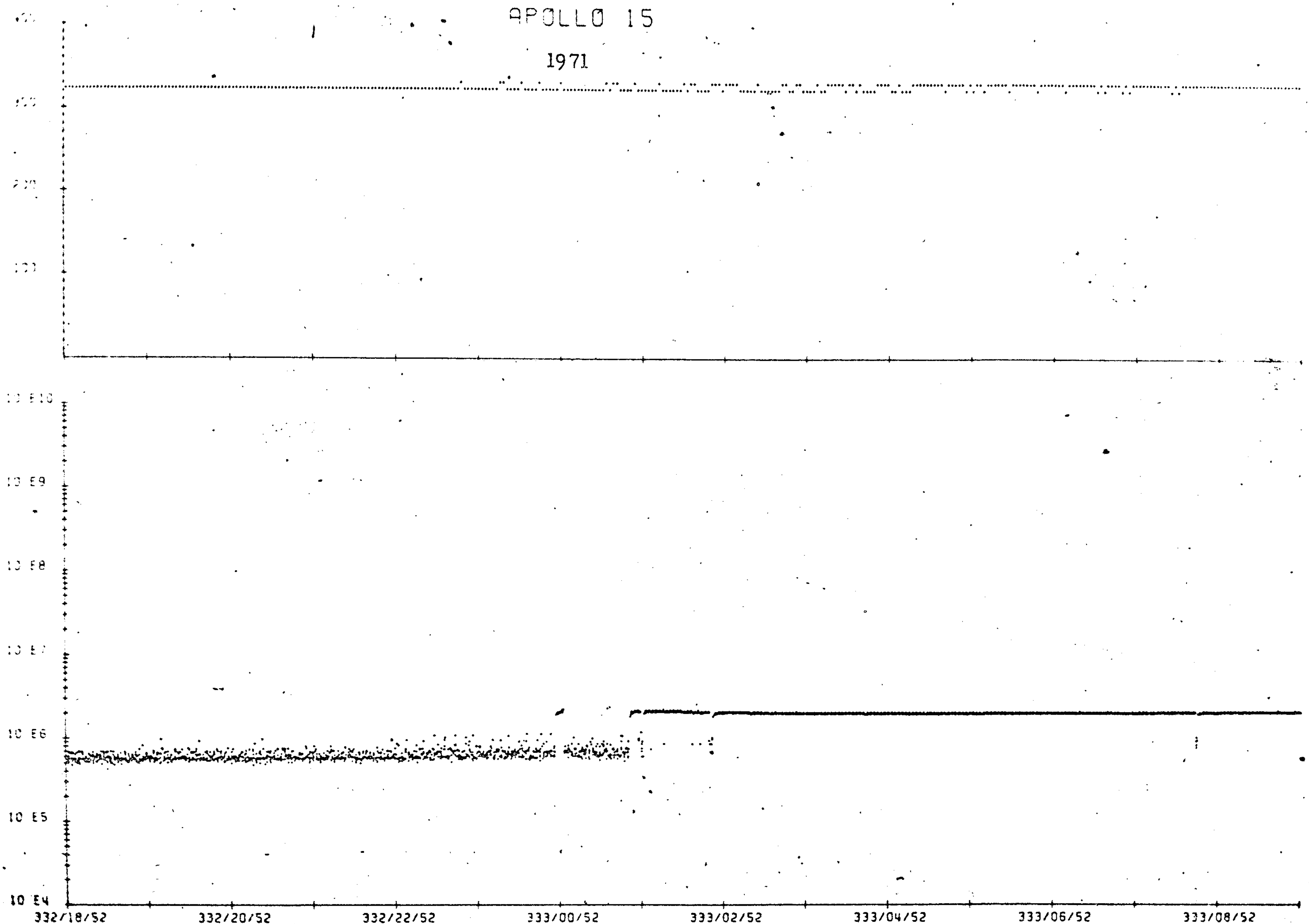
APOLLO 15
1971
400
300
200
100
10 E10
10 E9
10 E8
10 E7
10 E6
10 E5
10 E4
332/18/52
332/20/52
332/22/52
333/00/52
333/02/52
333/04/52
333/06/52
333/08/52

FIGURE 8

Bibliography of Key Papers

F. S. Johnson, D. E. Evans, and J. M. Carroll, "Cold Cathode Gauge (Lunar Atmosphere Detector)," Apollo 12 Preliminary Science Report, NASA SP-235, 93-97, 1970; Apollo 14 Preliminary Science Report, NASA SP-272, 185-191, 1971; Apollo 15 Preliminary Science Report, NASA SP-289, 13-1 - 13-5, 1972.

F. S. Johnson, "Lunar Atmosphere," Reviews of Geophysics and Space Physics, 9 (3), 812-823, 1971.

F. S. Johnson, D. E. Evans and J. M. Carroll, "Observations of Lunar Atmosphere," Space Research XII, Proceedings of 14th Plenary Meeting of COSPAR, Seattle, Washington, Akademic-Verlag, Berlin, 99-105, 1972.

F. S. Johnson, D. E. Evans and J. M. Carroll, "Vacuum Measurements on the Lunar Surface," Journal of Vacuum Science and Technology, 9 (1), 450-456, 1972.

F. S. Johnson, D. E. Evans and J. M. Carroll, "Lunar Atmosphere Measurements," Proceedings of the Third Lunar Science Conference, D. R. Criswell, editor, Supplement 3, Geochim. Cosmochim. Acta, 2231-2242, 1972.