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September 6, 1984

Docket Nos. 50-348
50-364

Director, Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Attention: Mr. S. A. Varga

Joseph M. Farley Nuclear Plant - Units 1 and 2
Proposed Technical Specification Change
to D.C. Distribution System Requirements

Gentlemen:

Alabama Power Company submitted a proposed technical specification change related to the Auxiliary and Service Water Buildings Battery systems on May 3, 1983. The proposed Technical Specifications ensured compliance with FSAR battery load assumptions with margin, provided increased confidence of the batteries' operability and allowed time to correct certain battery conditions without undue plant shutdown. This change would update the Farley Technical Specifications to conform with the format of the most recent Westinghouse Standard Technical Specifications (NUREG-0452, Revision 4), current industry practice, and Farley specific design parameters. Since May of 1983 Alabama Power Company has made five (5) docketed submittals and held numerous telephone calls with the NRC Staff in an effort to support the review of this proposed technical specification change.

In May of this year, Alabama Power Company received a copy of an NRC Staff position for the surveillance of the Auxiliary and Service Water Building Batteries. This position was identical to the Westinghouse Standard Technical Specifications, which includes surveillance acceptance criteria which do not consider Farley specific design parameters. Alabama Power Company then provided, informally, the enclosed response which identifies each of the technical differences between the Standard Technical Specification and the Farley specific proposal and provides the technical justifications for Alabama Power

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Company's position. The technical justifications have been provided to and concurred with by the Auxiliary Building Batteries' manufacturer. The enclosed material and this letter are being provided in order to further facilitate the NRC review of the proposed technical specification change. This additional information, as well as the previous submittals which have been provided subsequent to the May 3, 1983 letter, were submitted to substantiate the variances from the Standard Technical Specifications based on Farley specific design parameters. Such submittals, however, have only provided additional justification and have not materially changed the originally submitted proposed change.

If there are any further questions, Alabama Power Company is prepared to discuss the technical issues of this proposed change, at the NRC Staff's convenience, in a meeting in Bethesda, Maryland.

Yours very truly,

R. P. McDonald

RPM/CJS:ddb-D6
Enclosure
cc: Mr. L. B. Long
Mr. J. P. O'Reilly
Mr. E. A. Reeves
Mr. W. H. Bradford

Specific Comments - Battery Technical Specification Change

The proposed battery surveillance requirements are included in Enclosure 1:

1. NRC Proposed Change

   Float Voltage for Category A Limits and Category B Limits should be 2.13 volts vice 2.02 volts and so indicated in T.S. Table 4.8.2.

   APCo Response

   The existing Technical Specifications requires a minimum float voltage of 2.02 volts. APCo proposed a float voltage of 2.07 volts in a submittal to the NRC dated May 3, 1983 based upon the guidance of IEEE Standard 450-1980. In accordance with discussions with the NRC Staff, APCo resubmitted, in letter dated January 27, 1984, Table 4.8-2 designating 2.02 volts as the float voltage limit based on the original Technical Specification criteria.

   The purpose of the battery technical specifications is to ensure that the batteries can perform their design function (i.e., provide a specified current discharge for two hours). Failure to comply with the battery technical specification results in shutdown of one or both Farley units within two hours. Technical Specifications should therefore define the minimum acceptable functional requirements rather than long-term optimization practices. APCo is committed to utilizing internal procedures to optimize battery performance.

   APCo's purpose in pursuing this technical specification change was to obtain a reasonable indicator of battery and battery cell degradation. The IEEE Standard 450-1980 float voltage criteria of 2.13 volts was not originally proposed because this criteria is based on optimizing long term life expectancy rather than determining battery degradation. APCo's current practice designates the "worst cell" as the pilot cell for Category A testing. Based on the worst case pilot cell, a Category A and B limit value of greater than or equal to 2.08 volts with an additional requirement that the average float voltage of the battery cells be greater than or equal to 2.13 volts is therefore recommended.

   Utilizing a Category A and B limit of less than 2.13 volts is justified because (1) cell voltage is not, by itself, a comprehensive indication of the state of charge of the battery, (2) a single cell (pilot cell) can have a degraded voltage (less than 2.08) and the battery as a whole can still perform its design function as discussed in the bases of the Standard Technical Specifications, and (3) IEEE Standard 450-1980 does not consider a battery to be potentially degraded unless its voltage drops below 2.07 volts.

Specific Comments

Farley would have experienced problems complying with the NRC proposed voltage criteria of 2.13 volts over the past four years. Evidence of this is provided by battery cell data taken for this period of time for the six battery sets. This data, taken monthly, indicated that in twenty cases the presence of at least one cell with a voltage below 2.13, with 2.10 volts to 2.11 volts being the predominant values. The low cells were scattered randomly throughout the battery sets.

Cell voltages of less than 2.13 volts under normal float charge are, therefore, not an unusual occurrence, and based on Farley experience, have certainly not indicated inoperability of an entire battery. In the 20 cases where at least one cell was below 2.13 volts, the minimum average specific gravity was 1.197 on a 1.210 battery. A specific gravity of 1.197 equates to a capacity of approximately 90% of the batteries capability which is well above that required by the FSAR load profile. Also, in every case equalization restored the battery cell voltages to within normal balance criteria. Equalization at Farley takes from 72 to 200 hours, being restricted by d-c coil voltage limitations of 138 volts.

The susceptability of lead calcium battery cells to variations in float voltage as compared to lead antimony and the reasons for this characteristic are provided in Attachments 1 and 1A which depicts Gould lead calcium cell voltage characteristics and typical lead calcium and lead antimony characteristics. For a Gould lead calcium cell of 1.215 specific gravity, a cell float voltage of 2.2 volts is obtained at a float charge of 5.5 milliamps/100AH. For lead antimony (new battery) this value is typically 63 milliamps/100AH while for an older battery it is over 400 milliamps/100AH. A small change in float charging current of only 3.2 milliamps/100AH on lead calcium cells (e.g., caused by slight battery case leakage due to dust, miscellaneous contamination, or an acidic condition), can cause a cell voltage to drop .1 volts from 2.2 to 2.1 cell voltage. This is below the NRC Proposed value of 2.13 volts and would require, if the NRC value is adopted, APCo to initiate immediate corrective action to equalize voltage. Based on experience at Farley, this is not an indication of a discharge condition, but rather simply a variation in float voltage. Further, the steep slope of the TAFEL Lines of Lead Calcium, shown in Attachment 1 and 1A and comparison of lead calcium and lead antimony float current requirements suggest that lead calcium cells will have a wider float voltage variation per cell than older type batteries (particularly in actual plant environments).

Further discussion of lead calcium float voltage variations is provided in Attachment 2, a paper by Robert N. Alexander, President of South Western Battery Company. This paper supports lead calcium float voltage imbalance as a common characteristic of lead calcium batteries.

Specific Comments

Table 4.8-2 (Enclosure 1) contains voltage individually as a criteria for action. The values selected then must credibly delineate where battery capacity or operatility is in question. From Farley's experience it is apparent that 2.13 volts does not meet this requirement. Neither does 2.10 volts since at this value batteries have been completely operative with, in the 20 cases, a minimum of 90% capacity. Therefore, a value lower than 2.10 volts is indicated as being appropriate.

Using Attachment 1, which is applicable to the Farley batteries, negative plate polarization ceases at approximately 2.16 volts and positive plate polarization ceases where no current enters the battery at the open circuit voltage of 2.055 volts. As discussed in Attachment 3, at a positive plate polarization of not greater than 25 millivolts, accelerated positive plate corrosion takes place. Such corrosion seriously degrades battery life if allowed to continue. This value is 2.055 volts, open circuit voltage, plus .025 volts polarization for a total of 2.08 volts. Since this is a value which is critical to overall battery operation, APCo maintains that 2.08 volts is the voltage below which corective action is required. A value greater than or equal to 2.08 is therefore selected by APCo for limits in Category A and B. It should be further noted, however, that even though a cell may be in jeopardy for the long term at 2.08 volts, the capacity of the battery is still not known until specific gravity is measured. Cell voltage and specific gravity in combination are, in APCo's opinion, accurate indicators of battery condition whereas cell voltage alone is not.

In conclusion, a Category A and B limit of greater than or equal to 2.08 volts with an additional requirement that the average float voltage be greater than or equal to 2.13 volts are considered not only more appropriate float voltage limits, but are enhancements from the existing 2.02 float voltage limit. These limits, considered in conjunction with specific gravity criteria discussed below, are more than adequate to ensure battery operabilty and capacity.

Specific Comments

2. NRC Proposed Change

Float Voltage for Category B Allowable Value should be 2.02 volts.

APCo Response

The NRC Staff and APCo agree on the Category B allowable float voltage value.

3. NRC Proposed Change

Specific Gravity for Category A and B Limits should be 1.200 and 1.195, respectively, with the additional requirement that the specific gravity for the average of all connected cells be greater than or equal to 1.205.

APCo Response

NRC Proposed Category A and B Specific Gravity Limit Values of 1.200 and 1.195 vs APCo Proposed Values of 1.195 and 1.190

The existing Technical Specifications require a limit, as approved by the NRC, of 1.190 because the Technical Specification limit serves two (2) different batteries (Auxiliary Building and Service Water). These batteries were supplied by different manufacturers and have different recommended specific gravities. For human factors concerns, APCo prefers to maintain a single Technical Specification limit for both batteries.

The scope of Standard IEEE 450-1980 states that it is limited to providing recommended practices, including acceptance criteria, to optimize the life and performance of large lead storage batteries. Specific gravity and the frequency of inspections of the batteries are important ingredients in the optimization of battery performance. As a result, the IEEE Standard proposed frequencies of inspections and associated acceptance criteria are such that the specific gravity will not degrade between inspections. In the judgement of APCo, if the frequency of inspections had been increased, then the established limit values could have been lower. APCo currently performs the IEEE-450 quarterly inspection for each battery cell every 31 days. This is three (3) times as frequent as either technical specifications or the IEEE Standard require; therefore, the proposed specific gravity values are considered conservative for the Farley Nuclear Plant.

Specific Comments

The APCo proposed limits can be further justified based upon the margin within the batteries. Supporting information for the margins described below are included in Attachment 4. There is greater margin for the Service Water Building battery than the Auxiliary Building battery; therefore, only the Auxiliary Building battery is discussed below.

A fully charged Auxiliary Building battery has a specific gravity of 1.215. With this specific gravity, there is approximately a 40% margin between the Auxiliary Building battery capacity and the FSAR assumed loads. The APCo proposed values of 1.195 and 1.190 for the Category A and B limits are conservative for Farley since the 1.190 specific gravity value represents a margin of greater than 10 percent and 1.195 represents a 16 percent margin to the battery capacity when discharged at the FSAR required loads. Recognizing that it is the "worst" cell that is considered the pilot cell, and that the APCo proposed Category A value has been increased from the existing 1.190 value to 1.195, in all likelihood each cell would be above the APCo proposed Category B limit of 1.190. This, in conjunction with the average limit of 1.195 discussed below, guarantees that the battery would have an actual margin of greater than or equal to 16% which represents a 6% increase over existing T.S. requirements.

The margins for 1.190 and 1.195 specific gravity values are conservative since they assume that the battery is discharged at the FSAR rate to arrive at the beginning specific gravity of 1.190 and 1.195. These margins include a penalty for "depletion", the seriousness of which is proportional to the discharge rate. More specifically, should discharge occur during operation, it is expected that the rate of discharge would be much less than the FSAR discharge rate. Therefore, the specific gravity values of 1.190 and 1.195 represent more battery capacity under actual operating conditions than the above 16% and 10% margin estimates.

NRC Proposed Category B Average Specific Gravity Limit Value of 1.205 vs APCo Proposed Value of 1.195

The NRC proposes that the specific gravity for the average of all connected cells be greater than or equal to 1.205. APCo proposes that the specific gravity be 1.195 which is based on the FSAR required loads plus an adequate margin of 16%. The minimum average specific gravity to meet the FSAR loads is approximately 1.181 as shown in Figure 2 of Attachment 4.

Additionally, bringing the average of all cells up to 1.205 is not required to meet FSAR loads as described above. Therefore, the APCo proposed specific gravity of 1.195 for the average of all connected cells is adequate because it exceeds the value required to meet the FSAR requirements with sufficient margin.

4. NRC Proposed Change

Category B specific gravity should have an allowable value of 1.205 for individual cells and an average value for all connected cells of 1.195. The NRC also proposed changing the cell allowable variance from .080 to .020.

APCo Response

NRC Proposed Category B Allowable Specific Gravity Value 1.205 vs APCo Proposed Value of 1.190

The NRC proposes to change APCo's Category B allowable specific gravity of 1.190 to 1.205. The 1.190 value proposed by Alabama Power Company is the currently existing value in the Farley Technical Specifications. The 1.190 value provides a margin of over 10% above the FSAR design loads as discussed in the above response to NRC Proposed Change #3. Also stated in this response and applicable to this concern is the argument that the more frequent inspection intervals of APCo exceed the requirements of IEEE Standard 450-1980, and therefore the more stringent limits of the IEEE Standard need not apply.

Additionally, IEEE Standard 450-1980 is predicated on the assumption that the values provided therein are indicators of when corrective action is recommended to be taken to optimize battery performance not when a battery is to be determined inoperable. Technical specification values should be the minimum required values for operability, not recommended optimization practices since the technical specifications require plant shutdown in 2 hours when batteries are declared inoperable. The corrective action recommended by IEEE Standard 450-1980 for reduced specific gravity of individual cells is to equalize the cells. This process, developed by the battery manufacturer, requires from 35 to 180 hours; this period is significantly longer than the two (2) hours permitted by the technical specifications before one or both of the units must be shut down. The technical specification Category B allowable value for specific gravity should therefore be 1.190 to allow battery cells to be equalized rather than needlessly replaced due to an overly restrictive technical specification limit of 1.205.

Specific Comments

NRC Proposed Category B Allowable Average Specific Gravity Value of All Connected Cells of 1.195 vs APCo Proposed Value of 1.190

The NRC proposes to change the Category B allowable average specific gravity for all connected cells from 1.190 to 1.195. APCo proposes that this value remain 1.190. An average specific gravity value of 1.190 for all connected cells ensures that the battery as a whole will perform its design function with margin (10%) when compared to the FSAR required loads. The minimum required specific gravity to meet the FSAR assumed loads is 1.181.

NRC Proposed Category B Specific Gravity Allowable Variation Value of 0.020 vs APCo Proposed Value of 0.080

The NRC proposal for changing .080 to .020 has been interpreted by Alabama Power Company to mean a change of the surveillance to read:

".020 below the average of all connected cells"

The NRC proposal to change the 0.080 specific gravity value to 0.020 is acceptable to APCo if the wording of the criteria is modified to read:

".020 below the allowable average (1.190) of all connected cells"

The allowable average of all connected cells has been shown in the previous response to NRC Proposed Change #3 to have sufficient margin above the FSAR required loads (greater than 10% margin for a specific gravity of 1.190). Use of the "average of all connected cells" instead of the "allowable average" would involve unnecessary replacement of cells when only an equalization charge is required.

CJS:ddr-D8

ENCLOSURE 1

MAY 3, 1983 SUBMITTAL

TABLE 4.8-2

BATTERY SURVEILLANCE REQUIREMENTS

	CATEGORY A (1)	CATEGORY B	
Parameter	Limits for each designated pilot cell	Limits for each connected cell (2)	Allowable (3) value for each connected cell
Electrolyte Level	>Minimum level indication mark, and ≤ 1/4" above maximum level indication mark	>Minimum level indication mark, and ≤ 1/4" above maximum level indication mark	Above top of plates, and not overflowing
Float Voltage (4)	≥ 2.07 volts ≥ 2.02 (1-27-84) ~~≥ 2.13 (NRC PROPOSED)~~ ≥ 2.08 (APCO PROPOSED)	≥ 2.07 volts ≥ 2.02 (1-27-84) ≥ 2.13 (NRC PROPOSED) ≥ 2.08 (APCO PROPOSED)	> 2.02 volts
Specific Gravity (a)	≥1.195 (b) ≥1.200 (NRC PROPOSED)	≥ 1.190 ≥ 1.195 (NRC PROPOSED) Average of all connected cells > 1.195 > 1.205 (NRC PROPOSED)	If a cell is less than 1.190, then it shall not have decreased more than .080 from the value observed in the previous 92 day test. [1.190 → 1.205 (NRC PROPOSED); .080 → .020 (NRC PROPOSED)] Average of all connected cells ≥ 1.190 ≥ 1.195 (NRC PROPOSED)

(a) Corrected for electrolyte temperature of 77°F.

(b) Or battery charging current is less than 2 amps when on float charge.

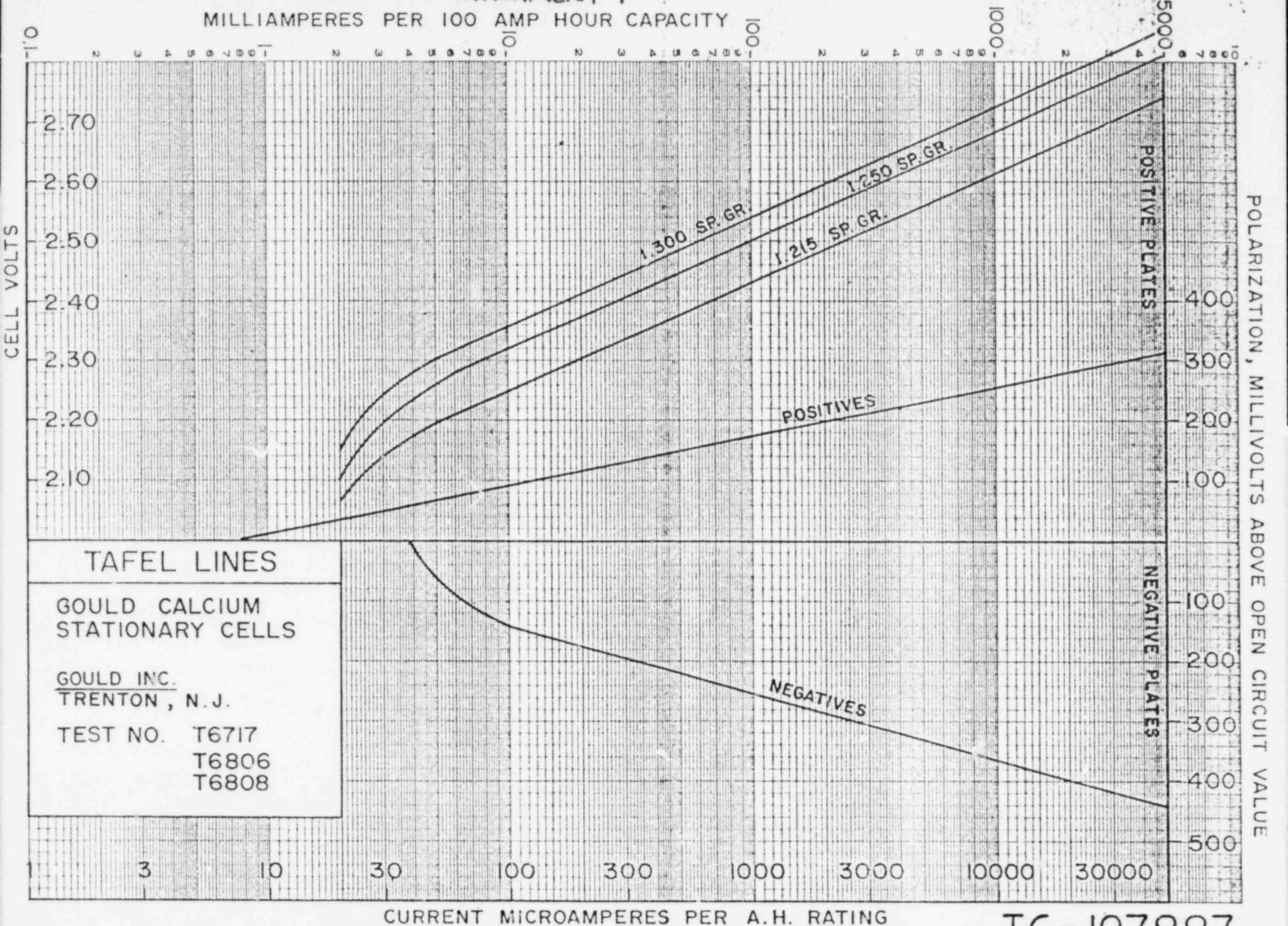
(1) For any Category A parameter(s) outside the limit(s) shown, the battery may be considered OPERABLE provided that within 24 hours all Category B measurements are taken and found to be within their allowable values, and provided all parameter(s) are restored to within Category B limits within the next 6 days.

(2) For any Category B parameter(s) outside the limit(s) shown, the battery may be considered OPERABLE provided that they are within their allowable values and provided they are restored to within limits within 7 days.

(3) Any Category B parameter not within its allowable value indicates an inoperable battery.

(4) The average cell float voltage shall be greater than 2.13 volts in order for the battery to be considered operable. (APCO PROPOSED)

ATTACHMENT 1



TAFEL LINES

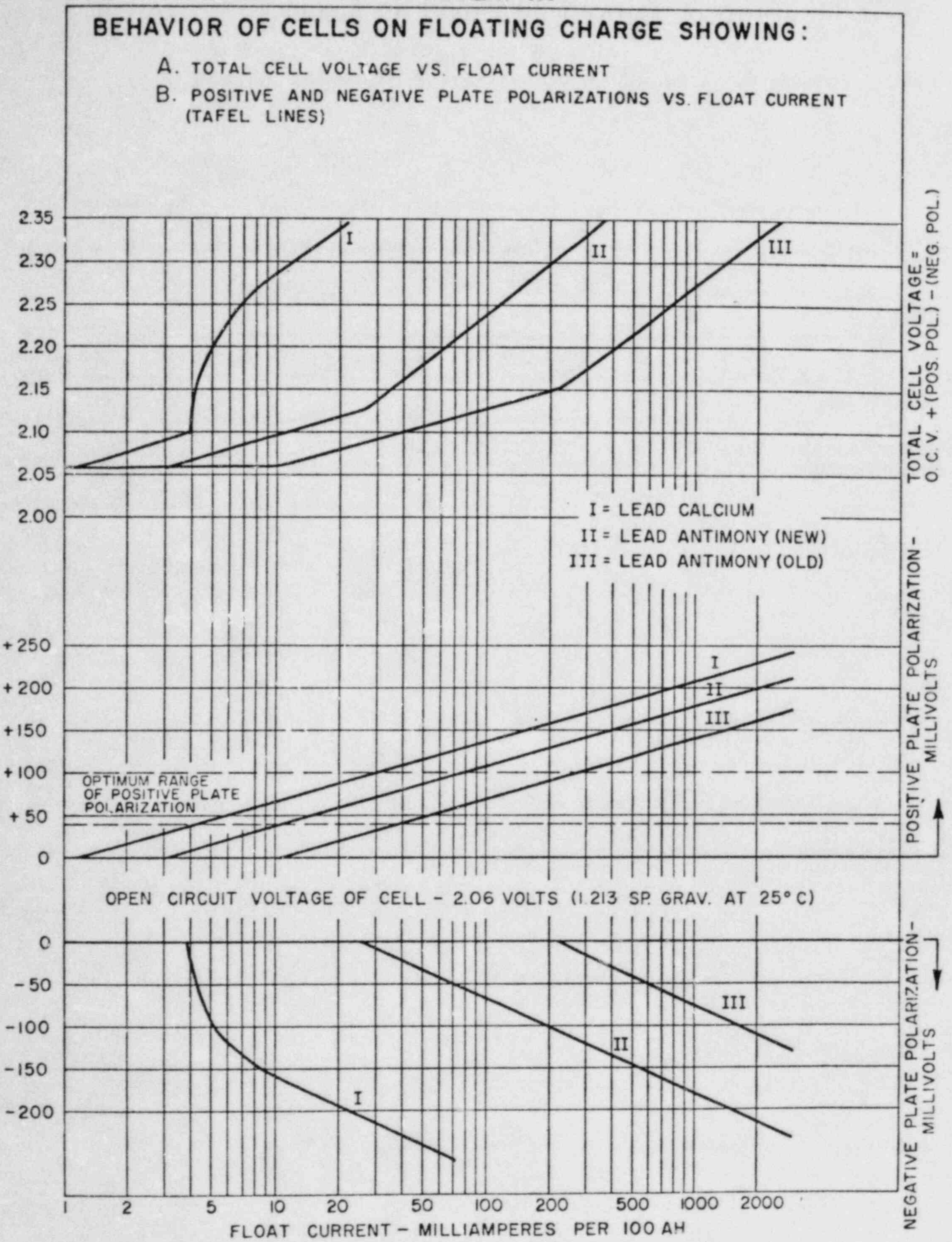
GOULD CALCIUM STATIONARY CELLS

GOULD INC.
TRENTON, N.J.

TEST NO. T6717
T6806
T6808

REV. A DATE: 8-8-78

TC-107887


BEHAVIOR OF CELLS ON FLOATING CHARGE SHOWING:
A. TOTAL CELL VOLTAGE VS. FLOAT CURRENT
B. POSITIVE AND NEGATIVE PLATE POLARIZATIONS VS. FLOAT CURRENT (TAFEL LINES)
2.35
2.30
2.25
2.20
2.15
2.10
2.05
2.00
I
II
III
TOTAL CELL VOLTAGE = O.C.V. + (POS. POL.) - (NEG. POL.)
I = LEAD CALCIUM
II = LEAD ANTIMONY (NEW)
III = LEAD ANTIMONY (OLD)
+250
+200
+150
+100
+50
0
OPTIMUM RANGE OF POSITIVE PLATE POLARIZATION
POSITIVE PLATE POLARIZATION - MILLIVOLTS
OPEN CIRCUIT VOLTAGE OF CELL - 2.06 VOLTS (1.213 SP. GRAV. AT 25° C)
0
-50
-100
-150
-200
NEGATIVE PLATE POLARIZATION - MILLIVOLTS
1
2
5
10
20
50
100
200
500
1000
2000
FLOAT CURRENT - MILLIAMPERES PER 100 AH

Attachment #2

idea probably arose from two sources:

1. When the lead-calcium battery is charged only a tiny float current will pass through it, even at elevated float voltages. Lead-antimony takes much more current at the same float voltages. The reason is the electrochemical development of the countervoltages of the two batteries, and has nothing to do with ohmic resistance. The behavior on float of lead-calcium resembles in some ways that of a "sulphated" battery, whose high countervoltage *is* developed from ohmic resistance. However, a "sulphated" battery on charge gasses heavily, while a calcium battery does not. The term "sulphated" is used in the vernacular, meaning a condition where a discharged battery has been allowed to stand until lead sulphate particles have become hard and crystalline.

2. The earliest lead-calcium batteries were made for telephone service exclusively, and were mechanically designed for maximum ampere-hour capacity at low rates of discharge without regard to one minute ratings. They had slightly higher internal resistance than other batteries specifically designed for switchgear service. This, however, is entirely a matter of mechanical design, and lead-calcium batteries designed for switchgear and even engine cranking service have been available for many years.

"Grids Corrode Faster than Antimony"

False. A properly manufactured lead-calcium positive grid corrodes at about 1/3 the rate of lead-antimony on test, and at 1/4 to 1/5 the rate of lead-antimony in service. *However*, if the lead-calcium grid is poorly made, it *can* corrode faster than its lead-antimony opposite number. Too high a calcium content, poor quality castings, or castings by high pressure methods into a relatively cool mold (die casting) can cause a high corrosion rate for lead-calcium alloys.[10] The techniques employed by the manufacturer are the determining factor.

The idea that lead-calcium corrodes more rapidly may have come from observations of older batteries of this type where some growth of the positive plates is apparent. This situation is normal, and a well designed lead-calcium battery has room to accommodate moderate positive plate growth. About 10% growth should be anticipated during the total life of the battery. As a battery remains in service, lead dioxide corrosion product builds up on the surfaces of its positive grids, which occupies more space than the base lead from which it was formed. In consequence, the corrosion product exerts an expansive force on the grid. The response to this force differs between lead-calcium and lead-antimony alloys. Both alloys have similar tensile strengths, but the antimony alloy tends to be brittle, while the calcium alloy is more ductile. The result is that under the pressure of the corrosion product, lead-antimony alloy cracks and breaks, while lead-calcium stretches.

Another possible source of this misunderstanding is that lead-calcium resembles pure lead and pure lead is used for the rosettes sometimes called "*corroding buttons*" which are pressed into the lead-antimony grid of the Manchester positive plate. "Therefore", the reasoning goes, "pure lead (or lead-calcium) must corrode more rapidly than lead-antimony". The fallacy is that most of the corrosion on the "corroding buttons" does not come about during float service. It is put there at the factory by first *chemically* corroding the lead with nitrates or chlorides, then by electrolytically converting this corrosion product to lead dioxide.

"Can't Be Cycled"

This is untrue. While the vast majority of lead-calcium batteries are built for floating service where they are not cycled frequently, there is no reason why they cannot be built for strictly cycling service.[8] This again is entirely a matter of mechanical design, a cycle service battery being considerably different from a floating service battery.

"Cells Won't Float Right"

This derives from the fact that lead-calcium cells in a battery exhibit wider variations in individual voltages than do antimony. The concern would be valid if the variations observed among calcium cells had the same meaning as they have for antimony. Fortunately, they do not.

No two cells of any battery are precisely identical. There are small differences in rates of self-discharge, and in traces of lead sulphate remaining in the plate pores. The lead-calcium battery on float is an excellent indicator of these minor and insignificant variations, while the lead-antimony battery is not.

Referring to Figure 5, it can be seen that within the float voltage range (2.17 to 2.25 volts/cells) a variation of a few milliamperes per 100 A.H. in float current will produce very large changes in cell polarization for the lead-calcium cell, while this same change in cell voltage with respect to current will be scarcely observable in the lead-antimony cell. The wide variations between cell voltages in a lead-calcium battery will be most pronounced following a recharge, when a few traces of lead sulphate remain in some of the cells. This situation, however, is completely harmless to the battery and will gradually correct itself.

A voltage variation problem is apt to occur if a lead-calcium battery is allowed to stand several months prior to installation. Lead sulphate particles remaining in the plates following manufacture, plus those produced by self-discharge, tend to clump together forming hard crystals which are not easily broken down by the float current. The response to charging current will vary among cells, creating fairly wide voltage variations. The actual amount of lead sulphate involved is very small, and generally harmless to the battery capacity, but years may pass before cell voltages stabilize. This situation is not a major problem, but it is annoying, and should be

avoided. The extremely low self-discharge rate of lead calcium cells offers a temptation to leave them off charge if lengthy construction delays occur; but in this instance, it is well to treat them with the same respect accorded lead-antimony batteries.

"Must Be Floated At A Much Higher Voltage Than Antimony"

Lead-calcium *can* be floated at higher voltages than lead-antimony without the damage that would be caused to lead-antimony at these voltage levels; however, lead-calcium doesn't have to be floated at a voltage significantly higher. The float range of the lead-antimony cell is 2.15 to 2.17 volts per cell, while the same range for lead-calcium is 2.17 to 2.25 volts per cell.

The source of the misunderstanding may be that the lead-calcium battery, when floated at 2.20 volts per cell or above will not require equalizing charges. It has been found that the float current passing through the battery at this voltage level is sufficiently high to cover the normal range of self-discharge variations among the cells. Users whose equipment can tolerate this slightly increased voltage may enjoy freedom from the chore of equalizing, and generally take advantage of this bonus.

A real problem existed with some of the earlier lead-calcium batteries floated at 2.17 volts per cell, when meter calibration error or charger voltage drift allowed the actual float voltage to fall to 2.15 volts/cell or lower. At this voltage level, there was not enough current passing through the battery to maintain the polarization of the positive plates above the required 40 millivolts, and there was difficulty keeping these positives charged. Because of this, modifications were made to the batteries causing a slight increase in current at lower float voltage levels, such increase being sufficient to maintain adequate polarization on the positive plates, and to make floating at 2.17 volts/cell safe and much less critical.

V. A FIFTY YEAR BATTERY?

In the autumn of 1967, Willihnganz of C & D Batteries presented a paper before the Electrochemical Society describing a method whereby batteries could be tested for life characteristics at an accelerated rate.[11] The method made use of the Arrhenius equation which in practical effect states that the rate of a chemical process doubles for each 10° C. rise in temperature. Willihnganz's method provides an extremely useful tool for the battery engineer who formerly had a wait of 15 to 20 years before the success or failure of his design could be told; moreover, the tests provided some highly interesting data concerning lead-calcium batteries, past and present.

In an effort to determine how well life as predicted by the accelerated test method correlated with actual field experience, laboratory personnel examined a significant proportion of lead-calcium batteries which had been in actual service for 15 years, and predicted probable life for a large majority of these batteries in excess of 20 years. The accelerated test method had predicted a life of from 20 to 25 years for these batteries produced in 1951, thus correlating excellently.

What is most significant is that the same accelerated test method, when applied to cells being manufactured in 1967, predicted in most cases a life span *in excess of 50 years*, suggesting that a great amount of progress had been made in lead-calcium battery technology.

The idea of a battery lasting 50 or more years is hard to digest; it would mean that during its use, both maker and user of the battery would spin out their working lives. Further, the equipment the battery operated would probably become obsolete long before battery failure.

It should be borne in mind that this 50 year life prediction is a mathematical extrapolation, however well the extrapolation agrees with performance over the last 20 years. It is moreover, based on the product of only one manufacturer, who is not claiming such life. Not all batteries would last 50 years, even if they possessed the potential. Adverse operating conditions and simple manufacturing errors would preclude this. Nonetheless, the distinct possibility, perhaps even the probability, exists that the 50 year battery is now in common use without being so acknowledged. Certainly a 30-year life for a well-made lead-calcium battery can be confidently and conservatively predicted.

Assuming that Willihnganz's extrapolations are valid, the lead-calcium battery should make possible some developments in the battery industry which will be of great benefit to the user. Among these are:

1. A battery of 50-year life, of great economic benefit to users such as large telephone companies whose equipment loads will probably continue increasing. As load grows, paralleled batteries could be added without the necessity of replacing earlier strings.

2. A battery of 20 to 30 year life, meeting the needs of most users whose equipment would become obsolete or its location changed at about this age. Such a battery could be provided using thinner grids at lower cost, and providing the same electrical characteristics in a smaller space and with less weight.

3. Maintenance free automobile batteries lasting 5 or 6 years, using thin grids with higher relative electrolyte capacity.

4. Batteries tailored to meet almost any age and maintenance requirement, at a cost consistent with the application.

sideration of float operation. They refer, of course, only to a "typical" lead-calcium cell design, the characteristics of which are representative of one type of cell suitable for this kind of service.

III. CELL BEHAVIOR, PARAMETERS FOR TYPICAL LEAD-CALCIUM CELLS

When a constant float voltage, V_f, is maintained across a cell, it is the cell polarization which is controlled. This is given by $\eta_{cell} = V_f - V^{o.c.}_{cell} = \eta_+ - \eta_-$ and is related to the float current I_f which flows through both positives and negatives by equations (15) and (16). Thus, specification of V_f and the plate parameters determines the condition of the cell during float operation. While the discussion here deals only with the steady-state, it is clear that a cell inadequately maintained in these circumstances will be no better maintained in actual use. From the previous section, adequate maintenance of positive plates is considered to require $\eta_+ > 25$ mV so that grid corrosion is not accelerated. Adequate maintenance of the negatives requires only that $\eta_- < 0$, but in both cases, some margin is obviously desirable.

Attachment 3

The quantities of principal interest, then, are I_f, η_+, and η_-. In the light of the previous discussion, these are taken to be determined by the parameters I^0_{o+}, I^0_{o-}, I^0_d, T, and V_f. In all of the calculations, b^0_+, b^0_-, and I_c are assumed invariant and, together with the temperature dependent factors, are assigned the values given earlier. I^0_{o+}, I^0_{o-}, and I^0_d depend on design and method of manufacture and can vary considerably. Cells with values lying within the limits given for the "typical" cell of the previous section are described in the following as "normal range" cells. As a point of reference, a cell with mid-range values of these parameters is hereafter described as a "median" cell. Temperature and float voltage depend, of course, on conditions of use and can also vary. Standard conditions, as in the Bell System, are taken here to be 25°C and 2.170 V/cell.

For a given set of parameters, I_f and then η_+ and η_- can be calculated from equations (15) and (16), taking into account two restrictions:

(i) η_+ must be positive or zero and η_- must be negative or zero. Solutions giving negative η_+ or positive η_- are physically inadmissible, for in reality the charge-discharge reactions poise the plate potentials at zero polarization and the plates then discharge. At $\eta_+ = 0$, the net discharge rate of the positive is $I_f - I_{o+} - I_c$; at $\eta_- = 0$, that of the negative is $I_f + I_{o-} + I_d$.

(ii) The rate of oxygen reduction at the negative cannot exceed the rate of oxygen evolution at the positive; that is, $-I_d$ can be no greater than $I_f - I_c$ or, when $\eta_+ = 0$, I_{o+}. Solutions for which this is not so are also physically inadmissible; instead, I_d can be assumed to become approximately equal to $I_c - I_f$ or I_{o+}. In the case of the former, from equation (14), the negative polarization becomes independent of I_f.

The following results are by no means all-inclusive but indicate, instead, some of the effects to be expected.

3.1 *Median Cell, Standard Float Conditions*

$I^0_{o+} = 7.5\ \mu A/Ah$, $I^0_{o-} = -7.5\ \mu A/Ah$, $I^0_d = -27.5\ \mu A/Ah$, $V_f = 2.170$ V/cell at 25°C. In this case,

$$\eta_{cell}/mV = 2170 - 2061 = 109,$$

$$= 70 \log [(I_f - 4)/7.5] + 110 \log [(I_f - 27.5)/7.5],$$

and $I_f = 50.5\ \mu A/Ah$, $\eta_+ = 55$ mV, $\eta_- = -54$ mV. This represents, more or less, the average behavior of a "typical" or, perhaps more accurately, a desirable cell. Both plate polarizations are good and float operation should be most satisfactory under these conditions.

3.2 *Normal Range Cells, Standard Float Conditions*

$I^0_{o+} = 5\text{–}10\ \mu A/Ah$, $I^0_{o-} = -(5\text{–}10)\mu A/Ah$, $I^0_d = -(20\text{–}35)\mu A/Ah$, $V_f = 2.170$ V/cell at 25°C. The ranges in the following tables correspond to the range in I_{o+}, 5–10 $\mu A/Ah$.

$I_f/(\mu A/Ah)$	$I^0_d = -20\ \mu A/Ah$	$I^0_d = -35\ \mu A/Ah$
$I^0_{o-} = -5\ \mu A/Ah$	35.3–41.2	47.4–52.8
$I^0_{o-} = -10\ \mu A/Ah$	45.5–54.8	56.8–65.7

η_+/mV	$I^0_d = -20\ \mu A/Ah$	$I^0_d = -35\ \mu A/Ah$
$I^0_{o-} = -5\ \mu A/Ah$	56–40	66–48
$I^0_{o-} = -10\ \mu A/Ah$	64–49	72–55

η_-/mV	$I^0_d = -20\ \mu A/Ah$	$I^0_d = -35\ \mu A/Ah$
$I^0_{o-} = -5\ \mu A/Ah$	−(53–69)	−(43–61)
$I^0_{o-} = -10\ \mu A/Ah$	−(45–60)	−(37–54)

In all cases the plate polarizations are adequate and float operation should be satisfactory under the standard conditions.

3.3 *Median Cell, Standard Float Voltage, Varied Temperature*

$I^0_{o+} = 7.5\ \mu A/Ah$, $I^0_{o-} = -7.5\ \mu A/Ah$, $I^0_d = -27.5\ \mu A/Ah$, $V_f = 2.170$ V/cell at 5, 15, 25, 35, and 45°C.

Attachment 4
Supporting Information For Battery Margin

1. The Auxiliary Building battery FSAR Discharge load (FSAR 8.3.2.1.1) is equal to:

   (430 Amps x 117 mins/60 min/hr) + (920 amps x 3 mins/60 min/hr) = 884.5 amp-hrs.

   which is divided by the required discharge period of 2 hours to obtain required Amperes. (884.5/2) = 442.25 amperes required.

2. Using the manufacturer's discharge curve for the NCX-1800 (See attached Figure 1, Typical Discharge Characteristics of NCX-1800) and the average discharge rate of 442 amps, the total amp hours available is 1440. The availability of 1440 amp-hrs in the battery is obtained by selecting 442 on the "X" axis, extending vertically until the 1.75 volt (FSAR 8.3.2.1.1) line is intersected, and then extending left horizontally to the "Y" axis where Amp-Hrs. (AH) is read as 1440. Note that the 442 amps is an average discharge rate. We consider this to be a conservative (on the high side) rate since battery characteristics are such that the lowest discharge rate, 430 amps in this case, should be used which would provide for a capacity total of over 1440 AH by using the same process as before, only starting at 430 amps on the "X" axis.

3. The FSAR loads are therefore equal to 61% of the Auxiliary Building Batteries Capacity and therefore there is approximately a 40% margin within the battery.

   884.5 Amp-hr./ 1440 Amp-hr. = .61 x 100 = 61% capacity

4. It should be noted that while a battery is being constantly discharged, even at a varied rate, the relationship of amp-hrs discharged to specific gravity is a straight line. This is verified by the manufacturer. Therefore, specific gravity at the 100% capacity line of 1440 AH can either be calculated or obtained by extension of the actual test data line, which is done in our case. The average beginning and ending specific gravities for 10 service tests exactly duplicating the FSAR loads were 1.216 and 1.163, respectively.

5. The FSAR Discharge Rate on Specific Gravity vs. Percent Discharge Graph was plotted (Figure 2) by drawing a line beginning at 1.216, the specific gravity value at 0% discharge, and ending at 1.163, the specific gravity where the battery is 61% discharged. Extending the straight line to the 100% discharge point (1440 AH) gives a specific gravity of 1.128.

6. The Specific Gravity vs. Percent Discharge Graph also has a line drawn depicting the eight (8) hour rate from manufacturer's data. This represents the battery's rated discharge capacity and is included to exemplify the straight line relationship of amp-hrs discharged to specific gravity.

7. The specific gravity range required to deliver the FSAR load is equal to:

   1.216 - 1.163 = .053 (from actual test data as plotted).

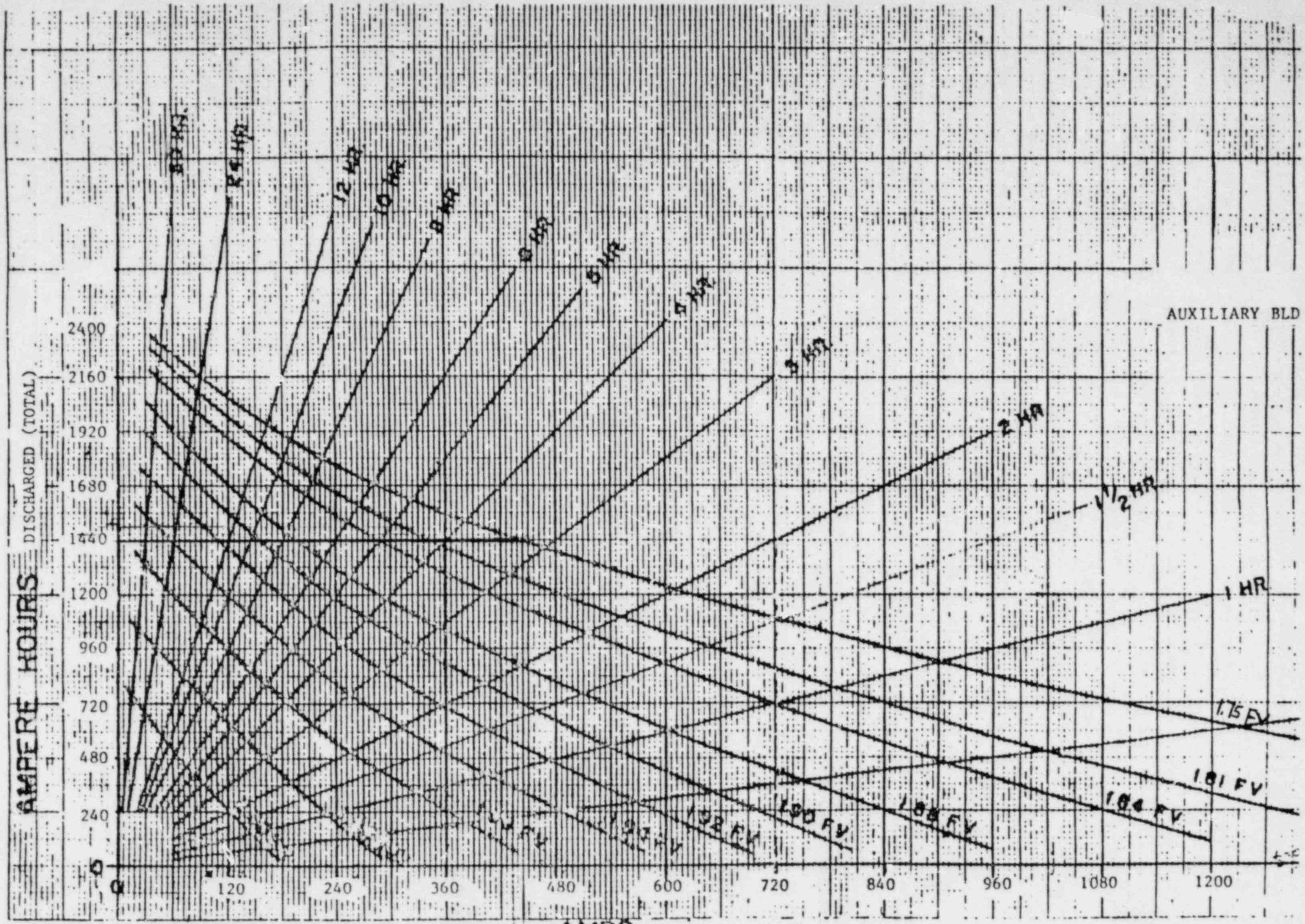
8. If we want to determine the minimum beginning specific gravity, we start from the lower specific gravity limit of 1.128 which represents 100% discharge (at FSAR rate). We then add the specific gravity range required to meet FSAR loads (1.128 + .053 = 1.181). 1.181 is the minimum specific gravity to start from where battery capacity would be equal to the FSAR assumed loads.

9. With the existing minimum specific gravity of 1.190 we can meet the FSAR loads with a margin of 10%. This margin is determined by subtracting the minimum specific gravity (from 8 above, from the APCo existing minimum value of 1.190 (1.190 - 1.181 = .009). This is the difference between the minimum FSAR value and the existing acceptance value. The capacity margin provided by the existing acceptance value is determined by dividing this difference (.009) by the battery capacity specific gravity range from 0% discharge to 100% discharge [.009/(1.216 - 1.128) = 10.02%]. This is the margin of battery capacity with existing Technical Specifications.

10. Similiarly, for the APCO proposed average specific gravity limit of 1.195, the margin of battery capacity is; (1.195 - 1.181)/ (1.216 - 1.128) = 16% margin.

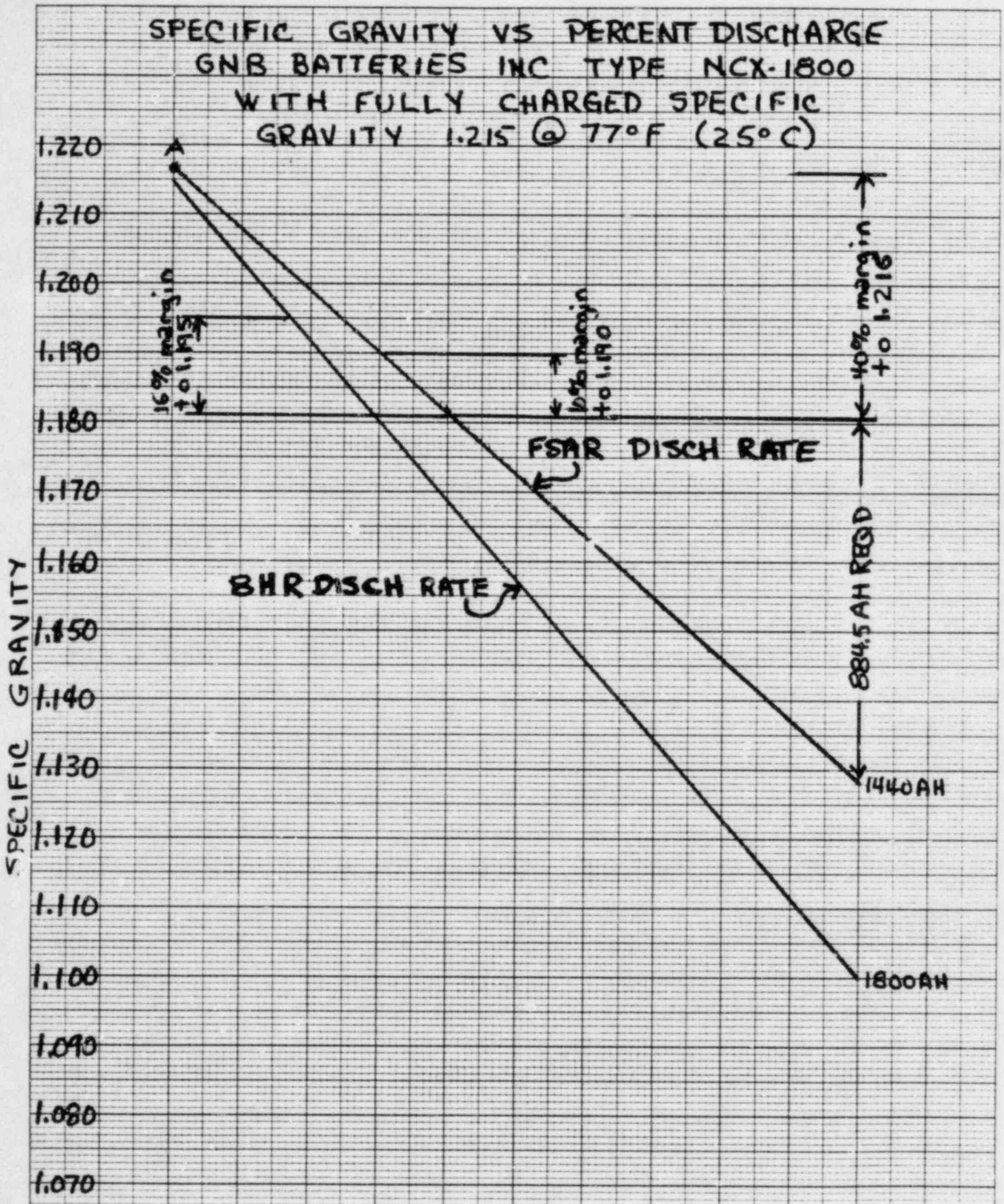
11. The Auxiliary Building Battery manufacturer concurs with this calculational methodology.

FIGURE 1
TYPICAL DISCHARGE CHARACTERISTICS OF NCX-1800



NCX-1800

FIGURE 2


SPECIFIC GRAVITY VS PERCENT DISCHARGE
GNB BATTERIES INC TYPE NCX-1800
WITH FULLY CHARGED SPECIFIC
GRAVITY 1.215 @ 77°F (25°C)
1.220
1.210
1.200
1.190
1.180
1.170
1.160
1.150
1.140
1.130
1.120
1.110
1.100
1.090
1.080
1.070
1.060
SPECIFIC GRAVITY
16% margin to 1.195
10% margin to 1.190
40% margin to 1.216
884.5 AH REQD
FSAR DISCH RATE
8HR DISCH RATE
1440AH
1800AH
0
20
40
60
80
100
% DISCHARGE