MISSION SIMULATOR TEST DATA

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I am going to go back and get an overview of a real-time mission simulation test program which was performed in conjunction with our ANIK 1A2 satellites.

(Figure 5-39)

This is the overview of the test program up to the last eclipse season, but not including it. There were ten cells which underwent the mission simulation. We are rigorous on most of the characteristics within the test program. We simulate the temperature profiles, electrical profiles, etc. The only thing we did not simulate was the g loading on the cells, and of course the vacuum, which should not affect the system.

By eclipse seasons, the end of the maximum, end of discharge voltage per eclipse season is defined through here and through here for the test program cells.

Superimposed upon that by eclipse season would be the A1 and A2 satellite cell voltages.

(Figure 5-40)

On this one, rather than comparing the end of eclipse discharge voltages, maximum DOD voltages by eclipse season, I have done it from a date of activation. You will see there is a far better correlation on these with the exception of the very early part in there. There is an excellent correlation. And again, out until the very, very end.

Going to the first figure, you will notice that at this point the divergence between some cells. Following the fifth eclipse season, we put some of these cells on a continual slow charge. Our satellite did not have the capability for trickle charge. We had either fast charge, slow charge, or open circuit. Our nominal way of handling the cells was open-circuit storage with reconditioning every 30 days or thereabouts.

After the fifth eclipse season, some of the things we saw indicated that the test program to develop a backup mode of operation, we should put some of the cells on slow charge. Now this slow charge is about a C/30. It is pretty high.

And from this point on all the slow charge cells were put on 255 milliampere storage season charge complete with the reconditionings every 30 days.

Also, at this point, it would probably be best to look at the second figure. Following this season right at this point, we elected to go and do our reconditionings down to 1 volt as opposed to 1.139, which we had done the previous seasons. This would be on not only the battery test facility, but on the satellites as well.

You can notice a sharp increase in this cell and not in this cell.

This open-circuit storage cell increased fairly well. You will notice in the next eclipse season, going the way we would, we probably would have been down below 1 volt.

You will notice that the increase in the DOD for the reconditioning did not affect the slow charge storage cells that much.

Now, I am not going to go through all the seasons. I am just going to show the more interesting ones. The first few seasons up to the first five, even ten eclipse seasons were quite nominal. You have all seen them, and I would like to go to the next Vugraph.

(Figure 5-41)

From seasons 5 – well, seasons 1 through 10 you notice very, very little difference with the open circuit storage probably outperforming the slow-charge storage cell by a very, very little bit.

And then on day – I think it was 24 – we had an operator error, which limited the C/10 charge return to 32.5 percent on that day, and we topped it up with a slow charge. The total return was 130 percent.

You will notice that the open-circuit storage cell the following day (day 25), dropped way down. It had very little effect on the slow-charge storage cell, and this story starts to repeat itself on and on.

(Figure 5-42)

Now, we are up to season 12, and the slow-charge storage cell is showing very good performance. Cells are showing very good performance, and the open-circuit storage cell is decreasing.

One of the things we wanted to do is check to see if there is anything growing in there that we might be able to see if we were to torque the pack. We torqued the pack and this is a pack of seven cells, seven ampere-hour cells. The following day this is what happened: it recovered. It started to drift off again and recovered. We can see the intermittent going on in there.

(Figure 5-43)

Now, we are up to the next eclipse season. We are coming out, it is dropping down. At that point, I believe we are doing about 120-percent charge return. The slow-charge storage cell again doing beautifully. This one is not; therefore, we had to increase the charge return to 140 percent at the fast charge rate. That helped. Still started drifting off.

(Figure 5-44)

And on and on again. The open-circuit storage going quite intermittent to take a look at it. Slow-charge storage was doing very well.

Now this is a high slow-charge rate.

(Figure 5-45)

One of the things that I elected to do was see if this really was a definite short or just a charge exceptance of what was going on.

We varied the temperatures at the end of slow charge for the eclipse days. We noted the slow-charge cell responded as it should, as we would expect it to. But the open-circuit cells showed very, very little response to this, which to me means that there is a charge-limiting short developing in it, and we are clamping on the voltage.

(Figure 5-46)

This plot was experienced, I believe, up around eclipse 13, 14, and we have seen it ever since. This is on the slow-charge cell, and we can see a short coming in during the slow charge, and then tapering back off. It goes down, and this recurs between once every day to two days.

So there is indeed a short on the slow-charge cell as well. But it is only during charge, it is not once the cell is either discharged or open circuited.

(Figure 5-47)

Every so often we pulled out cells for chemical analysis, and this is destructive testing. Unfortunately, we are only down to two cells for the entire test population right now, which sort of limits some of the more recent evaluation that I have done. But, to take a look at the very first portions here, the very first data points, these are the baseline cells.

We had, unfortunately, three lots for three spacecraft interspersed. Most of them were lot 4 cells. Almost all these cells, in our mission simulation tests, were lot 4 cells. I think there were about three lot 2s, and I think one lot 3 or something like that.

The negative electrode flooded utilization, and you can see, if you will allow me just a bit of artistic impression in there, looks like it is leveling out at around 80 percent.

(Figure 5-48)

This one is the total free charge which, again, looks like it is having a tendency to level out at around 5 ampere-hours. We started with about 2.4 ampere-hours. It looks like it is settling at about 5.

(Figure 5-49)

The overcharge protection is decreasing similarly, and again we look at it together with utilization and precharge, etc. It will be coming out something like this.

(Figure 5-50)

This is again the carbon content of the cells; and even the trickle charge – what is interesting is that the trickle charge cell is not increasing that much. One of the things that probably this means is that the cell was kept at the same temperature, being driven at the same temperature. It was a pack that was not being charged, and therefore there was a very small temperature differential, and the charge itself was not affecting the buildup of the carbon, it was due to the temperature.

So the effects are basically due to temperature; the buildup of carbon would be probably temperature, and probably very little effect due to the charge rate.

(Figure 5-51)

One of the things that we noticed in our test facility is the extreme dropoffs and the intermittents shown before, and also seen to a certain degree on our satellites, would be the cadmium migration. And this is what we attribute.

You will notice the cadmium in the separator looks like it is probably leveling out. Cadmium in the positive is still going up. Whether it is leveling out at this point I don't know. I don't have enough points there. It looks like it may be.

(Figure 5-52)

The electrode pore volume for the positive electrode has stabilized out quite well. There is no doubt that that is going along pretty straightforward – this is total pore volume. In the negative electrode, however, the pore volume is increasing quite steadily.

(Figure 5-53)

This is a plot of the negative electrode expansions that we have seen. The upper zone, the lower zone – again, this is artistic impression to a degree. It does look, indeed, as if it were leveling out again at the end of the eleventh season.

(Figure 5-54)

This is the positive electrode expansion, upper and lower zones, and again it looks as if perhaps the expansion that we have seen had somehow limited itself. I am sure we can all hypothesize. There is a limited amount of space within the cell for things to expand there before we are up against it.

(Figure 5-55)

Now, here is the thing which gets back to impedance, etc. This is micropore volume.

You will notice that although the positive electrode volume started to level off as the total volume, the micropore volume has all of a sudden started to take off. I suggest that this is probably where the electrolyte is going. It is going into the micropore sites, and it is escapting from the separator, is drying the cell out and this is one of the problems we are having, why we are seeing impedance problems, etc. The negative electrode is more or less steady. I am not sure what that is.

These were 7-ampere hour cells. The one notable characteristic was that they had silver in the negative plates. They were typical 1971 General Electric manufacture.

DISCUSSION

BETZ: I have a question for you. What kind of separators did you have in the cell?

HENDEE: That would be nylon.

BETZ: They were nylon separators?

HENDEE: Yes.

VASANTH: Kindly let us know whether the carbon content was increasing due to the cycling or the temperature had any effect?

HENDEE: The temperature – I should probably explain the temperature profile. This is a spinner satellite. The cells are pretty well on the outside of the satellite up against the solar panel. They very seldom go above about 74, 72°F.

Incidentally, I apologize, they are all in Fahrenheit, because this is how we started out. We didn't want to change in the middle of our program.

They are pretty well heat sumped to the deck. I would say that it would be that normally combining what we see in this data with that seen in other analyses, that it would be temperature, mainly temperature dependent and not charge dependent because we saw that the cell which was on continuous slow charge showed almost no increase in carbonate content over the cell which was in the open-circuit storage.

VASANTH: My second question is, did you analyze or did you have a chance to analyze the positive base for cadmium? Due to cadmium migration you could have, perhaps, cadmium deposited in the positive base?

HENDEE: I believe there was a part of that shown. I know I went through it a little bit fast.

VASANTH: Was the content of cadmium increasing due to cycling of the temperature in the positive plates?

HENDEE: Due to temperature?

VASANTH: Yes.

(Slide)

HENDEE: One of the other things, of course, that is probably indicative is that I believe – let me just go back through a detail plot here. I don't have it written down, but I was trying to see which one was the slow-charge cell and which one was the open-circuit cell.

You will notice that they are both living in the noise level of each other, and one was on continual relatively high-rate charge, the other one was open circuit, and it seemed to make very little difference.

The only thing I can say for the performance we have seen is that cadmium migration is probably going on in both cells, but it is in a different form in one cell. We have not analyzed it in detail as to the form between the slow-charge storage and the open-circuit storage.

McDERMOTT: I found your data toward the latter part, the quantification of the amount of pore volume increase in the micropore volume, very interesting.

I might suggest that the best way to find out where the electrolyte has gone is to soxhlet the electrodes separately and just test for OH.

The reason I have said that there has been some discussion over the years about where the electrolyte is going, and the discussion is centered about the increase in microcpore volume in the positive plate is drawing the electrolyte into the positive plate.

This may be true when you have got the positive plate versus the hydrogen electrode and nickel hydrogen, but in the nickel-cadmium system I think it could be that the negative plate is as well or better a competitor for the electrolyte than the positive plate, and your increase of total pore volume I think would possibly support this.

We have found experimentally that more times than not the majority of electrolyte ends up in the negative plate after cycling than it does in the positive plate.

(Slide)

SEITZ: There is an increase of cadmium, and it is given in grams. I don't know if it is grams per cell. But if it is grams per cell, we are seeing an increase up to about 10 ampere-hours of cadmium in the positive electrode. Since it is a 7-ampere-hour cell, then there is a loss of perhaps as many as 10. That is what you are showing.

I don't know whether you have cadmium in there originally, whether any cadmium had been built in. But, can you comment on the amount of transfer?

HENDEE: There's the original right there. That's our baseline.

SEITZ: Then that still corresponds to an increase in the order of 8 ampere-hours.

HENDEE: 3 grams.

FOUGERE: About this increase of both positive and negative plates, you said it is about 14 to 15 percent. Could you explain why you have such an increase on the negative plates?

HENDEE: In what, now? Thickness? No, I do not. Do you?

FOUGERE: It is surprising.

HENDEE: These are just observations.

RITTERMAN: Just a comment about where the electrolyte goes when it leaves the separator. In TRW we found most of the electrolytes to go into the positive electrodes rather than the negative.

HENDEE: I think that is to a certain degree borne out by exercising the cells and putting them into a certain amount of overcharge, too.

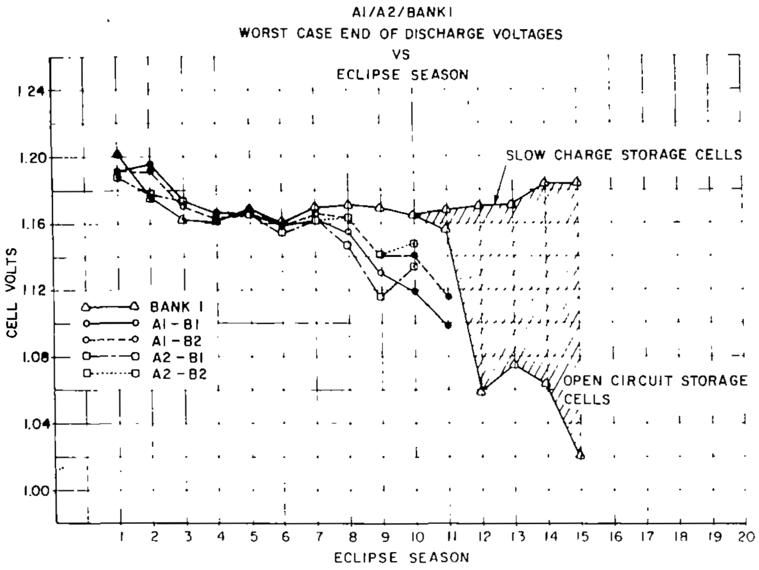
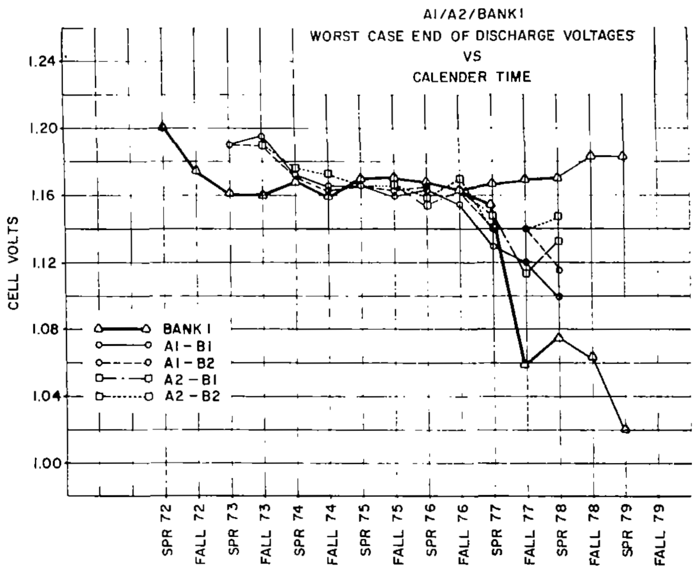


Figure 5-39



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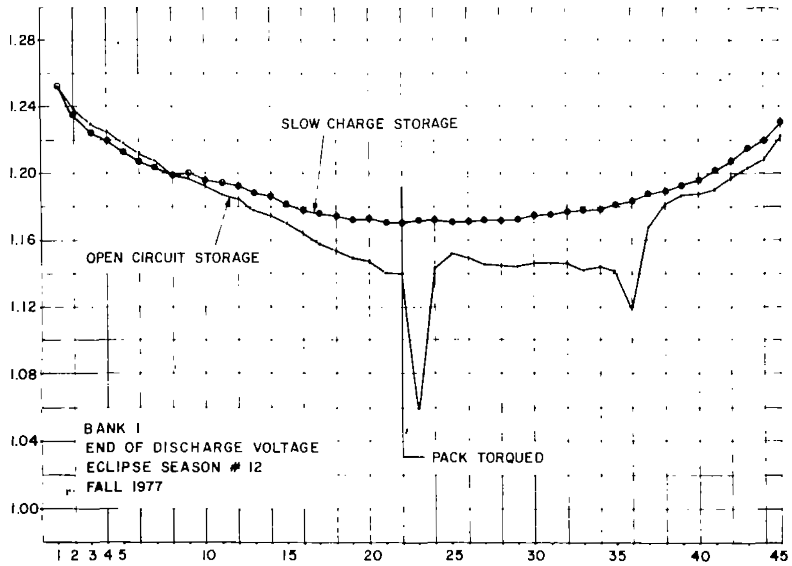

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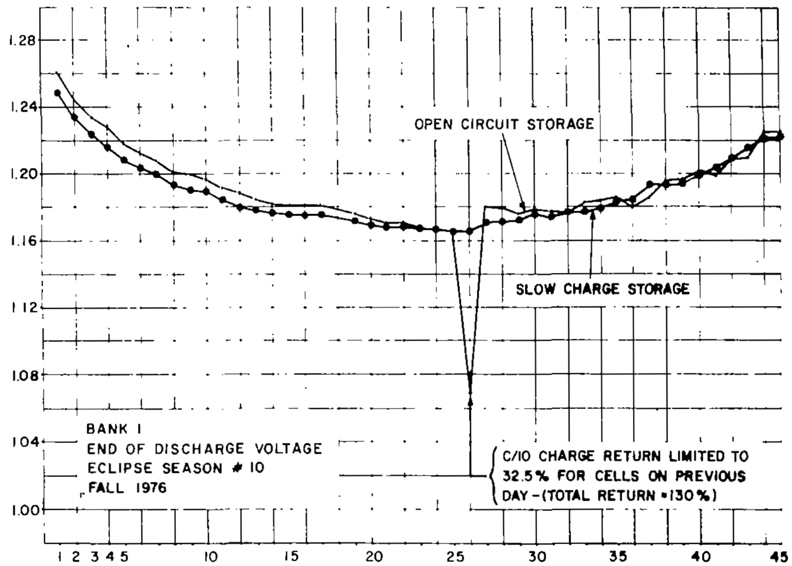

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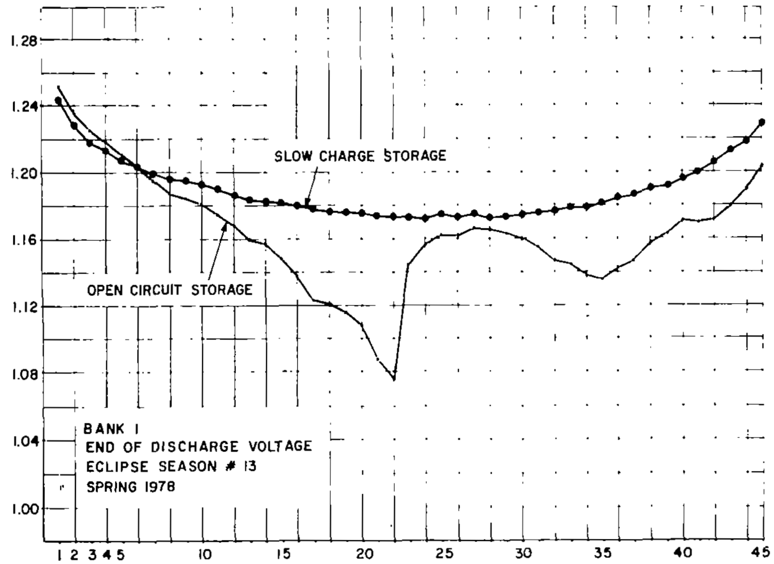

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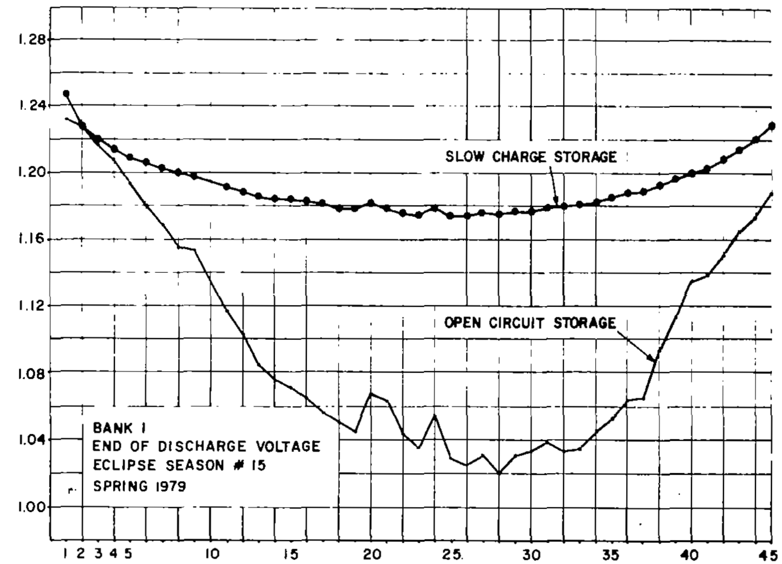

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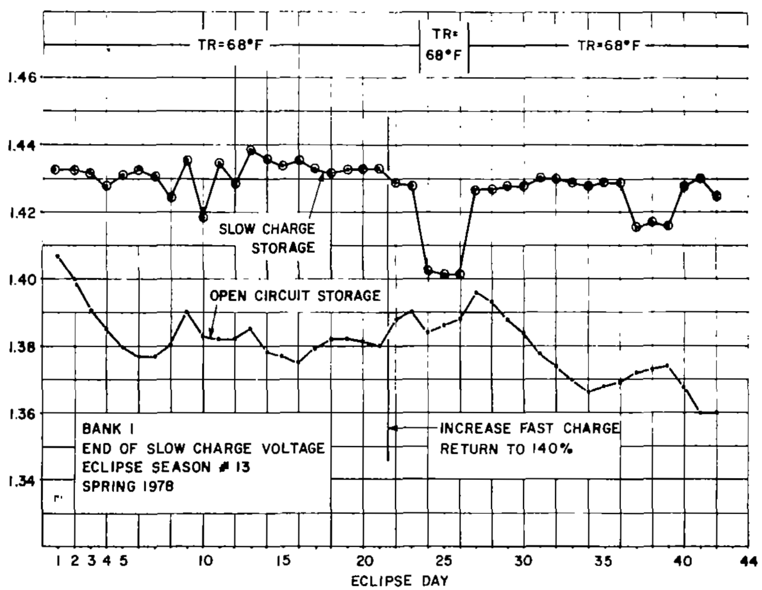

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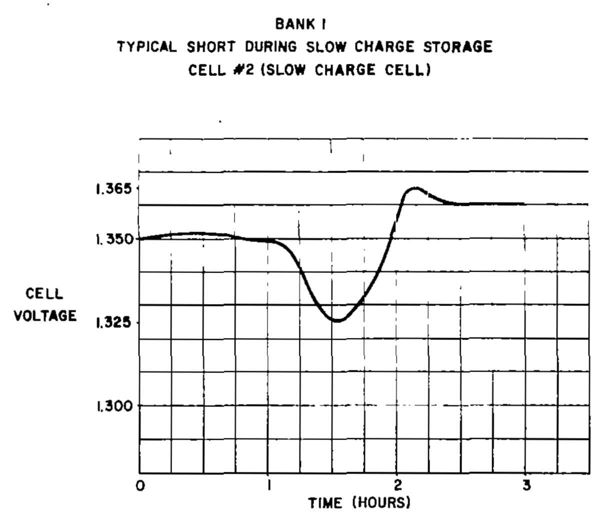

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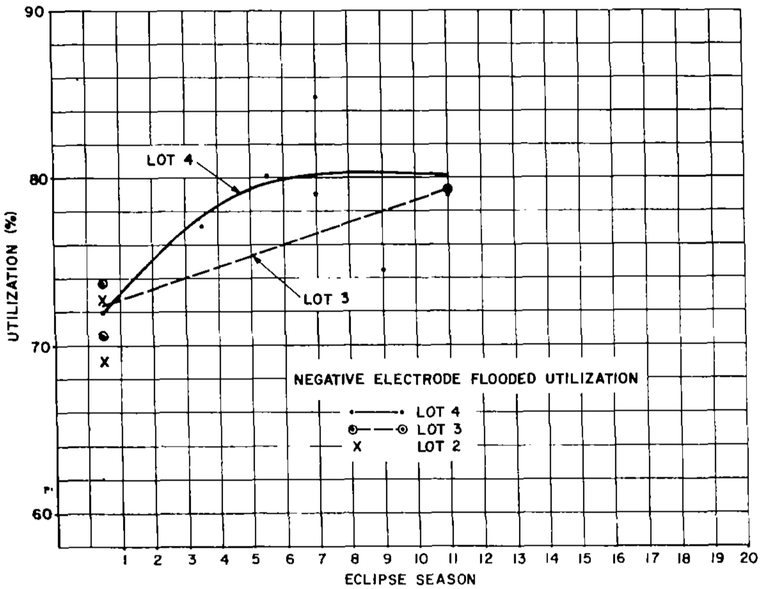

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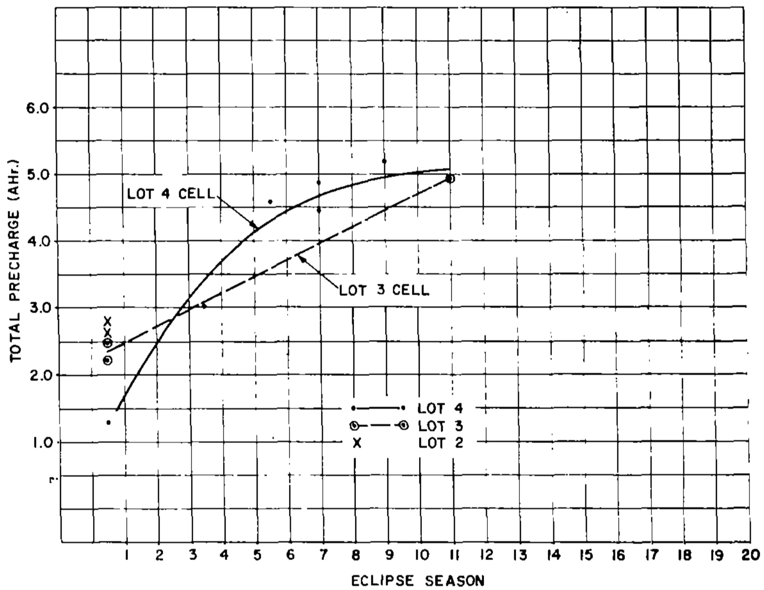

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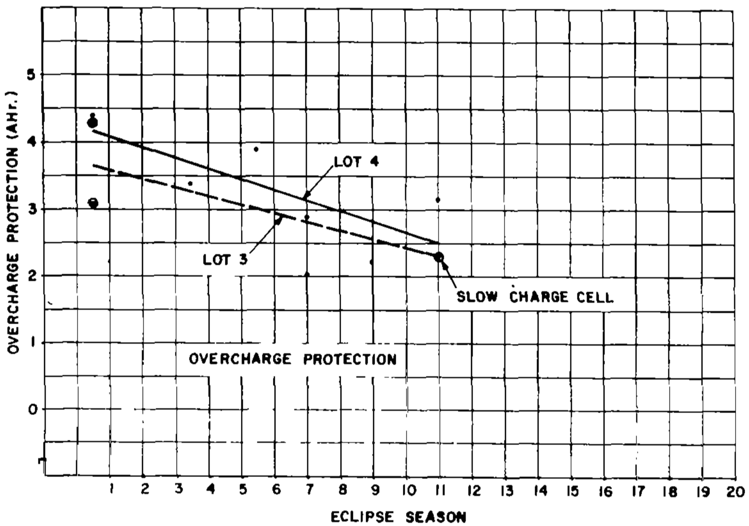

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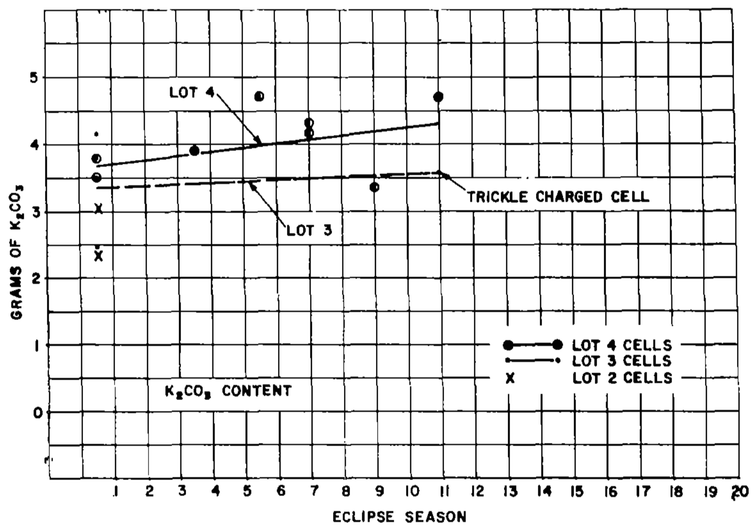

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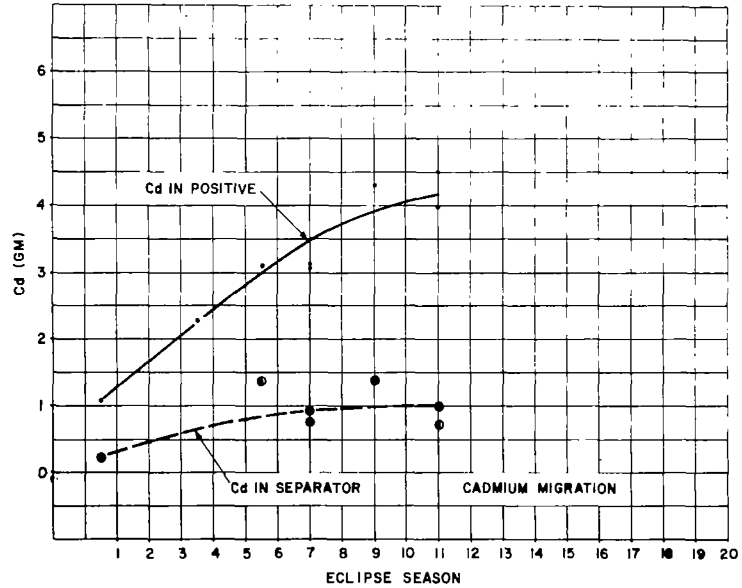

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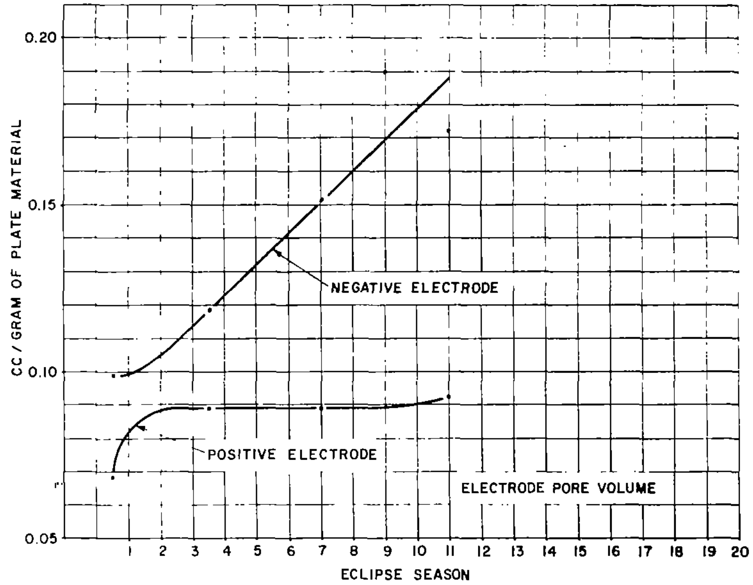

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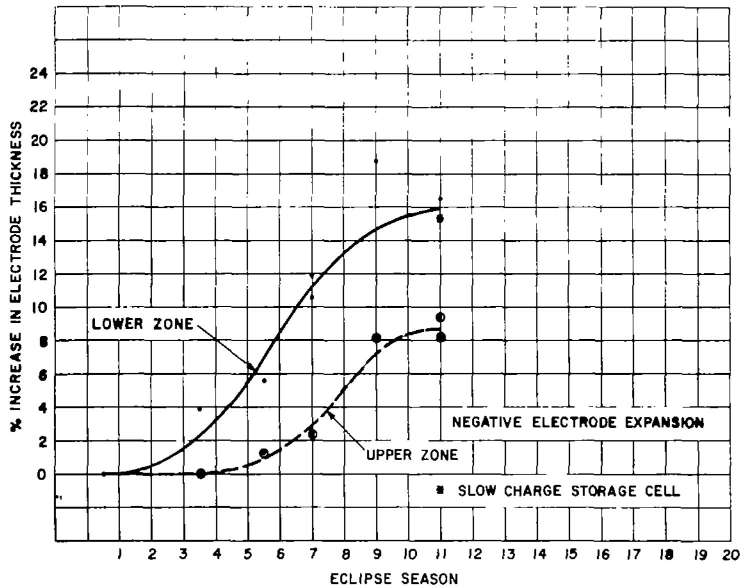

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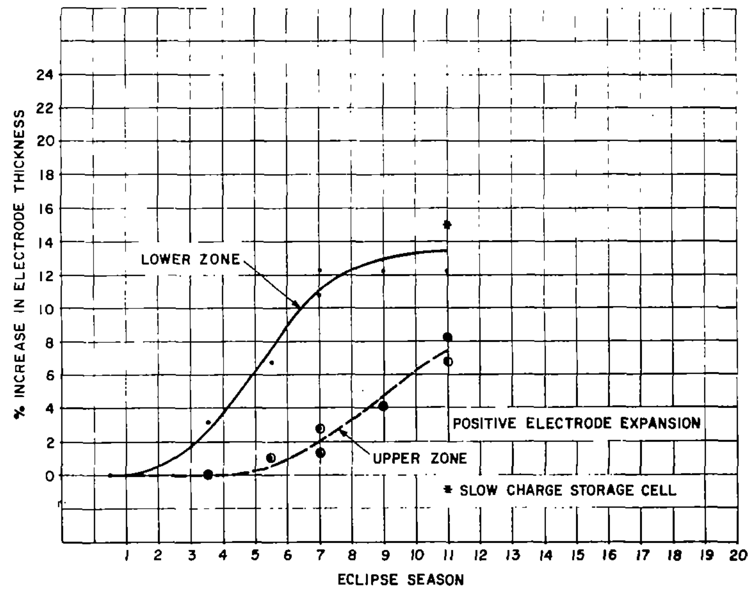

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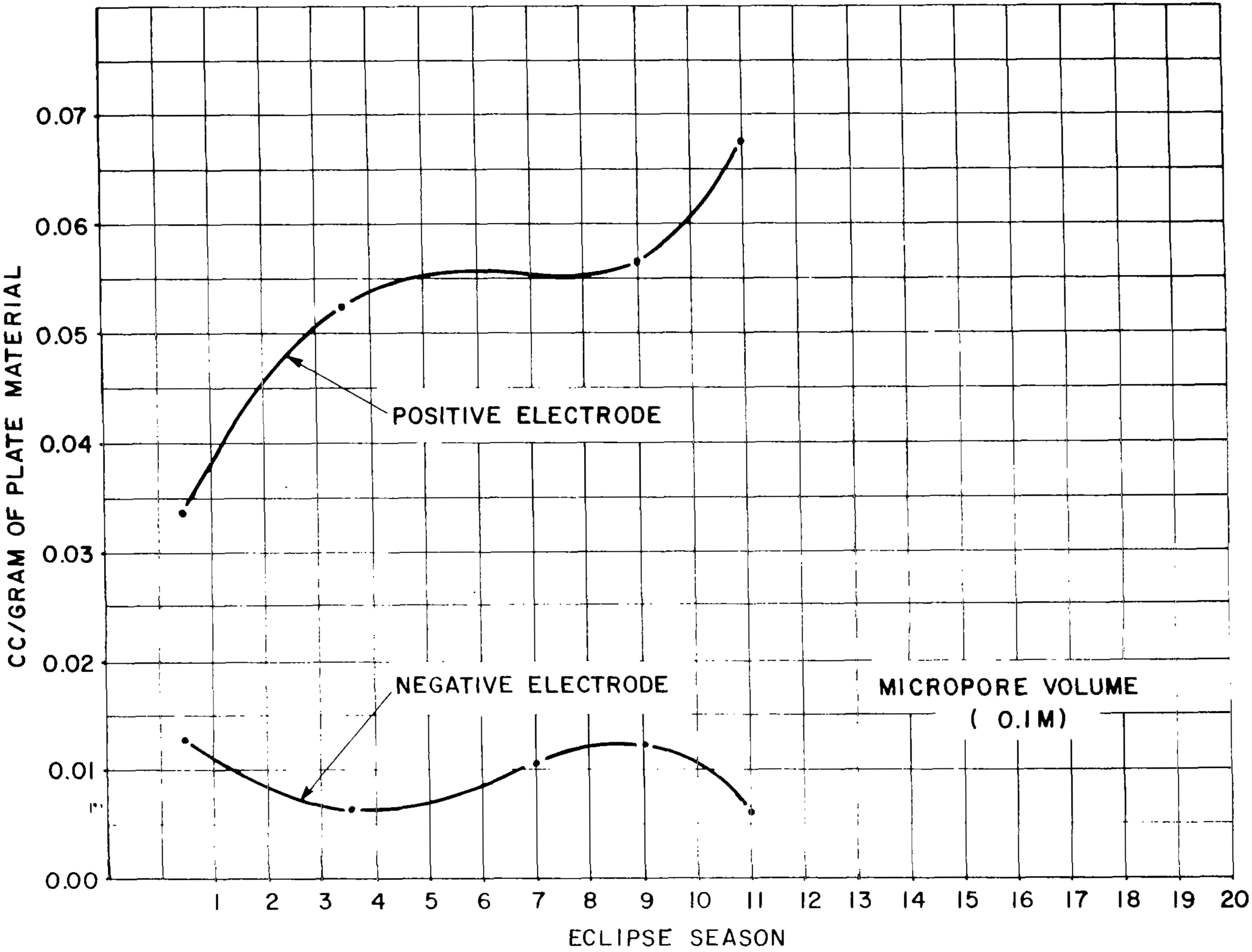
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POSITIVE ELECTRODE
NEGATIVE ELECTRODE
MICROPORE VOLUME
(0.1M)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
ECLIPSE SEASON

Figure 5-55