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RADIATION EFFECTS

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MR. LLOYD THAYNE: Gentlemen, I was preparing to present two papers here from the very beginning, during the seminar, and the other day in conversation with Ron, I was instructed that I had fifteen minutes to cover both of them. So if you see skeletons here, it is the skeletons of what was initially intended to be presented. Let me very quickly run through some areas. Because other speakers are covering radiation and long-life problems, I don't think it is necessary for me to go into any great depth.

Let's quickly go through a couple of areas that we have to be aware of with respect to radiation. Our colleague, Mr. Divita will cover in more detail the radiation effects problems that we are faced with in probes.

This graph (Figure 9-23) is related to cosmic radiation. It is in terms of displacement equivalents of 3 Mev electrons and 20 Mev protons, if they were to impinge on the components in question, i.e., the transistors, et cetera, that are inside of the boxes. It is assumed here the cosmic radiation is in the greater-than-100-Mev category. Notice that the shielding has very little effect. You get maybe a factor of two at the most and probably about a factor of one and a half change from no shielding to 225 mils of aluminum, assuming a spherical shielding condition. But note that the equivalent fluence is not high enough to be of concern.

Notice Figure 9-24 with respect to the problem of solar flares, the energies are somewhat lower and the effect of distance from the sun has a strong effect on total dose. The chart shows the equivalent 20 Mev proton displacement fluence in protons/centimeters squared/year. Here because of the low level of the particles in question, shielding, comes into effect quite significantly.

Shown in Figure 9-25 are some points I have taken from Pioneer 10 data. The projected impact on the probe missions with respect to going into Jupiter is quite encouraging. The actual measured

MAXIMUM EQUIVALENT FLUENCES DUE TO COSMIC RADIATION

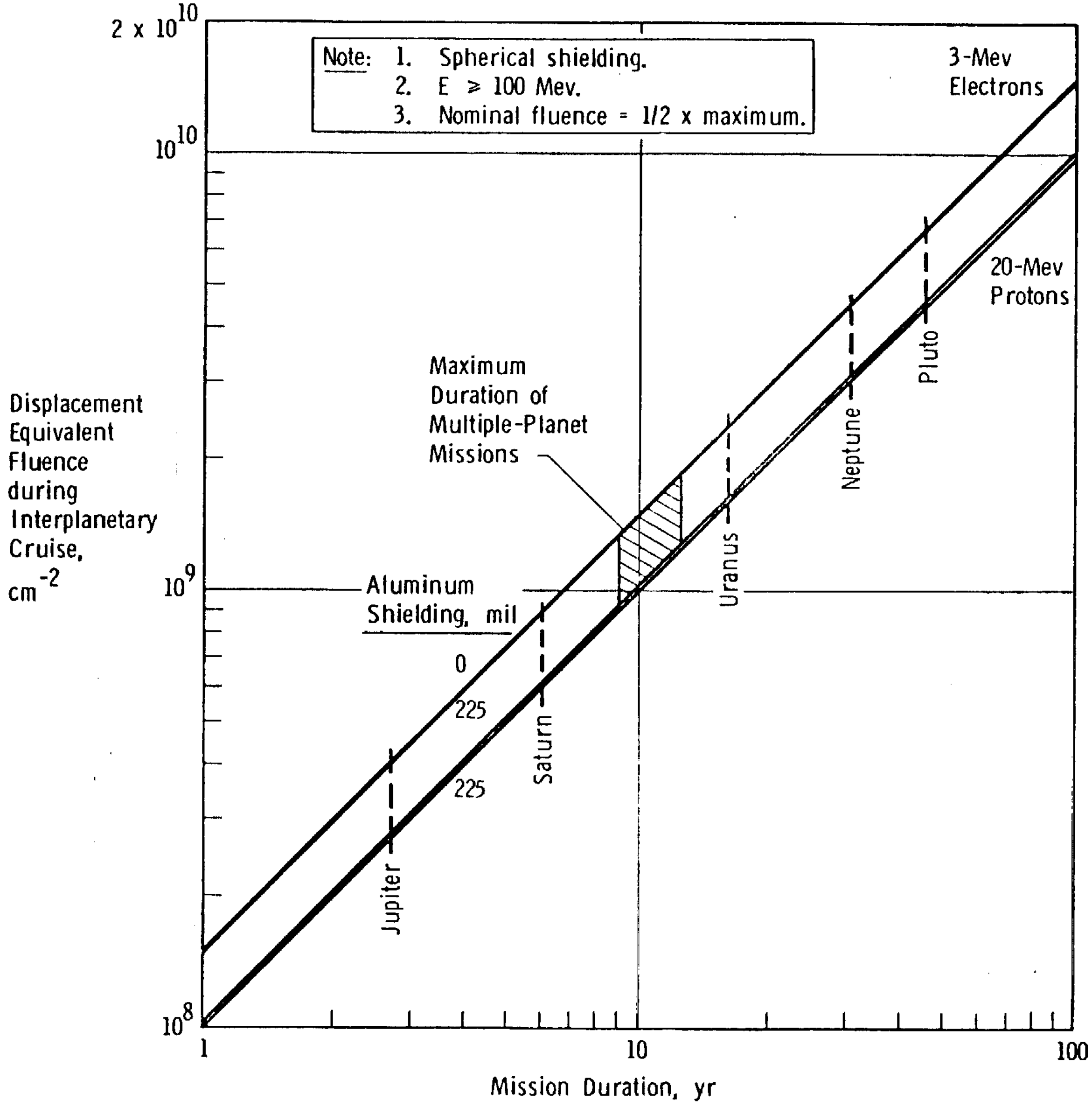

Figure 9-23

MAXIMUM EQUIVALENT FLUENCES DUE TO SOLAR FLARES

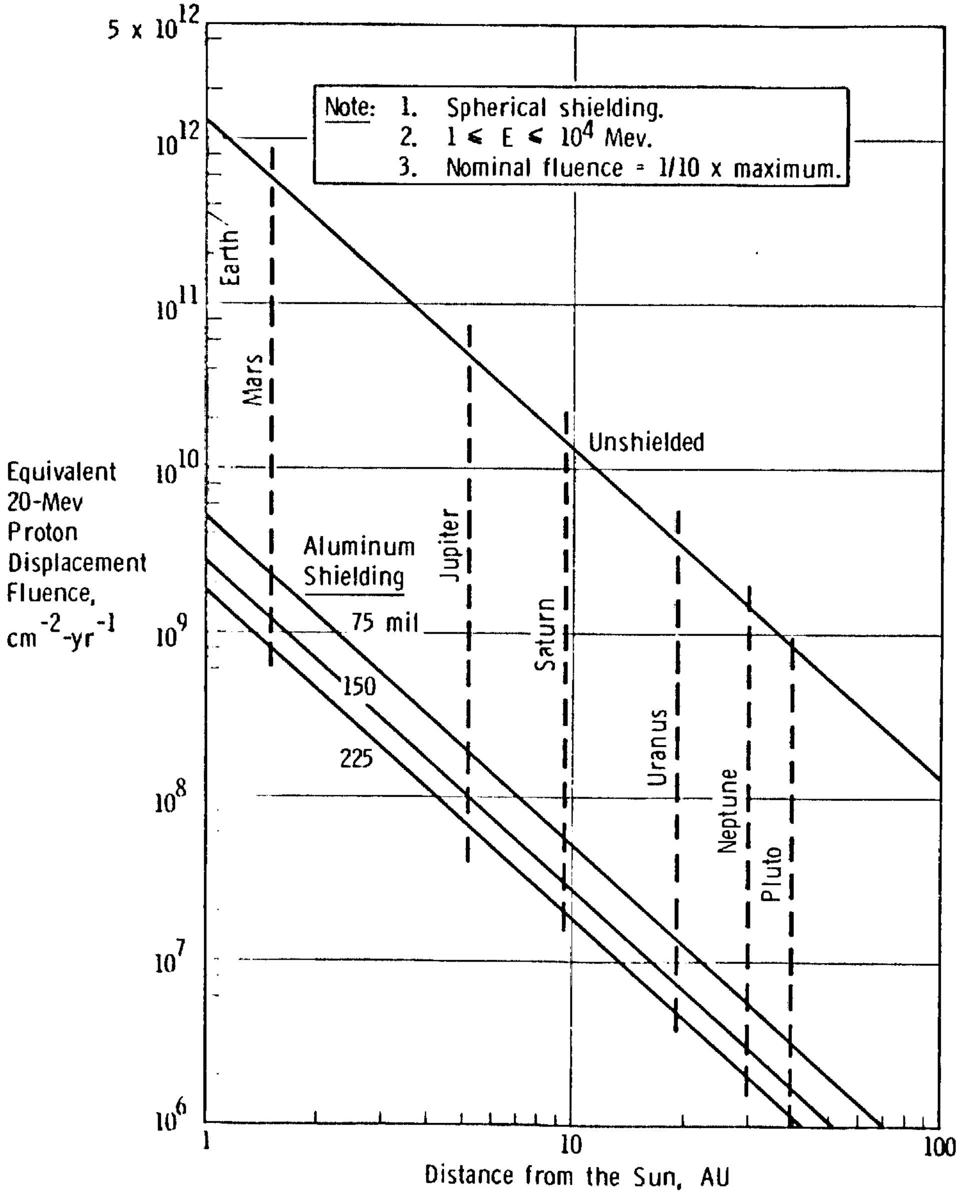

Figure 9-24

JUPITER PROTON MODEL & MEASURED DATA, EQUATORIAL PLANE

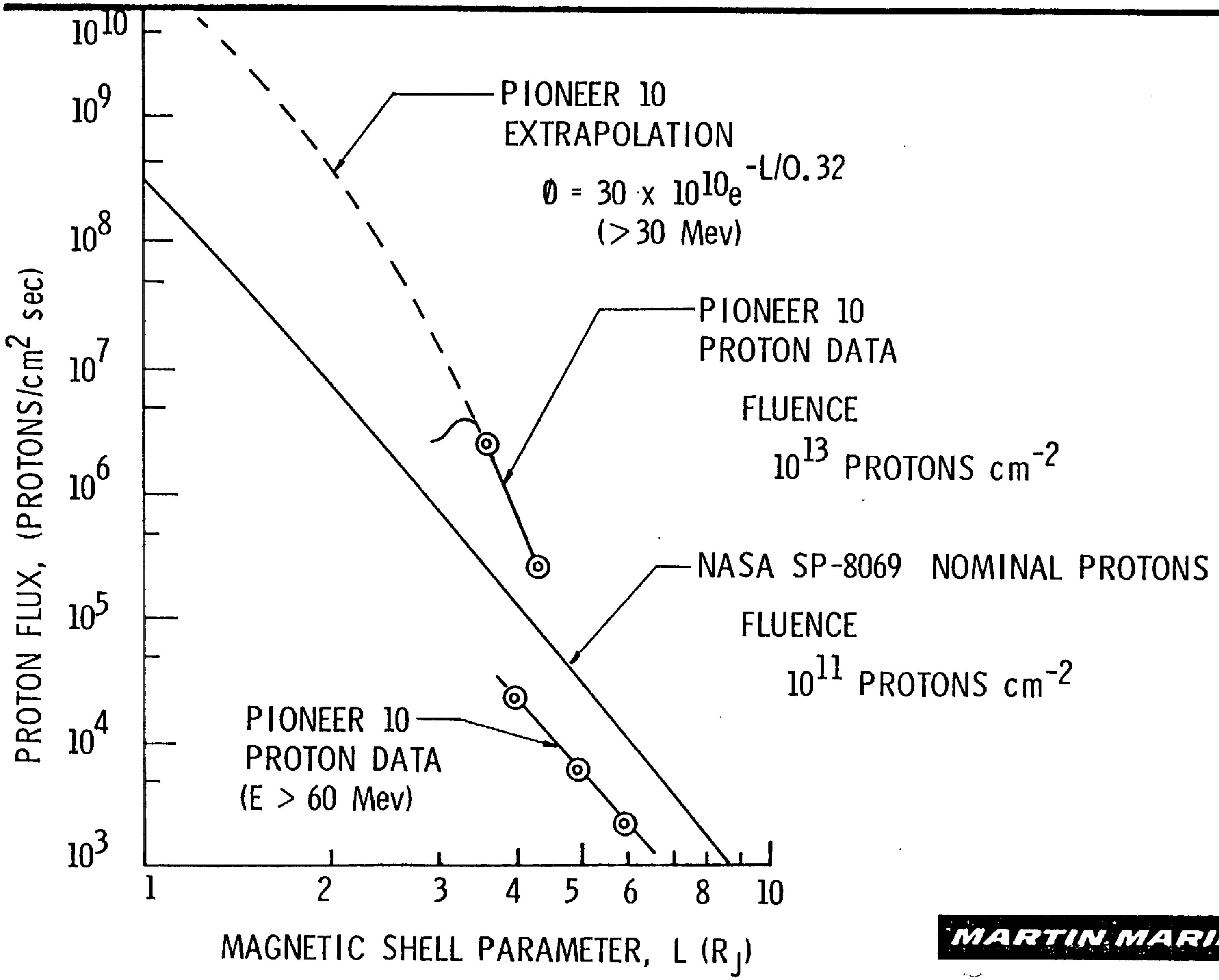

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FIGURE 9-25

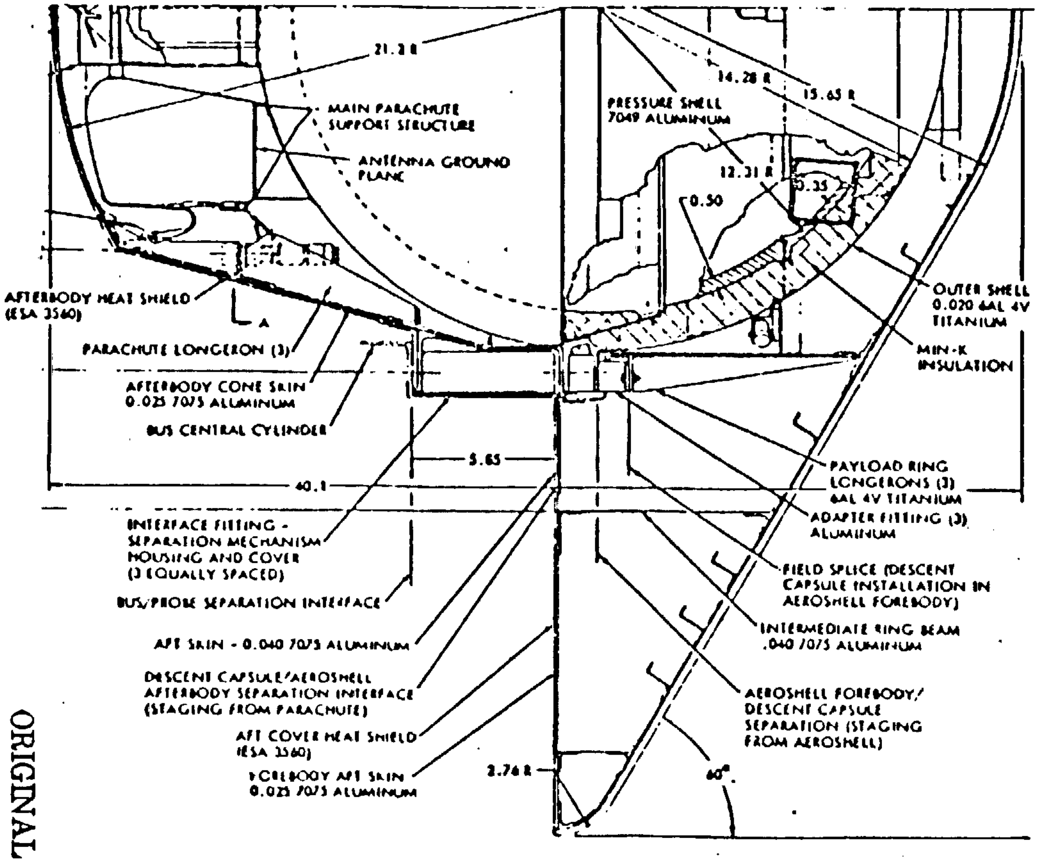
points are shown (circles) and it was noted that there was a tail-off at 3.6 R_J, approximately the orbital position of one of the satellites. The 60 Mev protons are slightly below the nominal proton fluence projected by NASA 8069.

The significant part is that if one were to integrate under the 30 Mev curve extended (dotted line), and assume that all protons below the 30 Mev level are removed, one still ends up with about 10^{13} protons per square centimeter by the time the probe enters. That is not quite acceptable, I think Mr. Divita will indicate later on that 10^{13} is probably a little more than we would care to have with respect to protons, since that is equivalent to probably 3×10^{14}. We don't really care to design probes to that level.

The 60 Mev proton fluence is somewhat below the NASA nominal model. If you were to take the nominal curve and assume that the probe goes into one R_J, then it ends up with about 10^{11} protons per square centimeter. I think we can live without any serious impact with that two orders of magnitude of improvement. One point of interest is that as you integrate under these curves, you find out that you can forget everything far out because it is only the last half of an R_J that is going to provide about 90 percent of the fluence anyway. So, integrating under the curves is kind of a waste of time and effort. You might as well just pick a point at 1.25 R_J and assume you are going to be in that area for the period of time it takes to go from 1.5 R_J to 1.0 R_J and that will either frighten you away or solve the problem for you.

I looked at the projected large-probe Pioneer-Venus version that was presented to Ames by Martin Marietta and I think that the Hughes large-probe is going to be similar in that in both cases you have to have a pressure vessel. This is the MMC hundred-bar probe, Figure 9-26 which has to have a pressure vessel. In this case, I found that the minimum thickness of the pressure vessel was about 350 mils of aluminum. I am not sure what it is for the

PROBE PROTON SHIELDING



LARGE PROBE CROSS SECTION

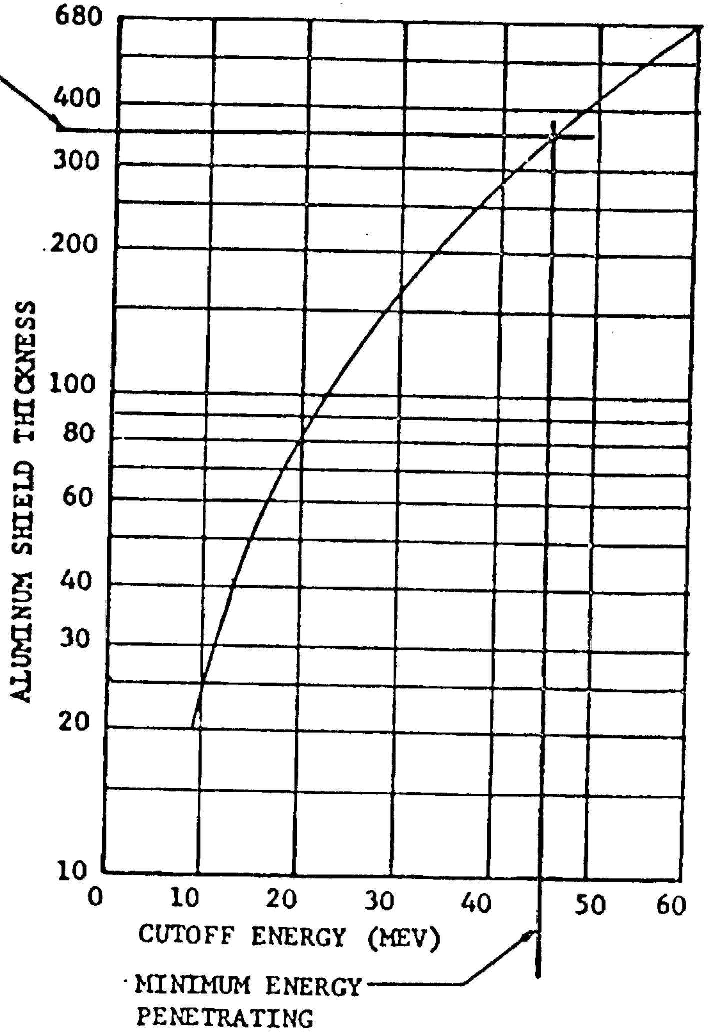


Figure 9-26

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Hughes probe but you can translate from 350 mils to any other point.

From the curve on the right, you will find that as the shielding thickness goes up, the minimum energy of the protons that get through the shield,and are, therefore, capable of doing damage to the electronics, increases. For the 350 mils thickness, essentially no protons with energies less than about 40 Mev are going to get through the shield. If you recall, from the previous chart, the 30 Mev and the 60 Mev proton levels essentially bracketed the NASA nominal model. If you could translate that 40 Mev to the nominal model we are talking about approximately 10^{11} protons per square centimeter as that which is projected to get inside of the pressure vessel. That is going to be reduced even further by the fact that you have all the ballistic paraphernalia on the outside; the heatshield and so forth are going to add additional shielding to the system.

Assuming then that we can get in with the type of trajectory that Pioneer 10 took, there is some capability of increasing our chances even more by taking advantage of the fact that the centroid of the magnetic field is offset from the center of the planet and tilted by some fifteen degrees in the nominal model from Pioneer 10. Notice Figure 9-27 -that the latest projections, that I have found at least, indicated that the centroid was offset about $0.2\,R_J$ from the center and up towards the northern pole by about $0.1\,R_J$. This gives us a little bit of help in getting the field off to one side. If one were to consider an entry in the southern hemisphere, assuming the same latitude on either side, one can see that you can save quite a bit by coming in on the side opposite the centroid. This isn't a matter of going in posigrade versus retrograde, it is a matter of timing as to what the position of rotation of the planet is at the time the entry takes place. There can be possibly as much as an order of magnitude but more probably a factor of two to five, improvement in the radiation expected by selecting the time of arrival of that probe with respect to the rotation of the planet.

JUPITER TARGET PATTERN

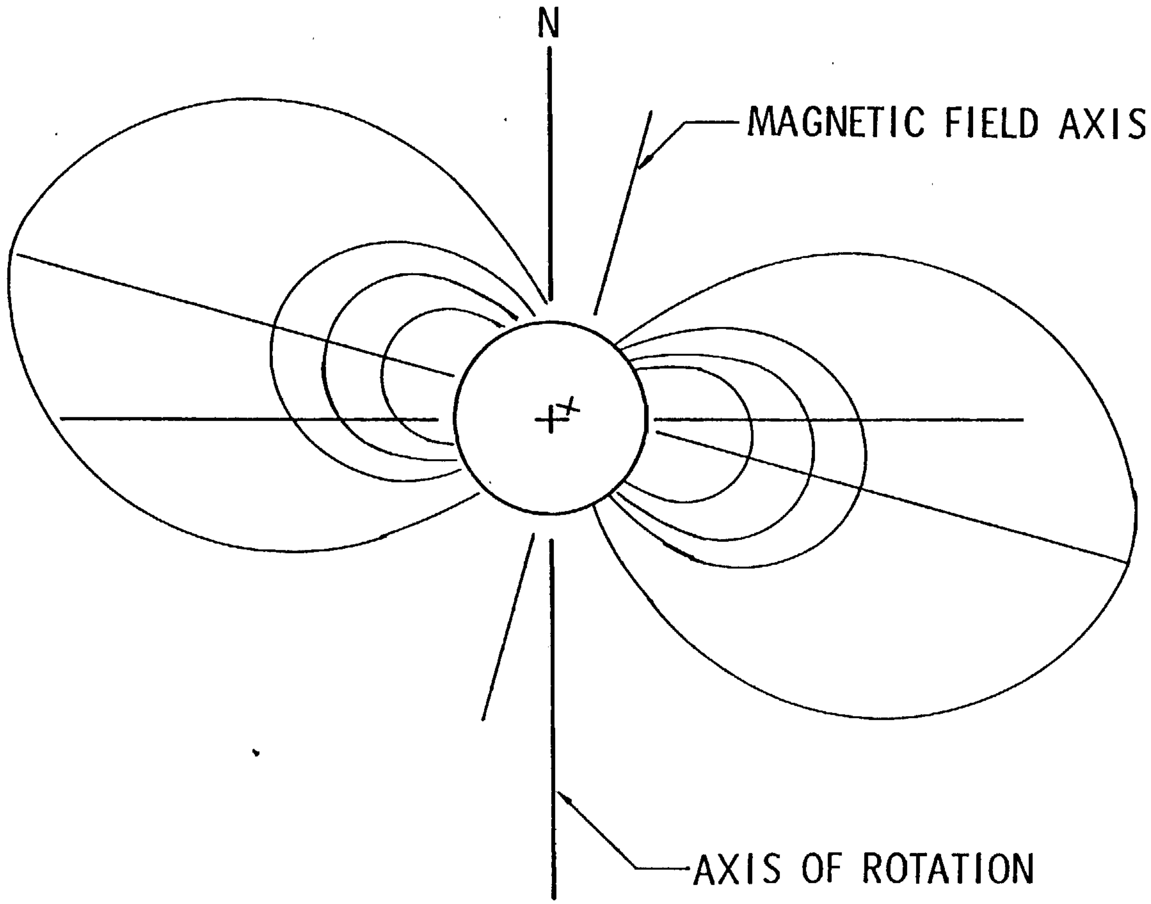

Figure 9-27

This is kind of a composite curve (Figure 9-28) because we are not presently talking about being able to drop in a 100-bar probe and then also go into orbit with our present payload capabilities unless one takes advantage of the Mars swing-by talked about the other day. (I am not really proposing that, but it is a possibility. If one were to take that course you could not only get a large probe into Jupiter, but you could also have sufficient capability to go into orbit with the bus.) But the point I wanted to show here was that once one has dropped off a probe or gone into orbit, that you can improve your radiation protection if you make the bus orbit such that it is an integer multiple of the rotational period of the planet; so that it always comes back at the location of minimum radiation.

That's basically the comments that I wanted to make with respect to radiation. Now let me tell you just a little bit about another problem I am concerned with, that of long-life batteries for these probes.

We've done a little testing on some batteries we have designed at Martin Marietta taking basically an Eagle Picher silver zinc cell, modifying the size of the plates, the separator material, the number of wraps, and so forth, in order to learn more about the critical areas that are involved. The standard cell starts with forty-eight watt-hours per pound and drops rapidly (Figure 9-29), which isn't very useful in any of these probe missions because we are beyond the twelve-month period on just about all of them.

From the modified cell we now have test data out beyond twenty-months with cells that still give us, at 30°F storage, right at forty watt-hours per pound in all three test modes: discharge, charge and float-stand.

MINIMUM RADIATION JUPITER ORBITER MISSION

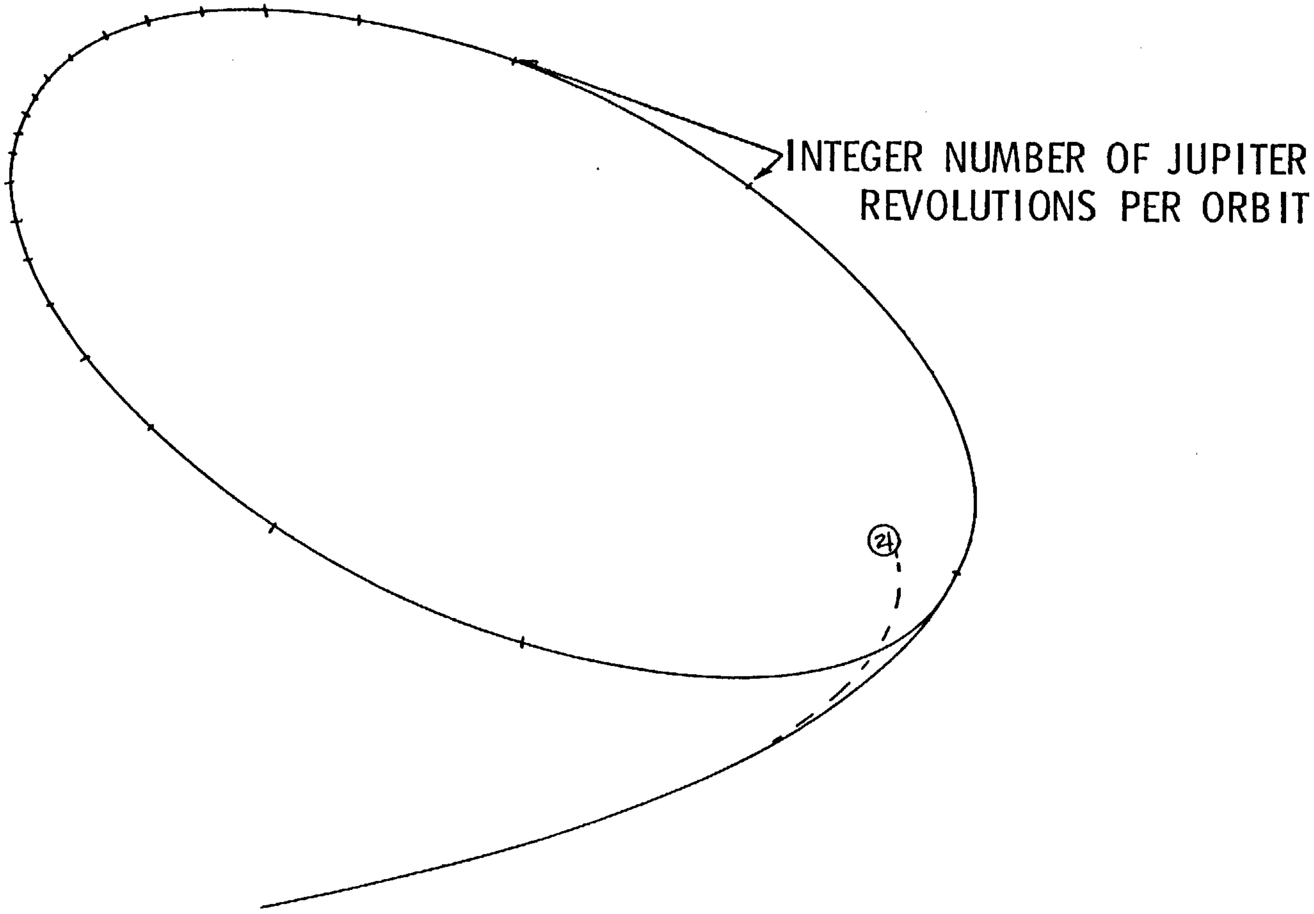

Figure 9-28

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MMC CELLS - 30°F STORAGE

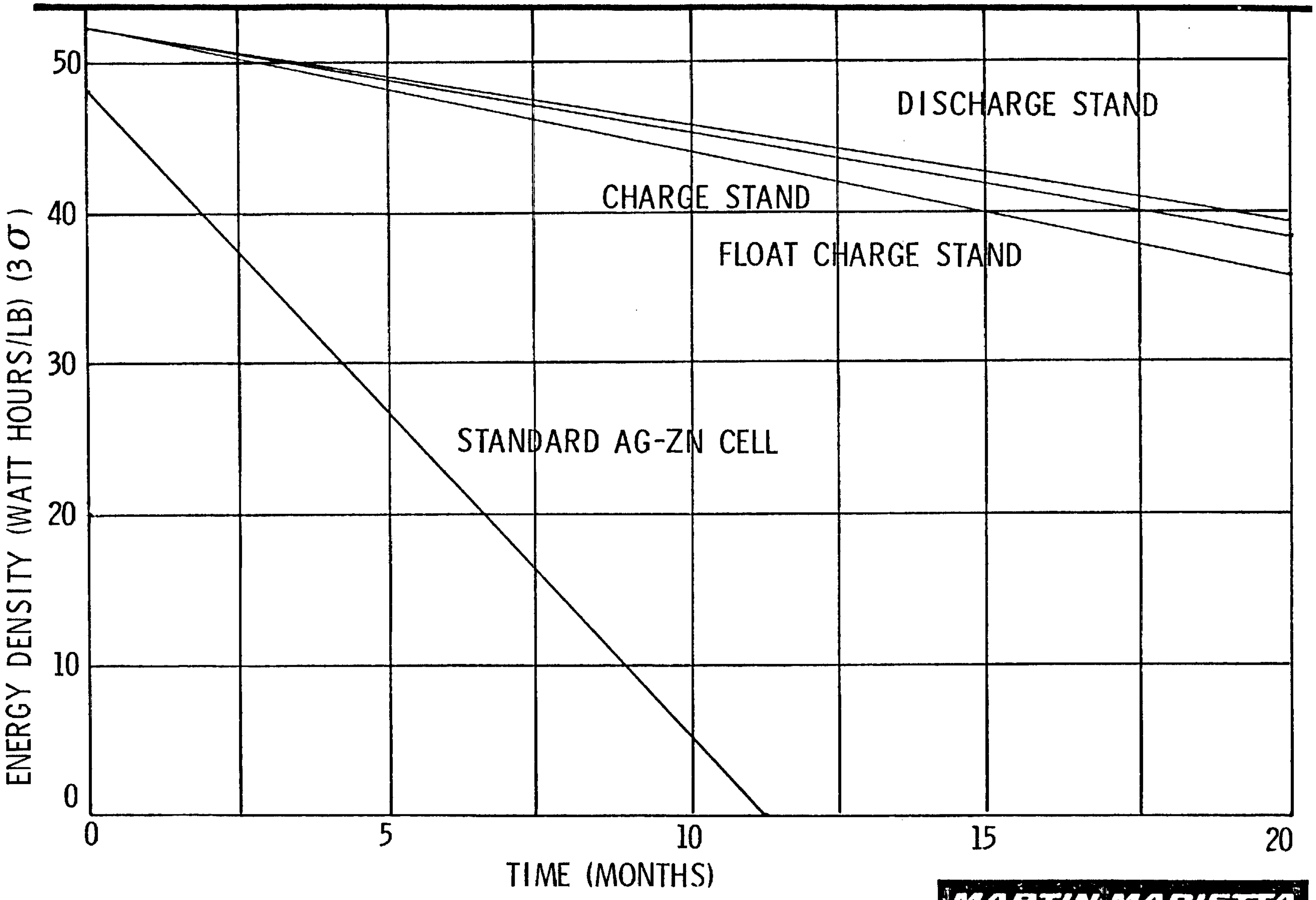

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Figure 9-29

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If we store them at about 55°F (Figure 9-30) we find that we improve that slightly over what we had at 30°F. I don't have a curve on the cells at 75°F, but we got less capacity out of the cells at room temperature than we did at either 30° or 55°. It just turned out that 55° is about the optimum temperature. At the colder temperatures we had charge problems on the cycles, and at the hotter temperatures, the degradation in the cells occurred faster.

I might make a comment before I go into the next slide. Those groups of cells that have had failures have shown no failure indication at all for some extended period of time and then suddenly the whole group goes in a very short period of time. The separators fail in essentially the same mode. It is a chemical oxidation of the separators that has occurred so far. We have had, to date, no shorting between the plates due to dendrites.

We talked to a few people about sterilization (that is a problem that we have been talking about here this morning) and some of the comments that have been made with respect to sterilization are shown on Figure 9-31. They are taken out of context. You don't see the question that was asked and you don't see the whole conversation that was held. So please consider that fact as you read them. It is obvious that some have done no sterilization work; some have found failures. For instance, Tom Hennigan at GSFC indicated that they had had some mechanical problems with the ESB units. You talk to Al Jordan at ESB and he likes to talk about the success they had on their Viking test. Sandy Seidman at Yardney says they have been successful.

But what it boils down to as you really dig into it is you find that all of them have problems. They all have, basically, the one problem and that is that when you heat these filled cells you have extreme gas pressures produced and you have structural failures of the cells. Now, they have done some work at Stanford,

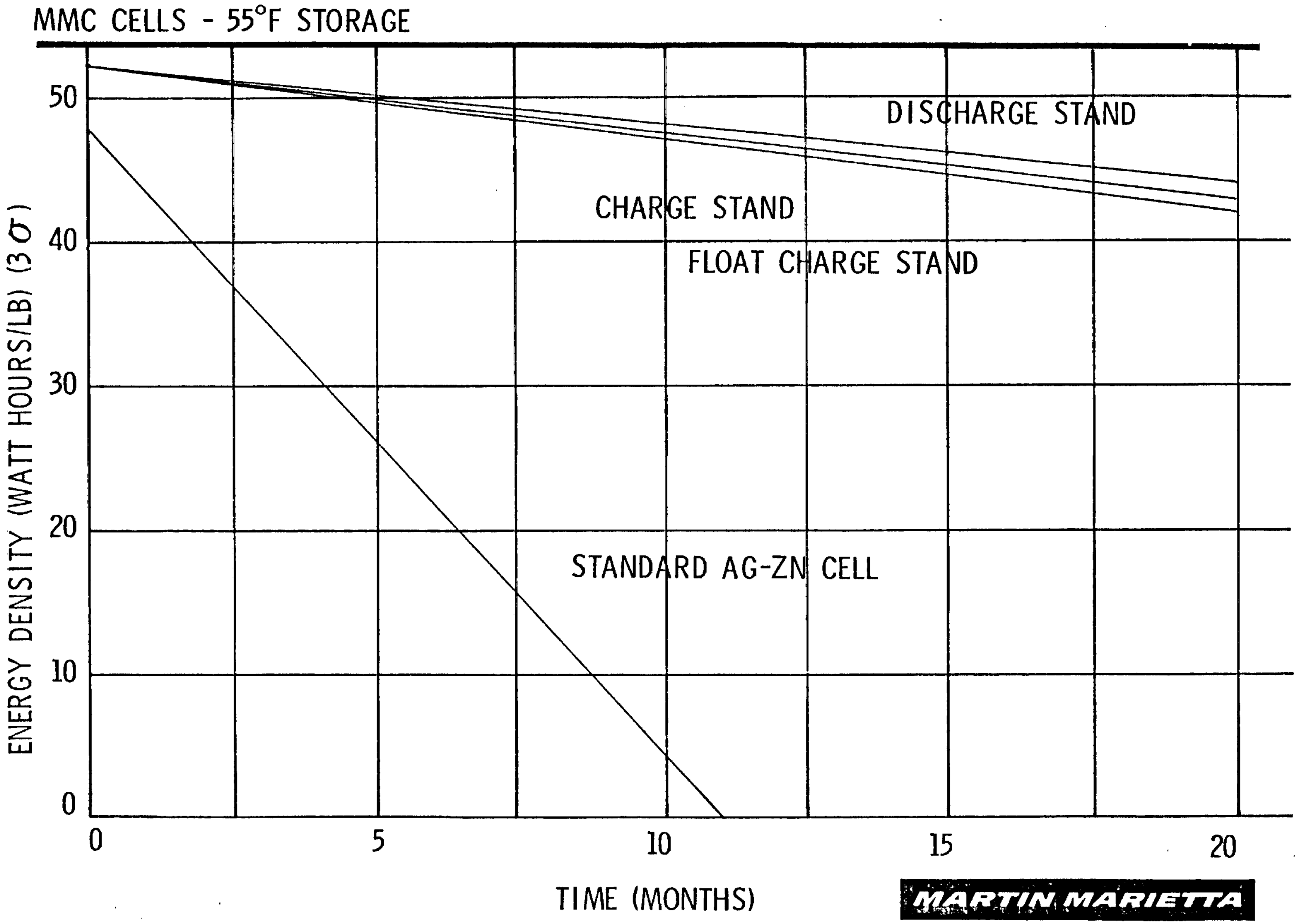

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Figure 9-30

STERILIZATION - AG ZN

CONTACT	COMMENTS
VERN BJORK - POWER SOURCES	NO STERILIZATION WORK
TOM HENNIGAN - GSFC	NOT TOO SUCCESSFUL, MECHANICAL PROBLEMS ON E.S.B. UNITS, NO WORK ON DRY CELLS.
JOHN BOZEK - LeRC	SUCCESSFULLY PASSED STERILIZATION (WET) (YARDNEY DESIGN - WORK AT STANFORD)
SANDY SEIDMAN - YARDNEY	SUCCESSFUL - POLYETHYLENE, ALSO PREDICT SUCCESS ON CERAMIC SEPARATOR CELLS.
JEFF WILSON - EAGLE PICHER	SUCCESSFUL - MECHANICAL SEAL BIGGEST PROBLEM
AL JORDAN - ESB	SUCCESSFUL ON VIKING TEST.

Figure 9-31

supported by Lewis, where they have beefed up the cell structure and have been able to solve some of that problem but it costs you quite a bit in energy density. No one who we talked to had done sterilization work on dry cells.

Long-life wet stand is discussed in Figure 9-32. We have found that we can get higher energy density for short periods of time but if we want them for any extended period of time, it drops off rather rapidly. Yardney has indicated that they are working on a ceramic separator cell that they are predicting will have a seven-year wet stand life. This would solve most of our headaches, but, unfortunately, we haven't got seven years to wait for them to prove it.

There is a great deal of difference of opinion as to whether or not there is in existence today a silver zinc cell that will last seven years in the dry stand to be activated after you get out there. (Figure 9-33). There are even concerns that you can put an active small secondary battery with it and have it work to activate the dry one when you get out there. Both McDonnell-Douglas and Martin have proposed a remote-activated battery for these deeper space probes but there are still a lot of problems that have got to be solved. It isn't something that we can say it is there, whenever we get around to using it we can use it. There are some problems that have got to be worked out. The one that comes up more frequently than anything else is that they don't know what happens in a vacuum with the plates. Some have mentioned that we ought to put some kind of an hermetic seal around it to avoid drying out the plates and the cracking that follows because you have got to band the plate edge so that when you go into the high-g forces, you don't tear them up.

So, those are just some points in passing. It is not a simple problem, it is not a solved problem, we have got to work it.

MR. TOMS: Thank you, Lloyd. Does anyone have questions for Lloyd? Bill Dixon?

LONG LIFE WET STAND - AG ZN

JOHN BOZEK - LeRC	LEAKAGE PROBLEM AFTER 21 MONTHS SOLVED BY MECHANICAL REDESIGN SOLVED PLATE SLOUGHING PROBLEMS.
EAGLE PICHER TEST @ MMC	40 WH/# @ 2 MO. 20 WH/# @ 7 MO.
MARTIN REDESIGN	40 WH/# @ 20 MO.
SANDY SEIDMAN - YARDNEY	WORKING ON CERAMIC SEPARATOR CELL THAT SHOULD HAVE 7 YEAR WET STAND LIFE. (For LeRC)

Figure 9-32

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LONG LIFE DRY STAND - AG ZN

JEFF WILSON - EAGLE PICHER	CONCERNED ABOUT PLATES DRYING, SHRINKING, AND CRACKING. (CAUSED BY BINDING OF PLATE EDGES TO WITHSTAND ENTRY g FORCES). NO VACUUM DATA AVAILABLE.
SANDY SEIDMAN - YARDNEY	7 YEAR DRY STAND LOSS, 25-30%. NO VACUUM PROBLEMS WITH HERMETICALLY SEALED OUTER CASE.
AL JORDAN - ESB	NEED SEALED CONTAINER TO AVOID VACUUM PROBLEMS. VACUUM EFFECTS UNKNOWN.
VERN BJORK - POWER SOURCE	NO PROBLEM WITH 7 YEAR DRY STORAGE.
BILL ROBERTSON - LeRC	NO PROBLEMS UP TO 8 YEARS DRY STORAGE.

Figure 9-33

DR. DIXON: Yes, I think there are a few points that he made that deserve some comment. This all has to do with the radiation portion of his talk. The first was I concur on the probe that the most significant part is the innermost L shell but I think with regard to the bus that goes by that is not necessarily true. Particularly if electrons are the problem rather than protons they seem to slope off more gradually with L shells. So, therefore, you are interested in things farther out for that purpose.

MR. THAYNE: Yes, my comments applied to the probe itself, and not necessarily to the bus. It's a whole new ball game when you are talking about the bus.

DR. DIXON: Also, with regard to the offset effect of the magnetic dipole, radiation fields are most likely symmetric with respect to the magnetic equator. It doesn't necessarily mean you want to land the probe on the side opposite the offset. You may want to land it on the other side and take advantage of a sweeping effect, sort of like the South Atlantic anomaly, it may lead to voids near the planet.

The third one has to do with the comment about the probe-orbiter mission. I think with the sort of probes we are talking about here, 350 pounds or so to Jupiter, we have shown that the Pioneer on the Titan launch vehicle can do both the probe and the orbiter missions.

MR. THAYNE: I think I agree with you if you talk about that size probe. My comments applied to the hundred-bar probe with the large shielding capability which is not in the three-hundred pound class but upwards of six-hundred to a thousand-pound class of deep-entry probe. If you get the probe small enough and the booster large enough, you can handle both or either problems. It is just a trade-off you have got to work.

MR. TOMS: Did Kane Casani want to make a remark?

MR. CASANI: Yes, I think your point about the battery life time, what happens to that battery during the seven years, is really going to be a problem. It is probably going to be one of the toughest problems that we are going to be confronted with on this probe. The thing I was wondering is, you showed a lot of data but you didn't show any specific energy numbers. What are we talking about in power densities of those batteries. Do you have any feel for that? What watt-hours per pound?

MR. THAYNE: You mean the earlier curves that I showed there?

MR. CASANI: On those last two you showed on wet and dry batteries.

MR. THAYNE: Okay. Right now for the wet batteries there is no way to predict how you would end up at seven years because we can't get much beyond two, if that, before we get total failure of the cells. And it looks like even without failures, it's sloping off to the point where you're down to maybe ten to fifteen watt-hours per pound for the wet cells.

For the dry ones, the bulk of the people that I talked to are projecting only five to ten-percent loss due to the seven-year stand. Some are projecting as much as twenty-five or thirty percent. You also get a projection of thirty to thirty-five percent due to sterilization, which, if you activate the battery while it's still on the bus, can be recovered by recharging the battery; so you can recover everything you lost in the sterilization of the dry cells in that mode. But if you use a remotely activated battery we are talking about twenty watt-hours per pound, because about half of the weight of the battery is going to be eaten up by the activation system. If you are lucky, you can micro-miniaturize it to that degree. We are talking of a forty watt-hour per pound battery and that much more weight in activation system.

MR. TOMS: Our next paper is concerned with the Jupiter radiation environment which an outer-planet probe will have to go through if it is on a Jupiter swing-by to Uranus. Ed Divita from JPL is going to talk about the kind of materials and hardware effects produced by the Jupiter radiation environment.