

NRL Report No. P-1332  
Lead Balance and Current Distribution Studies on  
Lead-Acid Storage Cells.

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SUBJECT

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Heat Balance and Current Distribution Studies on

Lead-Acid Storage Cells.



BY

NAVAL RESEARCH LABORATORY

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NAVY DEPARTMENT  
BUREAU OF ENGINEERING

Report on  
Heat Balance and Current Distribution Studies on  
Lead-Acid Storage Cells

for

U. S. Naval Research Laboratory  
Anacostia Station  
Washington, D.C.

by

Department of Chemistry  
University of North Carolina  
Chapel Hill, N.C.

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is extremely small.

The use of temperature measurements for determining current distribution is of no value except in the very early stages of the charge and discharge. The use of probing electrodes of steel is impossible due to gas formation on their surface. Potentials measured from leads soldered at various points to the back of the electrodes did not have a value of more than doubtful value. The use of mercury-mercurous sulphate reference electrodes to measure polarization appears to offer a method which should prove satisfactory for current distribution work. Various potential curves have been obtained for typical charges and discharges.

Tests made with one plate inverted indicate that uniform current distribution can be secured in this way.

## INTRODUCTION.

### (a) Authorization.

1. This problem was authorized by Bureau of Engineering letter SS/S62(7-30-D1) of 7 August 1935.

### (b) Statement of Problem.

2. The purpose of the work given in this report was to extend the studies which have been made by the author on the general problem of heat balance relationships in lead-acid storage cells. The work completed to date is discussed in Prior Work on Problem. As stated in that section the general problem has been solved as far as all heating and cooling effects are concerned except in the cases of the heating effects due to heat of formation of molecular gas and the heat effect of gravity equalization. However, it is also pointed out in that section that our knowledge of the above is limited to the gross effects. Little is known of the distribution of the heating or cooling due to the various causes. This last is concerned with the point of origin of the gas during the gassing phase of cell charge and the current distribution during charge and discharge.

3. The work given in this report was therefore concerned with the completion of the work on heat of formation of gases and the heating effect due to gravity equalization, the study of the point of origin of the gases, and the general problem of current distribution over the plates. This last is of course of great interest from the standpoint of plate and cell design.

### (b) Prior Work on Problem.

4. Prior to the work started by the author in 1934 at the U. S. Naval Research Laboratory no systematic studies seem to have been made of heat balance relationships in lead-acid storage cells. Since that time the studies have been continued and the results have been submitted to the Bureau of Engineering in three reports (see Bibliography).

5. General Temperature Characteristics. A normal charge on a cell of the WLH-29 type results in the generation of sufficient heat to raise the cell temperature approximately 30-35° F. The actual rise found will of course depend upon a number of conditions such as: temperature of cell surroundings, rate of ventilation, etc. Temperatures throughout the cell are fairly uniform although as much as an 8° difference between the interior of the cell and near the cell box may at times be found. This difference is found only in the early stages of the charge before gassing produces a mixing of the electrolyte. Temperature rise is most pronounced during the early stages of the charge when current values are high. During the latter stages of the charge the temperature, usually remains constant or decreases in value. Another rise is found when gassing commences. The following factors are important in cell temperature studies.

6. Irreversible Heat. This is a major factor in cell heating during the early stages of the charge when maximum current values are employed.

7. Reversible Heat. This effect is most pronounced with large charging currents.

8. Heat of Formation of Molecular Gases. This effect is only found during gas evolution. It is the major factor in cell heating during the gassing phase of cell charge.

9. Reversible Heat, Water Electrolysis. This effect produces a cooling action. It is only present when gassing takes place. During the studies data have been compiled for the proper calculation of this magnitude.

10. Radiation to Cell Surroundings. This effect is very difficult to estimate. Its magnitude depends upon the cell environment.

11. Evaporation Losses. Even under optimum conditions for evaporation this effect produces very little cooling.

12. Radiation (and Convection) to Ventilating Air. This effect is quite small in magnitude and is insignificant in cell temperature control.

13. Of the above effects all were well-understood when the work given in the present report was undertaken with the exception of the heat of formation of the molecular gases. Also little was understood about the heating effects that might result from the mixing of electrolyte due to diffusion from within the active material of acid of different gravity from that in the main body of the electrolyte.

14. It should be pointed out that little was understood as to the source or origin of the gas bubbles formed during the gassing phase of cell charge. This knowledge is necessary to determine the place at which the heat resulting from the formation of molecular gas is most pronounced.

15. It should also be pointed out that the effects discussed above are understood only from the standpoint of their gross magnitude. In other words it is known in only a very general way how these effects are distributed in the cell. The knowledge of current distribution therefore becomes a major question in the complete knowledge of heat balance relationships. This problem of current distribution was studied by Crennell and Lea but their work was concerned with the development of a method of calculating current distribution rather than a method whereby current distribution could be measured in a regular cell. (See Bibliography). Work on current distribution has also been carried out by Dr. C. G. Fink at Columbia University but the author understands that his work was concerned with methods of overcoming uneven current distribution rather than with the study of methods of measurement.

#### EXPERIMENTAL PROCEDURE.

##### (a) Apparatus.

16. Cells and single plates used in the tests discussed in this report were of the Exide KXH-7 plate type except in the case of the studies bearing on the temperature effects at the two plates (Tests 1 and 2). For the latter eleven-plate cells were used of approximately 200 ampere-hour capacity. Both types employed pasted plates.

17. Voltage measurements were made on either a Queen-Gray or a Leeds and Northrup Type K potentiometer. The less exact voltage measurements were made with voltmeters. Current measurements were made with ammeters of proper accuracy.

18. Temperature measurements were made with thermocouples of one junction constructed from No. 30 copper and constantan wire. The couples were enclosed in thin-walled rubber tubes, the ends being sealed with rubber latex cement. Ice-water mixtures were used for the cold junctions and the temperatures were obtained from the voltage measurements which were made with a Leeds and Northrup Thermocouple Potentiometer.

19. Gravity readings were made with a regular battery hydrometer.

20. Metallic probing electrodes were made of platinum wire sealed in the ends of glass tubes. These were held at the desired positions in the cells. The exposed platinum wire was of No. 27 gauge and in length was approximately one quarter of an inch.

21. For the polarization measurements with the mercury-mercurous sulphate electrodes a glass vessel similar in shape to those ordinarily used for calomel electrodes was employed. This type consists of a tube about six inches long into the bottom of which is sealed a platinum wire. On the outside this wire enclosed in a tube filled with mercury which furnishes the contact for the potentiometer circuit. The wire on the inside is covered with the mercury-mercurous sulphate paste which is of course in contact with sulphuric acid. A side arm which is bent at right angles extends to the point in the electrolyte at which it is desired to make the measurement. In the experiments discussed the sulphuric acid was of the same gravity as that found in the fully-charged cell under test.

22. In certain tests potentials were measured both from the mercury-mercurous sulphate electrodes and from points on the backs of the plates connected to the potentiometer circuit by means of lead leads soldered to the grid at the desired points. These leads were protected from the electrolyte by means of rubber tubes and rubber cement.

23. In cases where only two plates were employed they were held in position at the bottom by means of regular rubber feet such as are used in the KXH cells. At the top they were held in place with Bakelite spacers. The plates were approximately two inches apart.

24. In certain of the tests a KXH cell was used for the polarization measurements. In order to have space for the tubes from the reference electrodes the two middle plates (one lead and one peroxide) were removed. Both in these cases and with the tests with two plates there were no separators between the plates upon whose surfaces polarization measurements were being made.

25. In the tests wherein one plate was inverted the spacing was the same as in the other two-plate tests except that the peroxide plate was inverted and the lead was soldered in position and covered with rubber tubing and rubber cement for protection from the electrolyte.

26. For the resistance measurements KXH plates, both with the active material in place and with the active material removed, were used since it was with this type of plate that all the polarization measurements were made. Difficulty was found in making a good connection with the plates. It was necessary to have constructed a special type of clamp employing a brass screw that could be turned so as to embed the point in the grid material. The resistance measurements were made with a Kelvin bridge.

(b) Methods of Test.

27. While many tests were made only certain typical data are given in this report. In discussing the methods of test it will be more convenient to refer to the specific tests. A list of the tests as reported follows.

<u>Test No.</u>	<u>Purpose.</u>
1.	To determine if different heat effects are found at the lead and lead peroxide plates. Charge.
2.	To determine if different heat effects are found at the lead and lead peroxide plates. Overcharge.
3.	Polarization measurements. Two plates. Nine reference electrodes. Charge.
4.	Polarization measurements. Two plates. Nine reference electrodes. Overcharge.
5.	Polarization measurements. Two plates. Nine reference electrodes. Discharge.
6.	Polarization measurements. Two plates. Nine reference electrodes. Overcharge. Also with thermocouples so located as to measure heat effect due to diffusion.
7.	Polarization measurements. 7-plate KXH cell with two center plates removed. Nine reference electrodes. Charge.
8.	Polarization measurements. 7-plate KXH cell with two center plates removed. Nine reference electrodes. Discharge.
9.	Polarization measurements. 7-plate KXH cell with two center plates removed. Nine reference electrodes. Charge and Overcharge.
10.	Polarization measurements. 7-plate KXH cell with two center plates removed. Six reference electrodes. Discharge.
11.	Polarization measurements. 7-plate KXH cell with two center plates removed. Six reference electrodes. Charge.

<u>Test No.</u>	<u>Purpose.</u>
12.	Polarization measurements. Two plates. Peroxide plate inverted. Nine reference electrodes. Charge.
13.	Polarization measurements. Two plates. Peroxide plate inverted. Nine reference electrodes. Discharge.
14.	Polarization measurements. Nine leads soldered to back of each plate. Three reference electrodes. Charge.
15.	Polarization measurements. Nine leads soldered to back of each plate. Three reference electrodes. Discharge.
16.	Resistance Measurements on lead and lead peroxide plates.

28. Tests 1 and 2, typical of those tests made to determine if different heat effects are found at the lead and lead peroxide plates, were made to check further the theory of the heating effect due to the formation of molecular gas. An eleven-plate KXH cell was fitted with eighteen thermocouples. These were distributed in pairs at opposite points on separators as shown on Plates 1 and 2. It will be noted from Plate 2 that these couples form three groups as viewed from the sides of the elements. The distribution used was designed to check any possible differences due to differences in location in the cell as a whole.

29. Tests 3, 4, 5, and 6 are typical of the tests made with the two-plate cells. The purpose of these tests was to determine the polarization existing at both the lead and lead peroxide plates both on charge and discharge. Potentials were measured between the reference electrodes and the lead and lead peroxide plates. In Test 6 thermocouples were located in the electrolyte near the plate in the diffusion currents due to the electrolyte issuing from the active material into the main body of the electrolyte. Temperatures were determined on these couples in the usual manner.

30. Tests 7-11 inclusive were made with the 7-plate KXH cell with two center plates removed to make room for the reference electrode tubes. The purpose was the same as in the preceding paragraph.

31. Tests 12 and 13 were made to determine the polarization effects when one plate is inverted. In all tests with two plates the two leads were located opposite each other rather than staggered as in the ordinary arrangement. This was done to eliminate one factor making for better current distribution as the main purpose of Tests 3 to 6 was to test methods of measurement rather than to determine current distribution.

32. Tests 14 and 15 were made to determine the efficiency for current distribution measurements of the polarization values obtained from leads soldered to the back of the plates. Potentials were measured

between these leads and the mercurous sulphate reference electrodes and between various pairs of soldered leads.

33. The resistance measurements on the lead and lead peroxide plates were made for use in connection with the interpretation of the polarization data as a means of studying current distribution.

34. The locations of the soldered leads on the plate backs in Tests 14 and 15 and the location of the reference electrodes in the various polarization tests are on the proper Plates.

35. Observations of gas evolution on both the lead and lead peroxide plates were made in various tests under various conditions of charge and under various charging currents.

#### (c) Explanation of Calculations.

36. When single electrode potentials are given they are obtained from the reading as determined from the lead or lead peroxide plate and the mercury-mercurous sulphate electrode by adding or subtracting the single potential of the reference electrode. This was taken as .600 volt. Of course this value is only approximate and varies with the temperature and acid gravity. However, the data given are for comparison purposes and the absolute magnitude is not pertinent to the studies being made.

37. Resistance values for the lead and lead peroxide plates are obtained directly from the Kelvin Bridge.

### RESULTS.

#### (a) Data Obtained.

38. In this work many experiments were conducted but in order to keep the report from becoming too bulky only certain sets of typical data are included. The numbers of the tests and the purpose of each are given in Methods of Test. The actual data are given in Tabulated Data for Tests. This data and the methods by which they are obtained are probably clear from the text as already given.

39. In connection with the resistance measurements on the lead and lead peroxide plates it should be stated that similar values were found both with and without the active material present. It was expected that the peroxide would not add to the conductance due to its very high resistance. The lead would probably increase the conductance of the grid after being saturated with electrolyte but this would not affect the distribution of resistance which is the important factor in these considerations.

#### (b) Statement of Errors.

40. Temperature Readings. All temperature readings, whether obtained by thermocouples or by thermometers, are accurate to 1° Fahrenheit. More accurate readings were not considered necessary.

41. Voltage Readings. All voltage readings made on the potentiometer were determined in tenths of millivolts. However, in recording the data in this report the figures are given to the nearest millivolt. This was done because certain sources of error such as temperature changes, changes in position of tip of reference electrode, etc. made the last place of doubtful value. It should be stated that small changes in the position of the electrode tip produce considerable changes in the voltage values obtained.

42. Current Readings. These were accurate to at least a tenth of an ampere. Extremely accurate current readings were not necessary to the work and so were not made.

43. Resistance Measurements on Grids. These measurements were extremely hard to duplicate due to the difficulty of obtaining good connections on the grids. The values given are the average of several values. They may be considered accurate to about five percent.

## DISCUSSION OF RESULTS.

### (a) Heat of Formation of Molecular Gases.

44. It was hoped that different temperatures could be detected at corresponding points on the lead and lead peroxide plates. If this difference were in the proper direction it would be final proof that the theory of the heat of formation of the molecular gases is correct. As is known the heat of formation of the oxygen at the one plate is different from the heat of formation of hydrogen at the other plate. However, as seen in the data of Tests 1 and 2 such differences could not be noted. Temperature measurements were accurate to only 1° F. Perhaps more accurate measurements would have detected a difference but the problem of measurement would have been difficult due to the close packing of the plates. However, the data does show in a pronounced way the temperature increase during the gassing phase and thus furnishes still further circumstantial evidence in favor of the theory. Further consideration of the factors involved and discussion with certain thermodynamic experts lead to the conclusion that the theory is substantially correct. However, it is probable that the monatomic gases formed are not in the lowest energy state nor is the molecular gas necessarily in the normal energy state. If this is correct it means that the heat of formation would probably be less than the values used based on the normal state for the monatomic and molecular gas. This agrees with the results of the experiments with the WLH-29 cell in which in some cases less than the anticipated rise was obtained.

### (b) Heat of Mixing of Electrolyte.

45. During discharge water is formed from the electrode reactions and during charge sulphuric acid is formed. In an ideal cell the electrolyte would be of uniform concentration throughout the entire cell at any one time, the energy involved in the formation of the water or the acid as the case may be being tied in with the free energy change in the cell as a whole. In practice this is not usually

the case, the electrolyte in the pores of the active material where the electrode reactions take place being of different concentration from the main body of the electrolyte. The diffusion of this electrolyte from the active material into the main body of the electrolyte produces an irreversible heating effect whose magnitude depends upon the current flowing and the difference in gravity. Tests were made of the possible heat effect by placing thermocouples at various distances from the plate surfaces. These were placed in the diffusion currents which were visible to the eye in many of the charges employing large current values. Temperature effects which would produce rises that could be detected on thermocouple sensitive to 1° F. proved to be absent. This shows that this possible heating effect under the worst of conditions is negligibly small. A typical set of values is given in the data for Test No. 6.

(c) Origin of Hydrogen and Oxygen Gas.

46. The heat of formation of the molecular hydrogen and oxygen gas from the atomic gases will be evolved at the point of origin of the molecules. Many of the tests were used to determine by visual observation the places at which the gases were formed. Many different conditions of charge were employed. The gas bubbles both in the case of hydrogen and oxygen are formed in the active material and are evolved from cracks in the plate surface or from between the grid and the active material. It seems to be beyond question that evolution is from the interface between the active material and the grid. Of course gas bubbles in electrolysis phenomena evolve most easily from sharp points on the surface. It should be noted that when only two plates were employed evolution is just as strong from the back surface as from the surface facing the other plate.

(d) Methods of Measuring Current Distribution.

47. In the Bibliography is listed a reference to a paper concerning specific gravity changes during charge and discharge in submarine storage cells. The tests concerned were conducted by the Electric Storage Battery Company. Samples of electrolyte were obtained at proper time intervals and at various depths in the cell and the results plotted. They show that changes in the electrolyte near the bottom of the elements are small in charge and discharge. Maximum changes are obtained near the top of the elements. Otherwise the change is roughly proportional to the depth. Thus it is seen that the current density is greatest in the upper part of the cell. These results suggest that the use of gravity measurements as a means of studying current distribution. However, if much gassing takes place the electrolyte will be so stirred that gravity will be equalized throughout the cell. In the absence of gassing the method may prove effective although it is considered difficult to withdraw a truly representative sample from a position very far within the elements.

48. If the temperature readings made at various points in the cell in the numerous tests that have been made to date are studied it is found that on discharge the temperature rise is greatest in the early stages in the upper portions of the elements. As the discharge

continues the temperature effect becomes fairly equal throughout the elements. This shows that the current density is greatest near the top of the elements in the early stages of the discharge but as the discharge continues and the upper portion becomes exhausted the current density increases in the lower portions. On charge the same general effect is found. However, a slightly lower temperature may be found over the elements due to the cooling effect of the ventilating air. On charge, gassing produces a mixing of the electrolyte and hence an equalization of temperature. Therefore temperature measurements could be used as a means of measuring current density during charge and discharge as long as no gassing takes place. However, the results would be only approximate ~~apart to the~~ several factors affecting the cell temperature.

49. Schoop (see Bibliography) determined the equipotential lines over the face of a plate by rapidly revolving two lead electrodes between the plates. By this means he was able to determine the current distribution. Such a method requires that the electrodes be fairly far apart and so the method could not be applied to ordinary cells with their closely packed plates.

50. Crennell and Lea (see Bibliography) have worked out a method whereby current distribution can be calculated from: the fall in potential in the body of the plate, the resistance of the electrolyte between the plates, and the polarization at the plates. Their conclusions were tested by means of discharge measurements on a specially constructed cell. Now unless stratification is pronounced the gravity of the electrolyte should be the same throughout an idle cell. However, it will be different from place to place in the cell during charge or discharge the differences being due to differences in current density. Of course the fall in potential in the plates is fixed. Now the polarization at different points will be different due to differences in current density. Consequently it seems that voltage readings at various points will be different due to the first and last effect both of which depend on current density. This voltage should be a function of current density and the determination of its value from place to place should give a measure of the current distribution. It is this voltage which has been determined in the work reported on in this paper in the case of the tests using mercury-mercurous sulphate electrodes. It is termed the polarization at the various points. In reality it is of course the polarization plus the normal voltage at the particular point. The question is now raised as to the various methods whereby this voltage can be measured.

51. The first type of reference electrode used was made of platinum as discussed in Experimental Procedure - Apparatus. This type becomes bipolar during the passage of a current between the plates and hence gas forms on its surface. Hence it becomes useless for measuring point-to-point voltage.

52. In Tests 14 and 15 are given the results obtained when voltages are measured between the top of the elements and leads soldered at various points over the backs of the plates. Voltage

readings were also made between the various leads. An examination of the data shows that a general picture of the current distribution as we know it is obtained. Of course what we are actually measuring is the voltage drop produced by the current in the plate, the magnitude of the current of course being the factor we wish to measure. In this method the differences are small and it would be very difficult indeed to make such measurements on a typical storage cell with closely packed elements. The use of mercury-mercurous sulphate electrodes seemed to offer a much better method and so the above type of test was abandoned.

53. Tests 3 to 13 gives results typical of those obtained when mercury-mercurous sulphate reference electrodes are placed at various points in the cells. Voltage measurements are made between the reference electrodes and the straps at the tops of the elements. It should be pointed out in this connection that in the tests reported temperature control was not employed. However, the variations were always small and it is doubtful if changes produced by temperature effects played any part in the voltage values reported. In comparing the tests made with two plates and those made with the KXH cell with two center elements removed that in the first case the volume of the electrolyte was sufficiently large in comparison with the electrode surface so that gravity changes did not take place during charge or discharge. This of course was not true when the KXH cell was used. It should also again be pointed out that when two plates only were employed the straps through which the current passed into and out of the elements were always on the same end of the pair of elements.

54. The tests made with the KXH cell and which are represented by Tests 7-11 are considered as approximating most nearly the results found in a regular cell. Of course in this case there was no separator between the peroxide and the lead plates between which the reference electrodes were located. Moreover the quantity of electrolyte between these two plates is much greater than between two plates regularly spaced.

55. Upon examination of the data and plates of Test 7 it is seen that on charge the potentials at the lead plate rise very rapidly when the current is first started. Then the rise is fairly gradual until the cell becomes approximately fully charged. A very rapid and pronounced rise is then found due of course to the much increased voltage accompanying the onset of the gassing phase of cell charge. After this very rapid rise the voltages go over a very slight maximum and take fairly constant values for a given charging rate. At the peroxide electrode the same very rapid increase is found when the current is first turned on but after that there is usually a slight decline after which there is a gradual rise of the same nature as is found with the lead electrodes. The rise in voltage which takes place with the onset of gassing is much less steep than that found on the lead electrode. After this the voltage assumes approximately a constant value. As current lines are on the whole operating at right angles to the plate similar changes should be found on the two electrodes and such in a general way proves to

be the case. It should be pointed out that with the lead electrode a slight drop after the initial rise at the beginning of the charge is sometimes found. This drop in both the case of the lead and lead peroxide electrodes is probably due to sudden changes in the acid gravity in the pores of the active material and is perhaps to a certain extent regulated by the immediate prior history of the cell. Typical voltage curves for the lead and lead peroxide plates are given on Plate 17.

56. As stated above changes in the potentials of the lead plates take place with simultaneous changes at similar points in the peroxide plates. This is easily seen upon comparison of the time-voltage plots for the electrodes for a given charge. See for example Plates 13 and 14 as compared with Plates 15 and 16. Therefore for current distribution studies the voltages at either electrode may be used. However, the slopes and spacings of the lead values appear to lend themselves much more readily to examination and comparison.

57. For purposes of consideration a discussion will be given of the potentials as found in Tests 3, 4, and 7. These are quite typical. Discharges given results that fit into the same interpretation. In Test No. 3 two plates are used. Upon examination of Plates 22 and 23 it is seen that the plate resistance increases from around the lead straps in increasing circles. Consequently if two plates are placed with their lead straps opposite one another the same condition will hold. The current should therefore center around the straps, being smallest near the far edges of the plates. An examination of Plates 3 and 4 shows that points 3, 9, 2, and 6 do indeed show effects different from 1, 4, 7, 5, and 8. In other words the same circular distribution is found. Point 3 near the strap is particularly well-marked as expected. Now consider Test 4. Here after gassing is pronounced 1, 2, and 3 show maximum current values. This is to be expected. But 6 and 9 show minimum values. This is unexpected from the standpoint of plate resistance but in the overcharge the cell is gassing heavily and the rising gas forms a blanket of resistance over the electrode surfaces thus increasing the resistance of the path between the electrodes. This serves to cut down the current density and explains why these two points have changed groups. It will be noted that in the first part of the overcharge 4 and 7 show minimum currents as expected but as gassing sets in these points show a higher current density than the points 6 and 9. The distribution of the potentials at the points in the regular charge and in the overcharge can be explained on the basis of the operation of two resistance factors: grid resistance and change of resistance in electrolyte due to gassing.

58. Now consider Test No. 7. In this test the two plates have the straps at opposite ends, the same arrangement as found in a regular cell. An examination of the resultant resistance effects from those in the two individual plates shows that except for immediately under the strap and on the edges the resistance values show little difference over the face of the surface. Now an examination of the polarization curves on Plates 13 and 14 shows the maximum effect at point 6 (except for 9 which is located on the edge). This is according to predictions.

Later with the onset of gassing the current apparently falls off at 6. In the overcharge stage 9, 1, and 4 show maximum current values. The smallest values are found with 3, 8, and 2. This can again be explained by considering the effect of gas bubbles in increasing the electrolyte resistance. 7 and 8 on the edges show low currents due probably to the fact that the reference electrodes are situated close to the edge of the element and probably large overvoltage effects come into play even in the early stages of the charge. In both charges 3 and 7 it is seen that voltages at single points quite often cross one another in the earlier stages of the charge. One might expect them all to come to the same value but hardly to pass one another. This crossing gives an indication of the switching of the current density over the surface as the various areas become more or less charged. The great amount of "crossing" in Test 7 was to be expected due to the almost complete elimination of the resistance factor in the grid material, a condition which did not hold in Test 3.

59. It is therefore believed that the polarization values as obtained give a very good indication of current distribution. Distribution is as expected in the early stages of the charge when the grid resistance is the main factor, the electrolyte resistance being approximately the same throughout the cell. The explanation of the characteristics as found may be summarized as follows. In the early stages of the grid resistance is the important factor. Therefore current density will follow the grid resistance contours. As the charge continues and as the various areas become charged the current density switches to a greater value in the uncharged areas. When gassing sets in the resistance effect of the gas bubbles passing through the electrolyte produces an effect that offsets the grid resistance thus switching the current density to the bottom portions of the cell where electrolyte resistance will be at a minimum.

(e) Grid Resistance Measurements.

60. For the values obtained see Plates 22 and 23. As discussed above the resistance contours increase in all directions from the strap. This is as expected. An inspection of the plates used shows that the peroxide grid is much heavier than the lead grid and hence when the active material is removed shows the lowest resistance. With the addition of dry active lead no change is found but with active material wet with electrolyte no doubt the value becomes approximately equal to that of the grid on the peroxide plate. Of course the active lead peroxide has an exceedingly low conductivity.

(f) Effect of Inverting One Plate.

61. Tests 12 and 13 show the polarization effects produced when the peroxide plate is inverted in a two-plate combination. The effect is of course to equalize the grid resistance values. The distribution of the reference electrodes is the same as in Tests 3-6, see Plate 12. As is seen from the data the polarization is almost the same over the entire plate surface during all stages of the charge. This would indicate that this method of employing the plates would be effective in producing efficient current distribution.

(g) Some Practical Considerations of Cell Charging Procedure and Construction.

62. If the above interpretation of current distribution results is correct certain practical conclusions may be drawn in regard to practical charging procedure. Inverted plates would certainly produce more efficient current distribution. Also the effect of allowing a certain period of gassing at the end of a charge and the effect of overcharge may take on an additional interpretation. The idea in the overcharge is to remove all sulphate that may be left after a series of normal charges. This probably results from the fact that the gas increases the electrolyte resistance in the upper portion of the cell thus directing the current in greater quantities to the bottom portions of the cell where this excess sulphate is most likely to be found. In other words gassing is used as a means of effecting desired current distribution. Inverting alternate elements may do away with the need of employing gassing for this purpose.

63. The effect of varying the rib size in helping cut down inequalities in current distribution in the small plates used is illustrated by the tests. The question arises as to whether this has been properly considered in the construction of the plates for the large submarine cells. Certainly the subject is worthy of study in the iron-clad type of construction.

CONCLUSIONS.

(a) Heating and Cooling Effects.

64. Heat of Formation of Molecular Gases. Further confirmation has been obtained as to the correctness of the theory that the heat of formation of molecular gases is one of the major heating effects attending the gassing phase of cell charge. However, absolute proof was not obtained by detecting temperature differences at corresponding points on two plates.

65. Heat of Mixing of Electrolyte. As expected this effect proved to be negligibly small, even in those cases where diffusion current could be visibly detected.

66. Conclusions. It can be concluded that the knowledge of the various heating and cooling effects is complete from the standpoint of gross effect. The distribution of the effects within the cell can only be answered after a knowledge of current distribution is obtained.

(b) Source of Gas.

67. Both the hydrogen and oxygen gas is evolved from within the active mass of the plates in the pasted type of construction. With current passing only to one side of the plate the gas in both the case of the lead and the lead peroxide plate appears in equal quantities from both sides. The evolution is around the grids and from breaks or holes in the active material. It may be safely concluded that the formation takes place at the interface between the grid metal and the active material.

(c) Current Distribution Studies.

68. Metallic probing electrodes are of no use in measuring current distribution due to gas evolution from their surfaces.

69. Heat measurements are of use only in the early stages of charge and discharge.

70. The determination of potentials from leads soldered at various points over the back of the plates does not seem to offer a satisfactory method of determining current distribution.

71. The use of mercury-mercurous sulphate electrodes for measuring the current distribution by determining the polarization at various points over the plate surface appears to offer a method which can be adapted to lead-acid cells.

72. The current distribution as determined with the mercury-mercurous sulphate electrode is found to be as expected. During the early stages of cell charge and discharge the greatest current density is in the regions where the smallest resistance drop is found in the plates. This is usually near the upper parts of the plates and particularly near the straps. In the later stages of the charge the current distributes itself rather evenly as the various parts become charged. In the gassing phase of cell charge greatest density is near the bottom of the elements due to the high resistance of the electrolyte in the upper portions resulting from the gas evolution. However, data of greater accuracy should be secured before final conclusions can be arrived at.

73. The use of the mercury-mercurous sulphate electrode in connection with two plates one of which is inverted so that the current is led in from the bottom leads to the conclusion that much better current distribution is found in this type of arrangement. However, the data are too meager for positive conclusions.

74. Voltage Characteristics. In the early stages of the charge the voltage curves may cross one another thus showing that points do not come to the same potential but actually pass each other. An examination of a typical voltage curve for a point on a lead electrode shows that when the current is first started a sudden rise in voltage results. After the first sudden rise there may be a temporary falling off after which a gradual rise is found until gassing sets in. Then the potential rises very rapidly due to the necessary overvoltage to effect gassing. After this rise the curve goes over a slight maximum after which it is fairly flat. At the peroxide electrode essentially the same characteristics are found except that the drop after the first sudden rise is perhaps a bit more pronounced.

RECOMMENDATIONS.

75. The recommendations for the further study of heat balance relationships may be divided into two parts: those concerned with current distribution and those specifically concerned with heat

balance studies. These recommendations follow. Of course many problems concerned with storage battery construction and control have arisen during the work but recommendations are limited to the particular problem in question.

(a) Current Distribution Studies.

76. The further use of the mercury-mercurous sulphate electrode as a means of measuring polarization and the utilization of the polarization data from various points over the plate surface for purposes of obtaining current distribution should be studied. The data thus collected should be correlated with the other known facts about current distribution. Should the mercury-mercurous sulphate electrode prove satisfactory, as is now indicated, its application to large cells should be studied and a method developed for using it on closely packed plated such as are found in the commercial cell.

77. It is also recommended that further tests be made with inverted plates. It is believed that much better current distribution can be obtained.

(b) Heat Balance Studies.

78. Determination of the Heat Capacity of the WLH-29 Cell. No actual measurement of the heat capacity of the WLH-29 cell used in many of the tests has been made. The heat capacity value used has been one calculated from the specific heats of the substance making up the cell. Equipment is now available, with certain slight modifications for determining this heat capacity and it is recommended strongly that this be done. This will enable one to make a much more careful study of the available data.

79. Further Adiabatic Studies on the WLH-29 Cell. With the determination of the heat capacity as outlined above it is recommended that three or four charges be made with an entirely adiabatic procedure, that is, one in which heat transfer either into or out of the cell is completely eliminated. This could be easily done with the equipment now available at the Naval Research Laboratory. These charges should be conducted in such a way as to test all conclusions drawn to date.

80. Shipboard Tests. It is highly desirable to continue the studies as conducted to date on shipboard, particularly under normal operating conditions. Without such studies it will be impossible to calculate heat losses due to interchange with the surroundings in the battery space. Temperature phenomena may prove quite different from those found in laboratory practice.

81. Preparation of Complete Report. With the completion of the above all data and results should be assembled in one full and complete report on the problem.

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Table 1.

## Temperature Studies

To determine if different heat effects are found at lead  
and lead peroxide plates

Time	Gravity	Gassing	Data for charge, rate 10 amperes					
			Volts	Air	Temperatures			
					1	4	10	7
0830	1140	none	1.993-2.030	75°	72.5	72.5	72.5	72.5
0900	1145	none	2.124	75	72.5	72.5	72.5	72.5
0930	1145	-	2.125	75.5	73.5	74.0	73.5	73.5
1000	1145	-	2.125	75.5	75.0	74.5	75.0	75.0
1100	1145	-	2.127	78	75.5	75.5	75.5	75.5
1200	1145	-	2.127	76	75.5	75.5	75.5	75.5
1300	1145	-	2.128	79	76.5	76.0	76.0	76.0
1430	1150	-	2.133	79	78.0	78.0	78.0	77.5
1530	1150	slight	2.137	75	78.0	78.0	78.0	78.5
1630	1150	-	2.140	75	78.5	78.5	78.0	78.5
1810	1155	-	2.149	75	78.0	78.5	78.5	78.5
1905	-	-	2.154	75	78.0	78.0	78.5	78.0
1955	-	-	2.160	74	78.0	78.5	78.0	78.5
2115	1160	-	2.168	74	78.0	78.0	78.0	78.0
2245	1165	-	2.175	74	78.0	78.0	78.0	78.5
2400	1165	-	2.183	75	76.5	76.5	77.0	77.0
2500	1165	-	2.188	75	76.5	77.0	77.0	77.0
2600	-	-	2.195	75	77.5	76.5	77.0	77.0
2700	1180	-	2.200	75	78.0	78.0	78.0	78.0
2830	-	-	2.208	76	78.0	78.0	78.0	78.5
3000	1185	Consid- erable	2.221	75	78.0	77.5	78.5	78.5
3145	1200	-	2.232	75	78.0	78.0	78.5	78.0
3300	1210	-	2.240	75	78.0	78.0	78.0	78.0
3415	-	-	2.249	75	78.0	78.0	78.5	78.0
3530	1215	-	2.260	75	78.0	77.5	78.0	78.0
3630	1215	-	2.272	75	78.0	78.5	78.0	78.0
3740	-	strong	2.279	75	78.0	78.0	78.0	78.0
3830	1230	-	2.290	75	78.0	78.5	78.5	78.5
4000	1240	-	2.308	75	78.0	78.0	78.0	78.0
4140	-	-	2.328	75	78.0	79.0	79.0	79.0
4300	1255	-	2.340	76	78.0	78.5	79.0	78.5
4400	1260	-	2.352	76	79.0	78.5	79.0	78.5
4500	1260	-	2.364	76	79.0	79.0	78.5	79.0
4500	charge secured		2.364-2.235					

charge should be completed at 4200.

Table 1 (continued)

Time	Temperatures									
	17	14	2	5	11	8	3	6	12	9
0830	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5
0900	73.0	73.0	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5
0930	74.0	74.5	74.0	74.0	73.5	73.5	74.0	73.5	73.5	73.5
1000	74.5	75.0	75.0	74.5	74.5	75.0	74.5	74.0	74.5	74.5
1100	75.5	75.5	75.5	75.5	75.0	75.5	75.0	75.5	75.0	74.5
1200	76.0	76.5	75.5	75.5	75.5	75.5	75.5	75.0	75.5	75.5
1300	76.0	76.5	75.5	76.0	76.0	76.0	76.0	75.5	76.0	75.0
1430	78.0	77.5	77.5	78.0	77.0	77.5	76.5	77.0	77.0	77.0
1530	78.5	78.0	78.0	78.0	78.0	78.5	78.0	78.0	77.0	77.0
1630	78.0	78.0	78.5	78.5	78.0	78.5	78.0	78.0	78.0	77.5
1810	78.5	78.0	78.0	78.5	78.0	78.5	77.5	78.0	78.0	78.0
1905	78.5	78.0	78.0	78.5	78.0	78.0	77.5	78.0	78.0	78.0
1955	78.0	78.0	78.0	78.5	78.0	78.5	77.5	78.0	78.0	78.0
2115	78.0	78.0	78.0	78.0	78.0	78.0	77.5	78.0	77.0	78.0
2245	78.0	78.0	78.0	78.0	77.5	78.0	78.0	78.0	77.0	78.0
2400	77.5	77.0	77.0	77.0	77.0	77.0	76.0	77.0	77.0	76.5
2500	78.0	77.0	77.0	77.0	77.0	77.5	76.5	77.0	77.0	76.5
2600	78.0	78.0	77.5	76.5	77.0	76.5	76.5	76.5	76.5	76.5
2700	78.0	78.0	78.0	78.0	78.0	78.0	77.0	78.0	77.0	77.0
2830	77.5	78.0	78.0	78.0	78.0	78.5	77.5	77.0	77.0	78.0
3000	78.0	78.0	78.0	77.5	78.0	78.5	77.5	77.5	78.0	77.5
3145	78.0	78.5	78.0	78.0	77.5	78.5	78.0	78.0	77.5	78.0
3300	78.0	78.0	78.5	78.0	78.0	78.0	78.0	77.5	77.5	78.0
3415	78.0	78.0	78.0	78.0	78.0	78.5	78.0	78.0	78.0	78.0
3530	78.0	77.5	78.0	78.0	77.0	78.0	76.5	77.5	77.0	77.5
3630	78.0	77.5	78.0	78.0	77.5	78.0	78.0	78.0	77.5	77.5
3740	78.5	78.0	78.0	78.5	78.0	78.5	78.0	78.5	78.0	78.0
3830	78.5	78.5	78.0	78.5	78.5	78.0	78.0	78.5	78.0	78.0
4000	78.5	78.5	78.5	78.0	78.0	78.5	78.0	78.0	78.0	78.0
4140	79.0	79.0	79.0	79.0	79.0	79.0	79.0	79.0	78.5	79.0
4300	79.5	78.5	79.0	78.5	78.0	79.0	79.0	78.5	79.0	79.0
4400	79.5	79.5	79.5	78.5	79.0	79.5	79.5	79.5	79.5	79.5
4500	80.0	79.5	79.5	79.0	79.0	79.5	79.5	79.5	79.5	79.5

For key to location of couples see Plate 1.

Table 2.

Temperature Studies

To determine if different heat effects are found at lead and lead peroxide plates

Data for Overcharge - rate, 10 amperes

Time	Gravity	Volts	Temperatures							
			Air	1	4	10	7	17	14	
1100	1270	2.130-2.195	79°	74.5	74.5	74.5	74.5	74.5	75.0	
1120	-	2.399	80	75.5	75.5	75.0	75.0	75.5	75.5	
1150	1270	2.390	81	76.5	76.5	76.5	76.5	76.5	76.5	
1300	-	2.393	81	78.5	80.0	79.0	79.0	78.5	79.0	
1405	1270	2.385	81	80.0	80.0	80.0	80.5	80.5	80.5	
1500	-	2.387	80	81.0	81.0	81.5	81.5	81.5	81.5	
1600	-	2.390	80	82.5	82.0	82.5	82.5	82.5	82.5	
1645	1275	2.390	80	82.0	82.0	82.0	82.0	82.5	82.5	
1645	charge secured									

Time	Temperatures							
	2	5	11	8	3	6	12	9
1100	74.5	74.5	74.5	74.5	74.5	74.5	74.5	74.5
1120	75.5	75.0	75.0	75.0	75.5	75.0	75.5	75.0
1150	76.5	76.5	75.5	76.5	76.5	76.5	76.5	76.5
1300	78.5	78.0	78.5	79.0	78.0	78.0	79.0	79.0
1405	80.0	80.0	79.5	80.0	80.0	80.0	80.0	80.0
1500	81.0	81.0	80.5	81.5	81.0	81.0	81.5	81.5
1600	82.0	81.5	81.5	82.5	82.0	81.5	82.0	82.5
1645	82.0	82.0	81.5	82.5	81.5	81.5	82.0	82.5

for key to location of couples see Plate 1

Charge should be completed at 2030 at 9 amperes

Table 3.

## Current Distribution Studies

Test made with two plates in connection with the use of nine reference electrodes

Time	Current	Cell Voltage	Gassing	Voltages-Lead Electrode					
				1	2	3	4	5	6
1130	0-1.0	2.074-2.178	none	.361	.361	.362	.361	.361	.361
1145	1	2.232	-	.392	.390	.387	.396	.395	.394
1200	1	2.235	-	.396	.394	.390	.399	.398	.396
1300	1	2.240	slight on	.401	.399	.395	.404	.403	.401
1415	1	2.252	lead	.406	.403	.399	.409	.407	.406
1500	1	2.260	considerable	.409	.406	.401	.412	.409	.408
1600	1	2.268	on lead	.413	.408	.403	.416	.412	.410
1700	1	2.280	slight on PbO <sub>2</sub>	.416	.411	.406	.419	.415	.413
1800	1	2.290	-	.420	.414	.408	.422	.417	.416
1930	1	2.318	considerable on	.425	.418	.412	.428	.421	.419
2030	1	2.340	both	.427	.420	.414	.430	.424	.421
2130	1	2.360	-	.429	.422	.416	.433	.426	.423
2200	1	2.370-2.280	-	.430	.423	.417	.434	.427	.424

Time	Voltages-Lead Electrode					Voltages-Peroxide Electrode						
	7	8	9	1	2	3	4	5	6	7	8	9
1130	.361	.361	.362	1.705	1.705	1.705	1.705	1.705	1.705	1.705	1.705	1.705
1145	.393	.392	.392	1.830	1.832	1.836	1.827	1.828	1.829	1.829	1.830	1.830
1200	.396	.395	.394	1.831	1.833	1.837	1.828	1.830	1.831	1.831	1.832	1.833
1300	.402	.400	.399	1.833	1.835	1.840	1.830	1.832	1.833	1.833	1.835	1.836
1415	.407	.404	.403	1.839	1.842	1.847	1.835	1.838	1.839	1.838	1.840	1.842
1500	.410	.408	.405	1.842	1.846	1.850	1.839	1.842	1.841	1.841	1.844	1.845
1600	.413	.410	.408	1.848	1.852	1.857	1.845	1.849	1.850	1.847	1.851	1.852
1700	.417	.413	.411	1.855	1.861	1.866	1.852	1.857	1.858	1.854	1.859	1.861
1800	.420	.415	.413	1.864	1.870	1.875	1.861	1.866	1.867	1.863	1.867	1.870
1930	.425	.420	.417	1.888	1.895	1.901	1.884	1.891	1.893	1.887	1.892	1.895
2030	.423	.421	.419	1.906	1.913	1.919	1.902	1.909	1.911	1.904	1.910	1.913
2130	.430	.424	.421	1.926	1.933	1.939	1.922	1.929	1.931	1.924	1.929	1.932
2200	.431	.425	.422	1.934	1.941	1.947	1.931	1.937	1.940	1.933	1.938	1.941

Charge should be completed at 2030 at 9 ampere-hours

Table 4.  
Current Distribution Studies  
Test made with two plates in connection with the use of nine  
reference electrodes

Overcharge-charging rate-1 ampere - medium gassing

Time	Voltage Cell	Voltages--Lead Electrode								
		1	2	3	4	5	6	7	8	9
0845	2.107-2.200	.371	.371	.371	.371	.371	.371	.371	.371	.371
0900	2.368	.431	.421	.416	.436	.427	.423	.435	.427	.423
0930	2.382	.440	.430	.425	.443	.435	.432	.441	.434	.430
1030	2.402	.439	.431	.427	.442	.435	.433	.439	.434	.432
1130	2.409	.437	.431	.428	.441	.435	.434	.439	.433	.432
1230	2.412	.436	.430	.428	.439	.435	.431	.437	.433	.432
1400	2.415	.434	.439	.428	.438	.434	.434	.435	.432	.432
1500	2.419	.435	.430	.430	.438	.435	.435	.436	.433	.433
1600	2.422	.436	.431	.431	.438	.436	.437	.437	.434	.435
1700	2.423	.437	.433	.433	.440	.437	.439	.438	.436	.437
1800	2.427	.437	.433	.434	.440	.439	.440	.438	.436	.438
2000	2.435	.439	.436	.438	.442	.441	.443	.440	.440	.442
2100	2.440	.442	.439	.441	.445	.444	.447	.443	.442	.445

Time	Voltages--Peroxide Electrode								
	1	2	3	4	5	6	7	8	9
0845	1.728	1.728	1.728	1.728	1.728	1.728	1.728	1.728	1.728
0900	1.924	1.934	1.939	1.918	1.927	1.931	1.919	1.927	1.930
0930	1.935	1.945	1.950	1.931	1.940	1.943	1.933	1.940	1.944
1030	1.955	1.963	1.967	1.952	1.958	1.960	1.953	1.959	1.961
1130	1.963	1.970	1.973	1.960	1.966	1.966	1.962	1.966	1.968
1230	1.968	1.974	1.976	1.964	1.969	1.970	1.967	1.971	1.972
1400	1.973	1.979	1.979	1.971	1.974	1.974	1.972	1.975	1.975
1500	1.977	1.982	1.982	1.974	1.977	1.976	1.976	1.978	1.978
1600	1.979	1.983	1.983	1.977	1.979	1.977	1.978	1.980	1.980
1700	1.981	1.985	1.985	1.979	1.979	1.979	1.980	1.982	1.981
1800	1.983	1.987	1.986	1.981	1.980	1.980	1.982	1.983	1.982
2000	1.987	1.990	1.989	1.984	1.983	1.983	1.986	1.987	1.985
2100	1.990	1.992	1.991	1.987	1.985	1.985	1.989	1.989	1.987

Table 5.

## Current Distribution Studies

Test made with two plates in connection with the use of  
nine reference electrodes

Discharge data—discharge rate—1.5 amperes

Time	Voltage Cell	Voltages—Lead Electrode								
		1	2	3	4	5	6	7	8	9
1100	2.100-1.950	.373	.373	.373	.373	.373	.373	.373	.373	.373
1105	1.940	.333	.337	.337	.329	.331	.328	.333	.334	.333
1130	1.970	.333	.337	.338	.329	.330	.328	.332	.334	.333
1200	1.968	.330	.334	.335	.326	.327	.325	.330	.331	.330
1300	1.960	.326	.330	.332	.320	.323	.321	.325	.328	.327
1500	1.940	.318	.324	.327	.314	.317	.317	.318	.321	.322
1530	1.933	.316	.322	.326	.311	.315	.316	.315	.319	.320
1745	1.910	.304	.313	.318	.300	.306	.308	.304	.310	.313
1830	1.903	.300	.309	.314	.296	.302	.304	.300	.306	.309
1930	1.891	.294	.303	.308	.290	.290	.298	.293	.300	.302
2040	1.872	.282	.294	.300	.277	.286	.289	.281	.289	.293
2130	1.840	.254	.272	.281	.248	.263	.270	.252	.266	.273
2230	1.760	.192	.215	.232	.186	.205	.217	.187	.203	.217
2230	discharge secured									
2230	1.930	.324	.326	.328	.327	.327	.329	.329	.329	.331
2245	2.012	.337	.338	.339	.338	.339	.339	.340	.340	.341

Time	Voltages—Peroxide Electrode								
	1	2	3	4	5	6	7	8	9
1100	1.719	1.719	1.719	1.719	1.719	1.719	1.719	1.719	1.719
1105	1.597	1.584	1.593	1.601	1.600	1.602	1.597	1.596	1.597
1130	1.632	1.628	1.627	1.636	1.635	1.637	1.633	1.631	1.632
1200	1.631	1.627	1.625	1.635	1.634	1.636	1.631	1.629	1.630
1300	1.627	1.623	1.621	1.632	1.630	1.632	1.628	1.626	1.626
1500	1.616	1.610	1.606	1.620	1.617	1.617	1.616	1.613	1.612
1530	1.611	1.604	1.600	1.615	1.611	1.611	1.612	1.607	1.606
1745	1.600	1.592	1.587	1.604	1.598	1.596	1.600	1.594	1.592
1830	1.597	1.589	1.583	1.601	1.595	1.593	1.598	1.591	1.589
1930	1.591	1.582	1.577	1.595	1.589	1.586	1.591	1.585	1.582
2040	1.586	1.574	1.567	1.589	1.580	1.577	1.585	1.576	1.573
2130	1.584	1.565	1.554	1.588	1.572	1.565	1.583	1.569	1.561
2230	1.657	1.657	1.656	1.656	1.656	1.655	1.655	1.655	1.654
2245	1.663	1.662	1.662	1.662	1.662	1.662	1.662	1.661	1.661

Table 6.

## Current Distribution Studies

Test made with two plates in connection with the use of nine reference electrodes and six thermocouples.

Overcharge--charging rates as shown.--gassing strong

Time	Cell Voltage	Voltages-Lead Electrode									Current
		1	2	3	4	5	6	7	8	9	
1130	2.105-2.260	.374	.374	.374	.374	.373	.373	.374	.374	.374	0 - 1
1140	2.425	.406	.402	.401	.410	.407	.406	.409	.405	.405	1
1200	2.448	.416	.410	.406	.419	.414	.412	.417	.413	.411	1
1300	2.485	.429	.422	.418	.432	.426	.424	.430	.425	.423	1
1500	2.517	.440	.434	.432	.442	.439	.438	.440	.437	.437	1-2

no data on polarization taken beyond this time

Time	Current	Voltages--Peroxide Electrode								
		1	2	3	4	5	6	7	8	9
1130	0-1	1.725	1.725	1.725	1.725	1.725	1.725	1.725	1.725	1.725
1140	1	2.005	2.010	2.013	2.000	2.003	2.005	2.000	2.003	2.004
1200	1	2.023	2.029	2.033	2.019	2.024	2.026	2.020	2.025	2.027
1300	1	2.052	2.057	2.062	2.048	2.053	2.056	2.050	2.055	2.058
1500	1-2	2.069	2.074	2.077	2.066	2.070	2.070	2.068	2.071	2.071

Time	Current	Temperatures Couple Numbers					
		1	2	3	4	5	6
1130	0-1	73	73	73	73	73	73
1150	1	75	75	74	74	75	75
1200	1	75	75	74	74	75	75
1300	1	75	75	74	74	74	74
1510	1-2	75	75	75	75	75	75
1520	2	75	75	75	75	75	75
1600	2-3	75	75	75	75	75	75
1610	3	76	76	76	76	76	76
1635	3-5	76	76	76	76	76	76
1645	5	76	76	76	76	76	77
1715	5	77	77	77	77	78	78
1815	5	79	79	79	79	80	80
1900	5	80	80	80	81	81	81

Room Temperature - 73°

Table 7 (continued)

Time	Lead Electrode			Peroxide Electrode					9			
	6	7	8	1	2	3	4	5		6	7	8
0830	.347	.349	.348	1.647	1.648	1.649	1.647	1.648	1.650	1.648	1.650	1.648
0836	.388	.399	.398	1.862	1.805	1.861	1.862	1.860	1.869	1.856	1.860	1.866
0845	.391	.400	.400	1.854	1.847	1.851	1.855	1.851	1.859	1.849	1.850	1.857
0905	.394	.402	.405	1.843	1.845	1.840	1.845	1.840	1.847	1.839	1.836	1.845
1015	.400	.408	.412	1.838	1.829	1.835	1.838	1.833	1.840	1.832	1.829	1.840
1140	.405	.416	.415	1.847	1.841	1.847	1.848	1.845	1.851	1.841	1.841	1.856
1230	.409	.421	.418	1.857	1.852	1.859	1.857	1.855	1.861	1.849	1.851	1.865
1335	.415	.427	.423	1.873	1.868	1.876	1.873	1.870	1.874	1.863	1.867	1.882
1430	.421	.436	.430	1.897	1.893	1.902	1.893	1.900	1.900	1.884	1.890	1.907
1530	.436	.453	.445	1.970	1.965	1.962	1.961	1.958	1.964	1.947	1.955	1.974
1645	.522	.520	.528	2.013	1.997	1.987	2.012	1.997	1.998	2.001	1.993	2.013
1715	.543	.543	.549	2.014	2.000	1.993	2.013	2.001	2.003	2.004	1.997	2.015
1745	.551	.553	.558	2.012	2.002	1.997	2.012	2.003	2.006	2.004	2.000	2.015
1836	.552	.554	.558	2.011	2.002	1.998	2.011	2.003	2.007	2.004	2.000	2.014
1930	.550	.553	.557	2.011	2.002	1.998	2.011	2.004	2.007	2.005	2.000	2.014
2030	.548	.552	.555	2.011	2.001	1.998	2.011	2.004	2.008	2.004	2.001	2.014
2115	.548	.551	.555	2.016	2.002	1.999	2.011	2.004	2.008	2.005	2.001	2.014
2200	.547	.551	.555	2.012	2.002	1.999	2.012	2.004	2.008	2.005	2.001	2.015
2215	.354	.355	.354	1.847	1.846	1.844	1.846	1.846	1.847	1.847	1.848	1.847

Table 8.

Current Distribution Studies

Test made with KXH 7-plate cell, with two center plates removed and with nine reference electrodes

Discharge-rate of discharge 6 amperes

Time	Current	Gravity	Voltage Cell	Voltage-Lead Electrode									
				1	2	3	4	5	6	7	8	9	
1000	0-6	1200	2.039-1.890	.356	.356	.356	.356	.356	.356	.356	.356	.356	.356
1010	6	-	1.888	.304	.299	.305	.305	.305	.307	.307	.298	.300	.308
1020	6	-	1.882	.304	.299	.304	.302	.303	.307	.306	.297	.300	.308
1045	6	-	1.878	.302	.298	.303	.300	.302	.302	.306	.296	.299	.307
1115	6	1195	1.868	.300	.295	.300	.297	.299	.303	.299	.293	.297	.306
1215	6	1190	1.842	.297	.290	.296	.293	.294	.299	.289	.289	.292	.305
1345	6	1180	1.806	.293	.286	.291	.289	.288	.290	.282	.282	.283	.300
1500	6	-	1.768	.286	.288	.284	.281	.278	.279	.272	.271	.297	
1645	6	1165	1.645	.274	.268	.274	.258	.251	.253	.246	.244	.290	
1715	6-0	-	.900-1.800	-	-	-	-	-	-	-	-	-	-
1915	0	1160	-	.347	.346	.346	.346	.347	.346	.346	.345	.345	.347
0900	0	-	1.995	.347	.346	.346	.346	.346	.345	.346	.345	.347	

Time	Voltages-Peroxide Electrode								
	1	2	3	4	5	6	7	8	9
1000	1.675	1.675	1.675	1.675	1.675	1.765	1.675	1.675	1.675
1010	1.573	1.577	1.573	1.573	1.573	1.597	1.579	1.575	1.567
1020	1.571	1.575	1.570	1.573	1.571	1.568	1.578	1.575	1.567
1045	1.567	1.572	1.567	1.570	1.568	1.565	1.574	1.571	1.564
1115	1.558	1.564	1.558	1.561	1.559	1.555	1.565	1.562	1.552
1215	1.535	1.543	1.537	1.540	1.539	1.535	1.546	1.542	1.529
1345	1.503	1.511	1.506	1.507	1.510	1.507	1.514	1.514	1.497
1500	1.474	1.482	1.477	1.480	1.484	1.483	1.489	1.490	1.466
1645	1.383	1.387	1.382	1.402	1.410	1.409	1.416	1.420	1.376
1715	-	-	-	-	-	-	-	-	-
1915	1.589	1.590	1.591	1.589	1.590	1.591	1.589	1.590	1.588
0900	1.641	1.642	1.642	1.641	1.642	1.642	1.641	1.642	1.641

Table 9.

## Current Distribution Studies

Test made with KXH-7 plate cell, with two center plates removed and with nine reference electrodes.

## Charge and overcharge

Time	Cur- rent	Grav- ity	Voltage Cell	Voltage-Lead Electrode								
				1	2	3	4	5	6	7	8	9
0900	0-6	1160	1.997-2.160	.349	.348	.348	.348	.348	.348	.347	.348	.348
0906	6	-	2.260	.400	.400	.394	.400	.398	.397	.403	.404	.395
0915	6	-	2.255	.400	.401	.396	.402	.400	.399	.405	.407	.397
0930	6	-	2.250	.401	.402	.398	.403	.401	.401	.406	.410	.399
1000	6	-	2.245	.402	.404	.400	.405	.403	.403	.407	.413	.401
1030	6	1160	2.248	.404	.406	.402	.407	.406	.406	.410	.416	.403
1057	6	-	2.248	.405	.408	.404	.409	.408	.408	.412	.418	.404
1200	6	1165	2.258	.410	.412	.407	.413	.411	.411	.417	.422	.406
1245	6	-	2.268	.414	.415	.410	.417	.415	.415	.422	.424	.409
1345	6	1175	2.284	.419	.419	.413	.422	.420	.420	.428	.428	.412
1500	6	1180	2.312	.426	.426	.420	.432	.429	.428	.439	.437	.418
1600	6	-	2.395	.441	.439	.437	.448	.444	.443	.459	.453	.430
1630	6	1195	2.455	.455	.461	.469	.467	.469	.471	.478	.479	.462
1715	6	-	2.550	.523	.537	.544	.535	.541	.542	.539	.547	.536
1751	6	-	2.568	.548	.555	.558	.554	.558	.558	.557	.562	.552
1848	6	1200	2.567	.549	.554	.557	.553	.554	.554	.555	.560	.550
1924	6	-	2.567	.548	.554	.555	.553	.554	.554	.556	.561	.550
2027	6	-	2.566	.547	.552	.555	.552	.553	.553	.554	.559	.548
2300	6-0	1200	2.567-2.340	.546	.552	.553	.551	.552	.552	.554	.559	.548
1000	0	1200	2.082	.358	.359	.358	.358	.358	.358	.358	.358	.358
2130	0	1200	2.059	.358	.358	.358	.358	.358	.358	.358	.358	.358

Time	Gassing	Voltages-Peroxide Electrode								
		1	2	3	4	5	6	7	8	9
0900	none	1.642	1.643	1.643	1.643	1.643	1.643	1.643	1.644	1.643
0906	-	1.855	1.854	1.860	1.853	1.856	1.857	1.841	1.850	1.859
0915	-	1.849	1.848	1.853	1.848	1.850	1.851	1.845	1.843	1.853
0930	-	1.842	1.840	1.845	1.841	1.843	1.842	1.838	1.833	1.845
1000	-	1.835	1.833	1.837	1.833	1.834	1.834	1.830	1.824	1.837
1030	-	1.834	1.832	1.831	1.833	1.833	1.832	1.828	1.822	1.835
1057	-	1.834	1.832	1.836	1.831	1.833	1.833	1.828	1.822	1.836
1200	very slight	1.840	1.838	1.843	1.836	1.838	1.838	1.832	1.828	1.842
1245	-	1.846	1.845	1.850	1.843	1.844	1.845	1.838	1.836	1.851
1345	slight	1.859	1.858	1.864	1.855	1.857	1.857	1.848	1.848	1.865
1500	-	1.881	1.882	1.888	1.877	1.879	1.880	1.869	1.870	1.889
1600	moderate	1.942	1.943	1.944	1.933	1.937	1.937	1.921	1.928	1.950
1630	strong on PbO <sub>2</sub>	1.987	1.978	1.968	1.974	1.971	1.969	1.965	1.964	1.982
1715	strong on both	2.007	1.695	1.688	1.997	1.992	1.991	1.993	1.986	1.997

Table 9 (continued)

Time	Gassing	Voltages-Peroxide Electrode								
		1	2	3	4	5	6	7	8	9
1751	-	2.006	2.000	1.997	2.000	1.999	1.999	1.998	1.993	2.003
1848	vigorous	2.006	2.000	1.997	2.000	2.000	1.999	1.998	1.993	2.003
1924	-	2.006	2.001	2.000	2.002	2.001	2.001	2.000	1.995	2.006
2027	-	2.007	2.001	1.999	2.002	2.001	2.001	2.000	1.995	2.005
2300	-	2.009	2.004	2.002	2.004	2.003	2.003	2.002	1.998	2.008
1000	-	1.715	1.715	1.715	1.715	1.716	1.715	1.715	1.716	1.715
2130	-	1.692	1.692	1.692	1.692	1.692	1.692	1.692	1.692	1.692

Table 10.

## Current Distribution Studies

Test made with KXH, 7-plate cell with two center plates removed and six reference electrodes

Discharge, discharge rate 6 amperes

Time	Gravity	Current	Voltage Cell	Voltage-Lead Electrode					
				1	2	3	4	5	6
1030	-	0	2.019	.350	.350	.350	.350	.350	.350
1215	-	0-6	2.018-1.746	.350	.350	.350	.350	.350	.351
1230	-	6	1.660	.240	.241	.237	.236	.236	.240
1300	1175	6	1.647	.231	.232	.221	.228	.228	.230
1415	-	6	1.615	.219	.219	.212	.216	.222	.211
1530	1150	6	1.581	.207	.207	.192	.200	.204	.190
1645	-	6	1.420	.197	.183	.150	.175	1.68	.140
1800	1145	6-0	1.020-1.800	-.132	-.240	-.303	-.236	-.290	-.330

Time	Voltages-Lead-Electrode					
	1	2	3	4	5	6
1030	1.670	1.670	1.670	1.670	1.670	1.670
1215	1.670	1.670	1.670	1.670	1.670	1.670
1230	1.419	1.419	1.423	1.424	1.424	1.419
1415	1.415	1.416	1.421	1.420	1.420	1.417
1530	1.399	1.398	1.406	1.402	1.395	1.406
1645	1.380	1.380	1.396	1.387	1.383	1.397
1800	1.164	1.290	1.358	1.287	1.346	1.384

Table 11.

## Current Distribution Studies

Test made with KXH Cell, 7-plate, with two center plates removed and six reference electrodes.

Charge, rate of charge 0 amperes.

Time	Current	Gravity	Gassing	Voltage Cell	Voltages-Lead Electrode					
					1	2	3	4	5	6
0900	0 - 6	1150	none	1.982-2.180	.338	.338	.338	.338	.338	.338
0906	6	-	-	2.500	.385	.385	.393	.389	.386	.392
0930	6	-	-	2.267	.389	.388	.395	.393	.389	.393
1020	6	-	-	2.268	.395	.393	.400	.400	.394	.398
1200	6	1155	-	2.285	.403	.403	.411	.410	.405	.410
1315	6	-	very slight	2.315	.412	.415	.423	.423	.419	.422
1345	6	1160	-	2.330	.417	.419	.427	.427	.423	.424
1520	6	1180	vigorous on PbO <sub>2</sub>	2.500	.452	.433	.432	.448	.436	.430
1600	6	-	slight on Pb	2.508	.459	.438	.436	.452	.440	.434
1645	6	1185	-	2.512	.463	.441	.439	.457	.444	.438
1815	6	-	strong	2.520	.472	.450	.447	.467	.453	.446
1915	6	1187	-	2.525	.479	.457	.453	.474	.461	.453
2130	6	1190	-	2.547	.502	.480	.473	.499	.486	.475
2245	6 - 0	1193	-	2.570-2.320	.520	.499	.491	.517	.506	.495

Time	Voltages-Peroxide Electrode					
	1	2	3	4	5	6
0900	1.649	1.649	1.650	1.650	1.649	1.650
0906	1.887	1.886	1.880	1.884	1.886	1.882
0930	1.880	1.880	1.874	1.875	1.879	1.875
1020	1.875	1.876	1.870	1.870	1.876	1.872
1200	1.878	1.887	1.878	1.880	1.885	1.880
1315	1.907	1.904	1.897	1.898	1.902	1.899
1345	1.917	1.915	1.908	1.907	1.913	1.911
1520	2.051	2.068	2.069	2.054	2.066	2.070
1600	2.051	2.073	2.075	2.057	2.070	2.076
1645	2.053	2.075	2.076	2.059	2.070	2.077
1815	2.052	2.073	2.077	2.058	2.070	2.078
1915	2.051	2.073	2.078	2.057	2.070	2.078
2130	2.050	2.072	2.079	2.054	2.067	2.078
2245	2.052	2.072	2.080	2.054	2.067	2.078

Table 12.

Current Distribution Studies

Test with two plates, peroxide plate inverted. Nine reference electrodes used  
 Charge, charging rate 1.5 amperes  
 Room temperature approximately 80° F.

Time	Current	Gravity	Gassing	Voltage Cell	Voltage-Lead Electrodes									
					1	2	3	4	5	6	7	8	9	
0900	0-1.5	1230	none	2.073-2.230	.364	.364	.364	.364	.364	.364	.364	.364	.364	.364
0906	1.5	-	-	2.288	.434	.433	.430	.434	.433	.430	.434	.431	.429	.429
0924	1.5	-	-	2.252	.458	.436	.434	.438	.437	.435	.439	.436	.434	.434
0945	1.5	1230	-	2.248	.405	.403	.400	.404	.403	.400	.404	.401	.399	.399
1018	1.5	-	-	2.242	.407	.405	.402	.405	.405	.402	.406	.404	.401	.401
1045	1.5	-	-	2.241	.408	.406	.403	.407	.406	.403	.407	.405	.403	.403
1130	1.5	-	-	2.243	.409	.407	.405	.408	.407	.404	.408	.406	.404	.404
1215	1.5	1230	-	2.246	.410	.409	.406	.410	.408	.406	.409	.407	.405	.405
1245	1.5	-	-	2.249	.411	.409	.407	.410	.409	.406	.410	.407	.406	.406
1421	1.5	1232	-	2.258	.414	.411	.409	.413	.411	.409	.412	.410	.408	.408
1545	1.5	-	-	2.265	.415	.413	.411	.414	.413	.410	.414	.412	.410	.410
1715	1.5	1235	-	2.277	.418	.415	.413	.417	.415	.413	.416	.414	.412	.412
1818	1.5	-	-	2.288	.419	.417	.414	.418	.417	.414	.418	.415	.414	.414
2015	1.5	1240	very slight	2.320	.425	.422	.420	.424	.422	.419	.423	.421	.419	.419
2200	1.5	-	slight	2.387	.448	.444	.442	.445	.443	.441	.445	.442	.441	.441
2315	1.5	1240	medium	2.510	.527	.523	.521	.528	.525	.523	.528	.526	.524	.524
2406	1.5	1243	quite strong	2.630	.622	.619	.618	.620	.619	.618	.620	.618	.618	.618
2430	1.5	-	-	2.655	.640	.637	.637	.638	.637	.637	.637	.637	.636	.635
2500	1.5	-	-	2.670	.650	.648	.648	.648	.647	.646	.647	.646	.645	.645
2530	1.5	1245	-	2.676	.654	.651	.652	.651	.650	.650	.651	.649	.649	.649
2630	1.5	1245	-	2.685	.658	.656	.656	.656	.655	.655	.655	.654	.653	.653
2745	1.5	-	-	2.692	.663	.660	.661	.661	.660	.660	.659	.661	.659	.658
3015	1.5-0	-	-	2.708-2.360	.670	.667	.668	.668	.666	.666	.666	.668	.666	.665
3145	0	-	-	2.188	.363	.364	.364	.364	.364	.364	.364	.364	.364	.364

Table 12 (continued)

Time	Voltages-Peroxide Electrode								
	1	2	3	4	5	6	7	8	9
0900	1.713	1.713	1.713	1.713	1.713	1.713	1.713	1.713	1.713
0906	1.852	1.854	1.857	1.853	1.855	1.857	1.854	1.856	1.858
0924	1.846	1.848	1.851	1.848	1.849	1.852	1.848	1.850	1.952
0945	1.839	1.841	1.844	1.840	1.842	1.844	1.840	1.843	1.845
1018	1.833	1.835	1.838	1.834	1.835	1.838	1.834	1.836	1.838
1045	1.831	1.833	1.835	1.831	1.833	1.835	1.831	1.834	1.836
1130	1.830	1.832	1.835	1.831	1.833	1.835	1.831	1.834	1.836
1215	1.832	1.834	1.837	1.833	1.834	1.837	1.833	1.836	1.838
1245	1.833	1.836	1.838	1.834	1.836	1.838	1.835	1.837	1.839
1421	1.839	1.842	1.845	1.841	1.843	1.845	1.841	1.844	1.845
1545	1.846	1.849	1.851	1.848	1.849	1.852	1.848	1.851	1.852
1715	1.857	1.859	1.862	1.858	1.860	1.862	1.858	1.861	1.863
1818	1.866	1.869	1.872	1.868	1.870	1.872	1.868	1.871	1.872
2015	1.892	1.895	1.898	1.894	1.896	1.898	1.895	1.897	1.899
2200	1.931	1.934	1.937	1.934	1.937	1.939	1.936	1.939	1.940
2315	1.967	1.971	1.973	1.970	1.973	1.976	1.972	1.975	1.977
2406	1.994	2.000	1.998	1.997	2.000	2.000	1.999	2.000	2.001
2430	2.004	2.007	2.007	2.007	2.008	2.009	2.008	2.010	2.010
2500	2.012	2.015	2.014	2.015	2.016	2.016	2.016	2.017	2.018
2530	2.016	2.018	2.018	2.018	2.019	2.010	2.018	2.020	2.021
2630	2.020	2.022	2.022	2.022	2.023	2.024	2.023	2.024	2.025
2745	2.023	2.026	2.025	2.036	2.027	2.027	2.026	2.028	2.029
3015	2.030	2.032	2.032	2.032	2.033	2.034	2.032	2.034	2.035
3145	1.830	1.829	1.830	1.830	1.830	1.830	1.829	1.829	1.829

Table 13.

## Current Distribution Studies

Test with two plates, peroxide plate inverted. Nine reference electrodes used.

Discharge, rate of discharge, 2 amperes.

Time	Current	Grav- ity	Voltage Cell	Voltages-Lead Electrode								
				1	2	3	4	5	6	7	8	9
1200	0 - 2	1245	2.158-1.835	.365	.366	.365	.365	.366	.366	.366	.366	.366
1206	2	-	1.840	.171	.174	.172	.173	.172	.178	.169	.170	.172
1230	2	-	1.840	.176	.178	.176	.177	.177	.183	.172	.175	.173
1409	2	1240	1.820	.172	.175	.174	.175	.174	.172	.169	.172	.171
1518	2	-	1.810	.170	.172	.172	.172	.171	.170	.170	.170	.169
1600	2	-	1.802	.168	.170	.170	.169	.169	.168	.168	.168	.167
1700	2	1235	1.792	.165	.168	.168	.167	.168	.167	.166	.166	.165
1800	2	-	1.779	.162	.166	.166	.165	.167	.165	.164	.165	.163
1930	2-0	1235	1.752-2.000	.156	.158	.159	.161	.161	.159	.159	.160	.158

Time	Voltages-Peroxide Electrode								
	1	2	3	4	5	6	7	8	9
1200	1.800	1.800	1.799	1.799	1.799	1.799	1.799	1.799	1.799
1206	1.668	1.666	1.668	1.666	1.666	1.660	1.671	1.669	1.670
1230	1.664	1.662	1.664	1.662	1.662	1.656	1.667	1.664	1.666
1409	1.648	1.645	1.646	1.646	1.647	1.648	1.652	1.648	1.649
1518	1.641	1.640	1.639	1.640	1.640	1.641	1.641	1.641	1.643
1600	1.637	1.635	1.635	1.635	1.635	1.636	1.637	1.637	1.638
1700	1.629	1.627	1.627	1.627	1.626	1.627	1.628	1.627	1.629
1800	1.619	1.617	1.616	1.616	1.615	1.616	1.617	1.616	1.618
1930	1.600	1.597	1.597	1.597	1.596	1.597	1.598	1.597	1.599





Table 15.

## Current Distribution Studies

Test made with two plates and three reference electrodes. Nine lead leads soldered to the back of each plate.

Discharge, 1 ampere.

Time	Gravity	Voltage Cell	Voltages					
			Lead Electrode			Peroxide Electrode		
			1	2	3	1	2	3
0900	1245	2.092-1.940	.371	.371	.371	1.724	1.724	1.724
0920	-	1.915	.322	.322	.323	1.595	1.594	1.592
1215	-	1.980	.321	.322	.324	1.661	1.660	1.658
1430	1242	1.976	.320	.320	.322	1.659	1.658	1.656
1630	-	1.973	.319	.320	.321	1.656	1.656	1.654
1900	1236	1.965	.316	.317	.319	1.652	1.651	1.649
2215	1233	1.955	.312	.314	.314	1.645	1.643	1.641
0915	1227	1.892	.297	.299	.301	1.597	1.595	1.593
1045	-	1.871	.293	.295	.297	1.578	1.576	1.574
1215	-	1.850	.290	.292	.293	1.560	1.558	1.557
1415	-	1.811	.282	.284	.284	1.529	1.527	1.527
1630	1220	1.415	.210	.212	.201	1.255	1.249	1.252
1645	-	.800-1.760	-	-	-	-	-	-

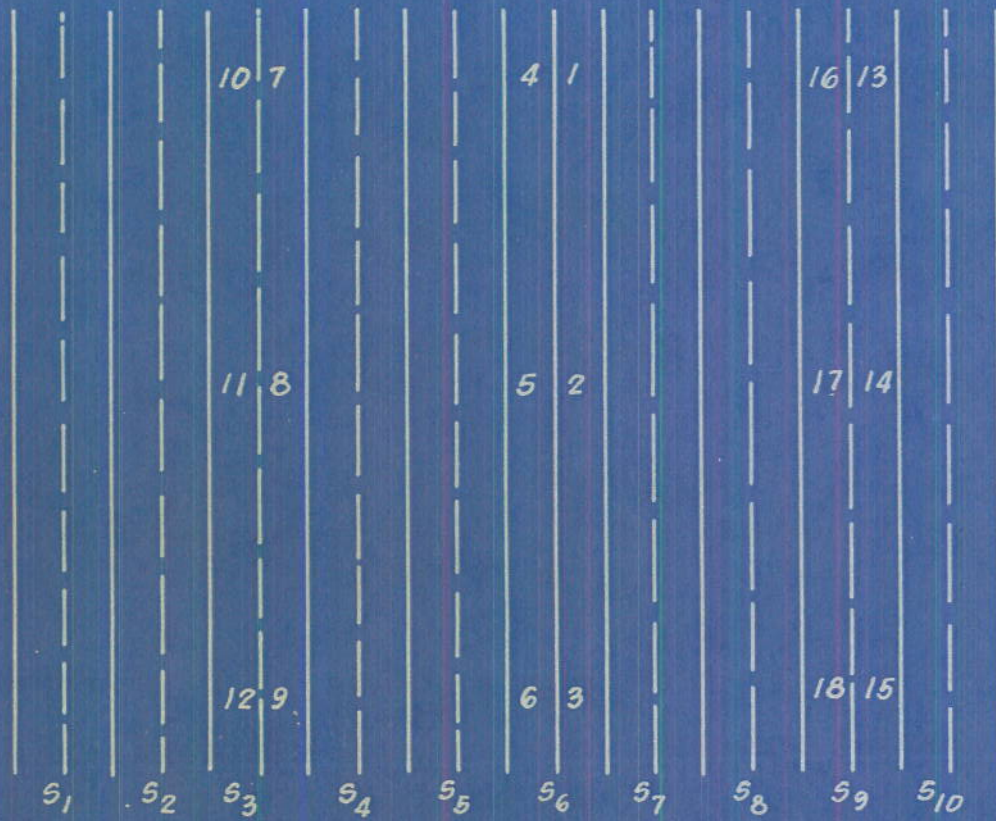
Time	Voltages--Lead Electrode								
	A-4	1-2	1-3	4-5	4-6	7-8	7-9	1-4	1-7
0900	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
0920	.02485	.00013	.00018	.00008	.00013	.00004	.00007	.00008	.00016
1215	.02465	.00013	.00019	.00009	.00013	.00004	.00007	.00008	.00016
1430	.02495	.00013	.00020	.00008	.00013	.00005	.00007	.00008	.00016
1630	.02505	.00013	.00020	.00009	.00013	.00005	.00007	.00009	.00016
1900	.02475	.00014	.00020	.00009	.00013	.00005	.00007	.00010	.00017
2215	.02480	.00014	.00020	.00010	.00013	.00005	.00007	.00010	.00017
0915	.02480	.00015	.00022	.00010	.00015	.00006	.00008	.00010	.00019
1045	.02490	.00015	.00022	.00010	.00015	.00006	.00008	.00010	.00019
1215	.02515	.00016	.00022	.00011	.00015	.00006	.00007	.00011	.00020
1415	.02515	.00015	.00022	.00011	.00014	.00006	.00007	.00011	.00020
1630	.02490	.00017	.00020	.00012	.00010	.00005	.00003	-	-
Time	Voltages--Lead Electrode					Voltages--Peroxide Electrode			
	2-5	2-8	3-6	3-9	A-13	10-11	10-12	13-14	13-15
0900	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
0920	.00004	.00007	.00001	.00003	.01750	.00009	.00013	.00006	.00010
1215	.00004	.00007	.00002	.00003	.01775	.00010	.00015	.00006	.00010
1430	.00004	.00008	.00002	.00004	.01805	.00010	.00014	.00006	.00010
1630	.00004	.00008	.00002	.00004	.01815	.00010	.00014	.00006	.00010
1900	.00005	.00008	.00002	.00004	.01815	.00010	.00015	.00006	.00010
2215	.00005	.00008	.00002	.00004	.01825	.00010	.00015	.00006	.00010
0915	.00005	.00010	.00003	.00004	.01855	.00010	.00014	.00006	.00009
1045	.00005	.00010	.00003	.00005	.01865	.00010	.00014	.00006	.00009
1215	.00006	.00010	.00003	.00005	.01875	.00010	.00014	.00006	.00008
1415	.00007	.00010	.00003	.00005	.01880	.00010	.00014	.00006	.00009
1630	-	-	-	-	.01870	-	-	-	-

Table 15 (continued).

Time	Voltages-Peroxide Electrode					
	16-17	10-13	10-16	11-17	12-15	11-14
0900	.00000	.00000	.00000	.00000	.00000	.00000
0920	.00003	.00006	.00010	.00003	.00000	.00001
1215	.00003	.00006	.00010	.00004	.00000	.00002
1430	.00003	.00006	.00010	.00004	.00000	.00002
1630	.00003	.00006	.00010	.00004	.00000	.00002
1900	.00003	.00006	.00010	.00004	.00000	.00002
2215	.00003	.00006	.00011	.00004	.00000	.00002
0915	.00003	.00006	.00010	.00004	.00000	.00002
1045	.00003	.00006	.00010	.00004	.00000	.00002
1215	.00003	.00006	.00010	.00004	.00000	.00002
1415	.00003	.00006	.00010	.00004	.00000	.00002
1630	.00003	-	-	-	-	-

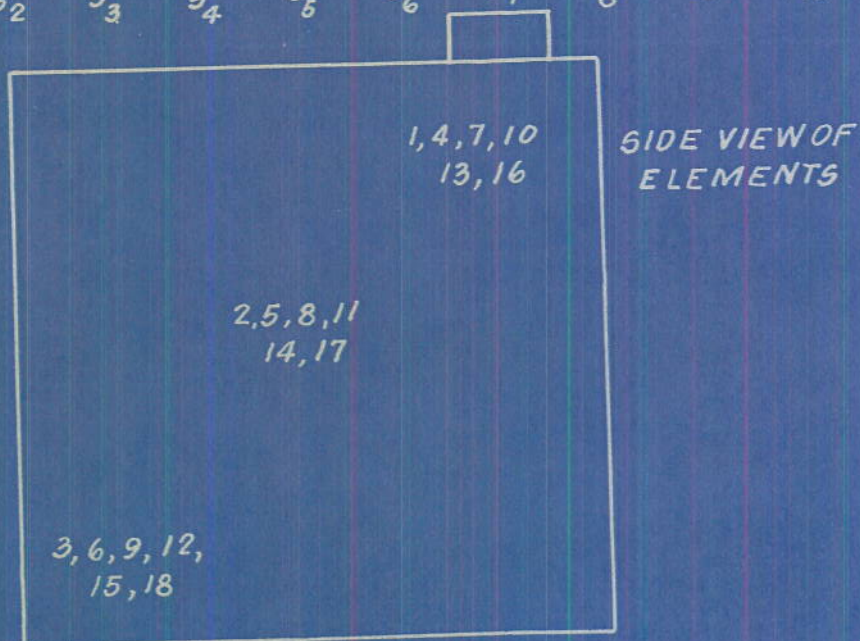
LOCATION OF THERMOCOUPLES--TESTS 1 AND 2

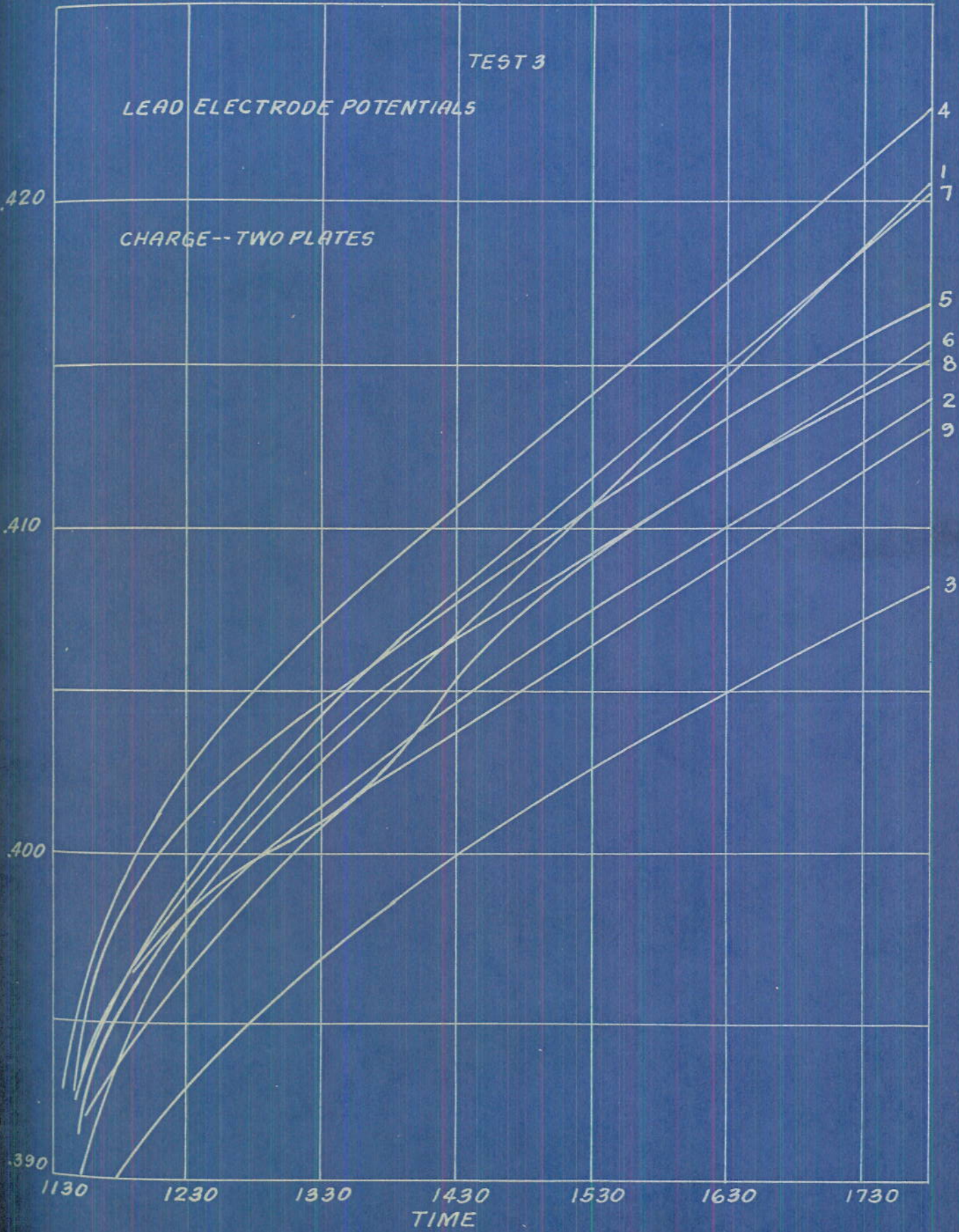
END VIEW OF ELEMENTS



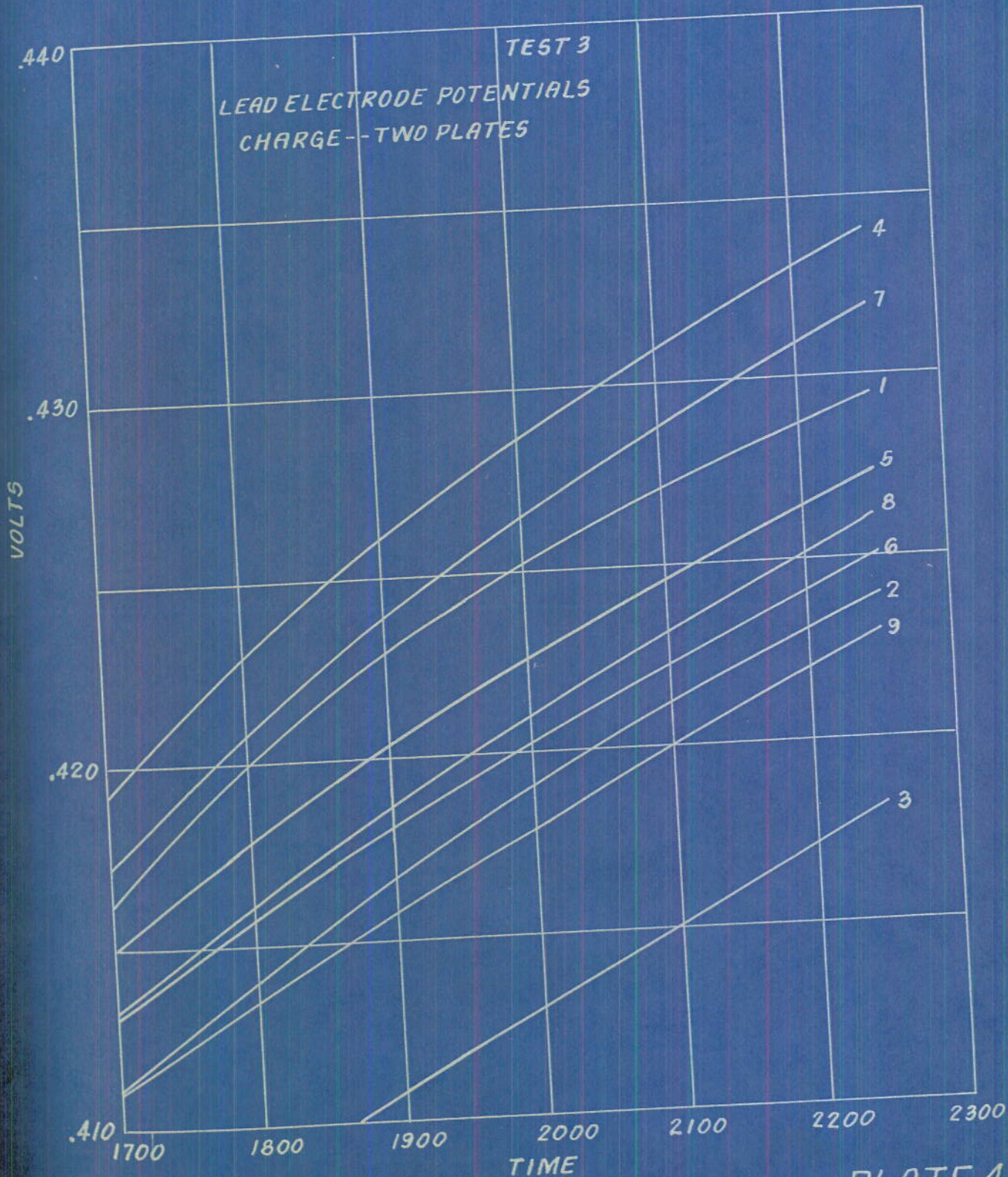
SOLID LINES---PLATES  
BROKEN LINES---SEPARATORS

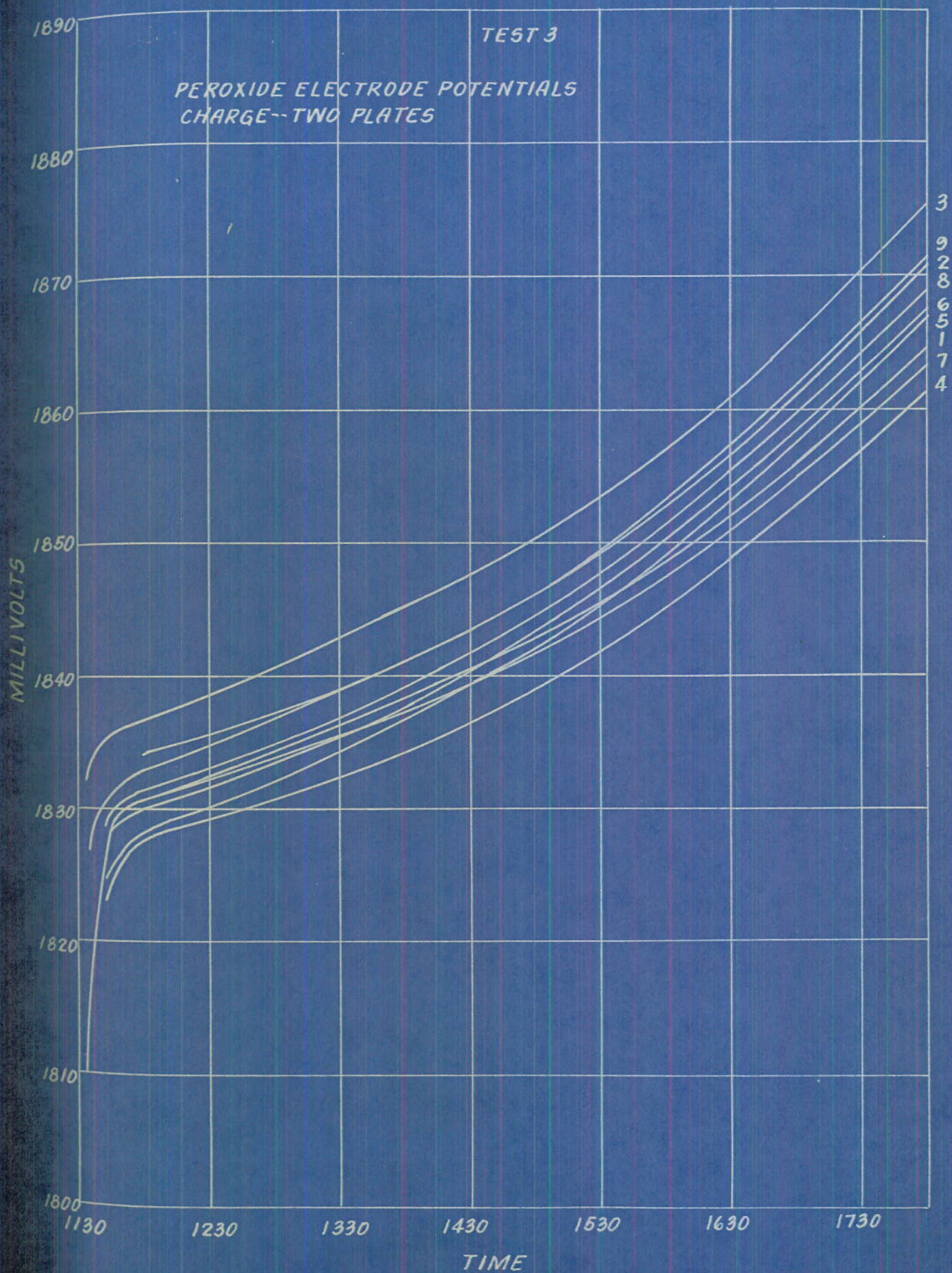
LOCATION OF THERMOCOUPLES---TESTS 1 AND 2  
TOP VIEW OF ELEMENTS

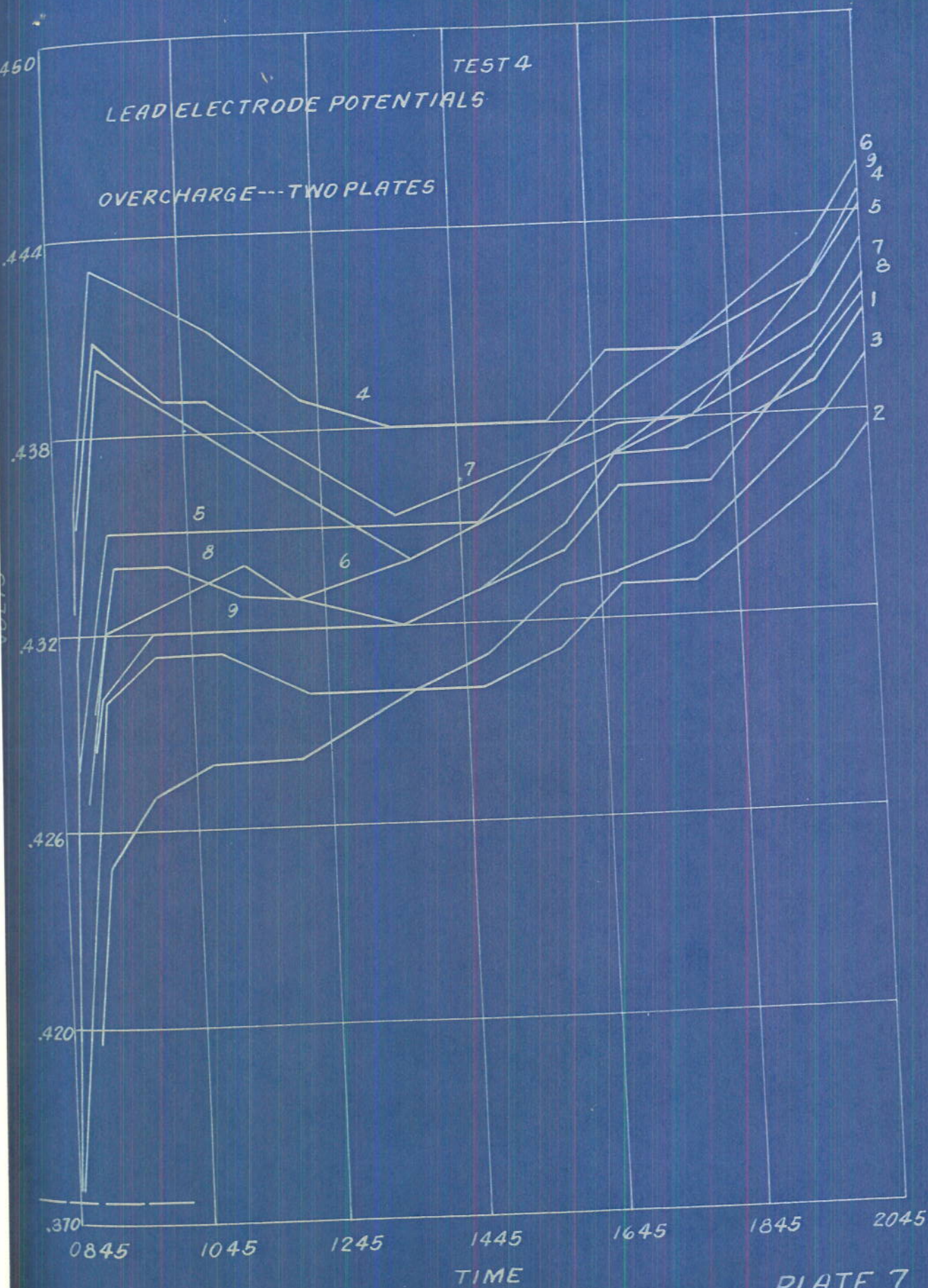


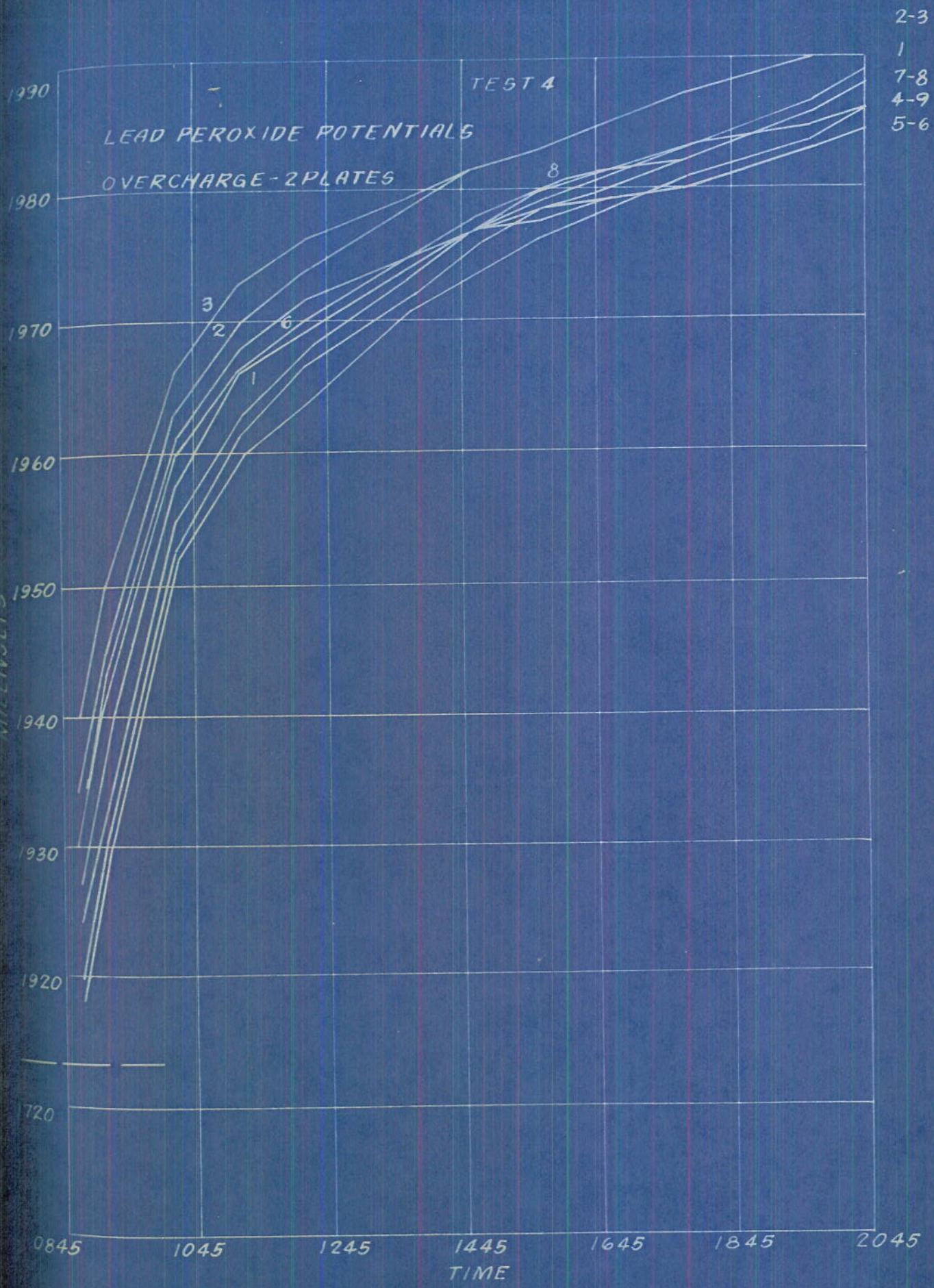


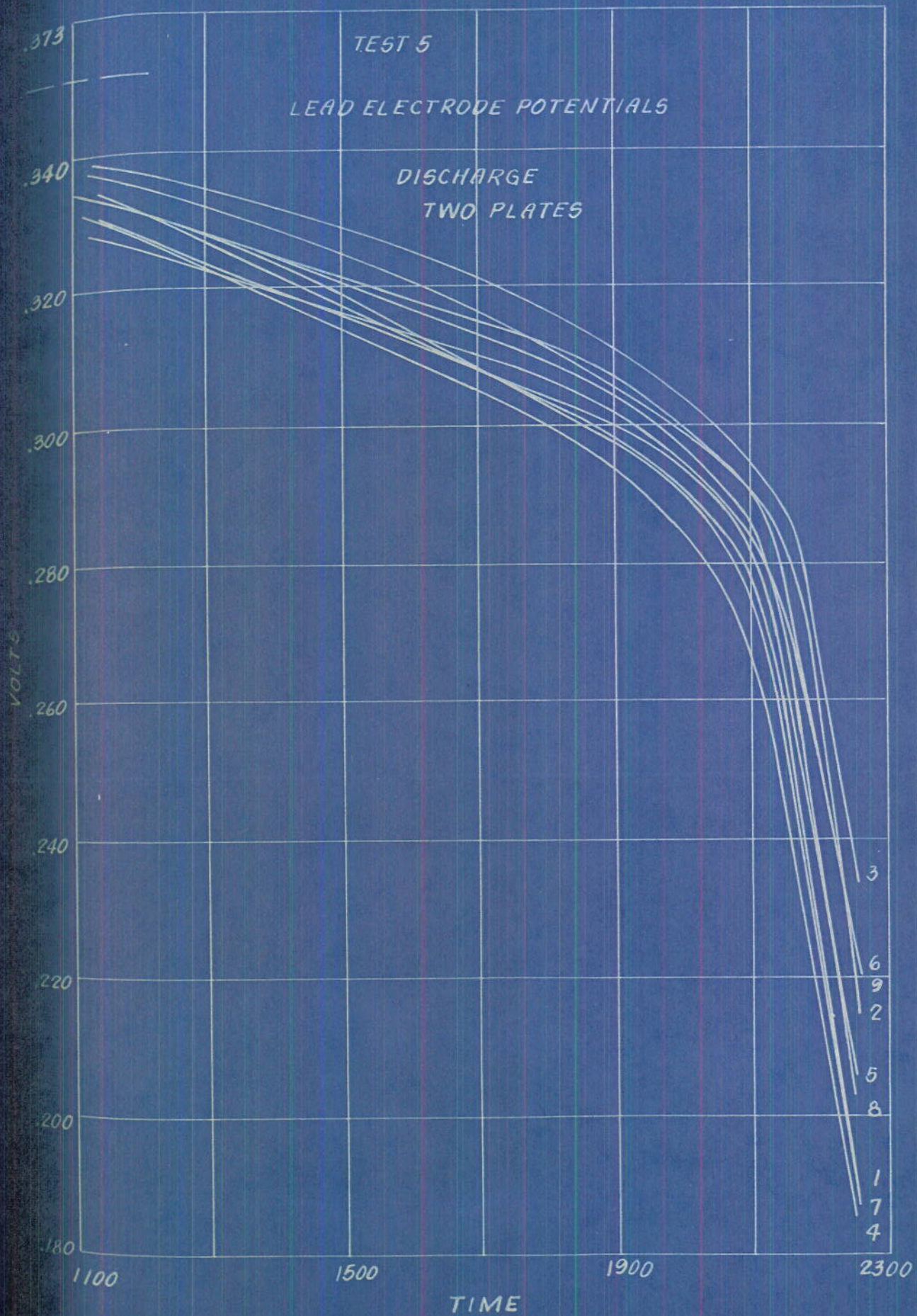
TEST 3  
LEAD ELECTRODE POTENTIALS  
CHARGE--TWO PLATES

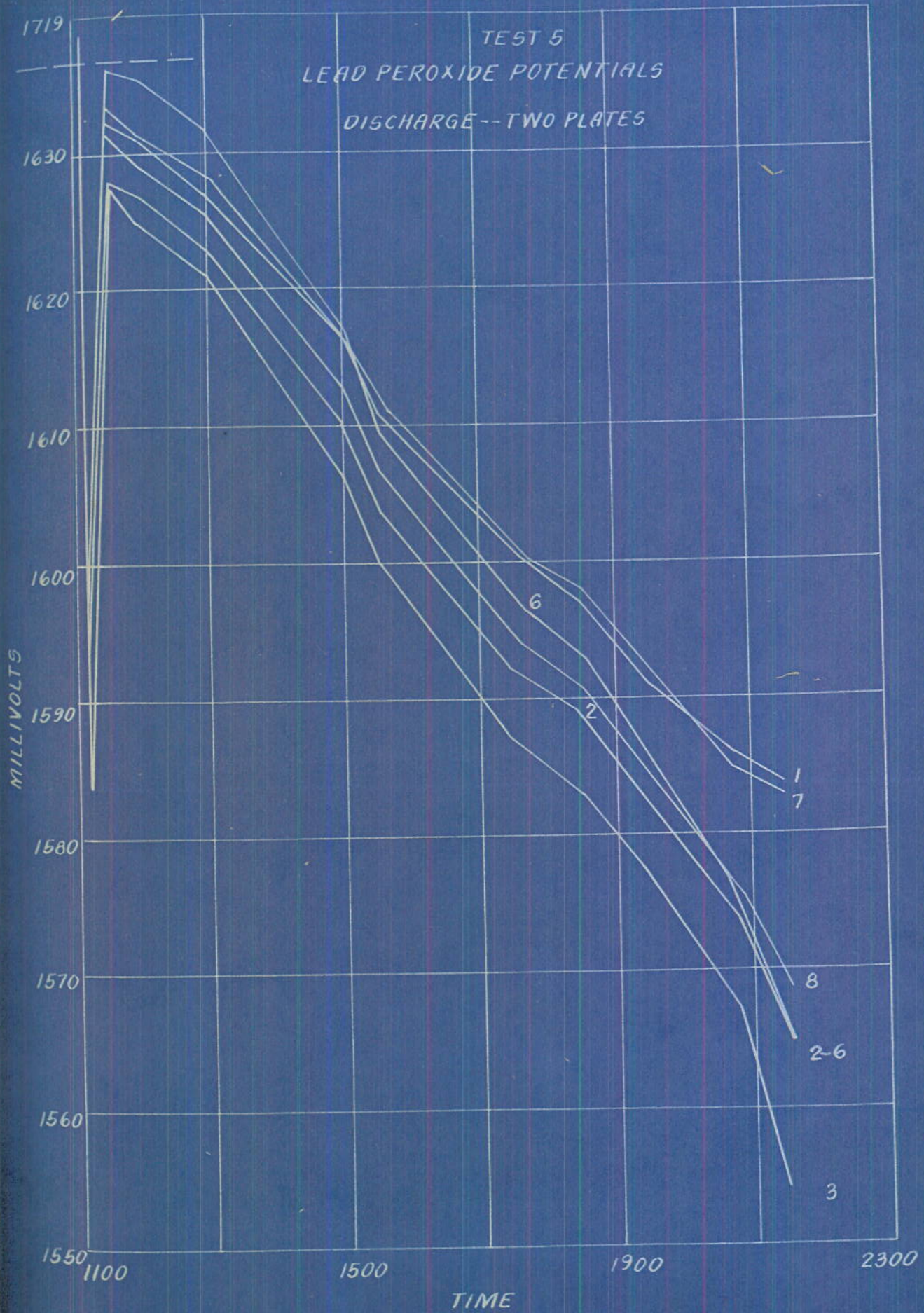










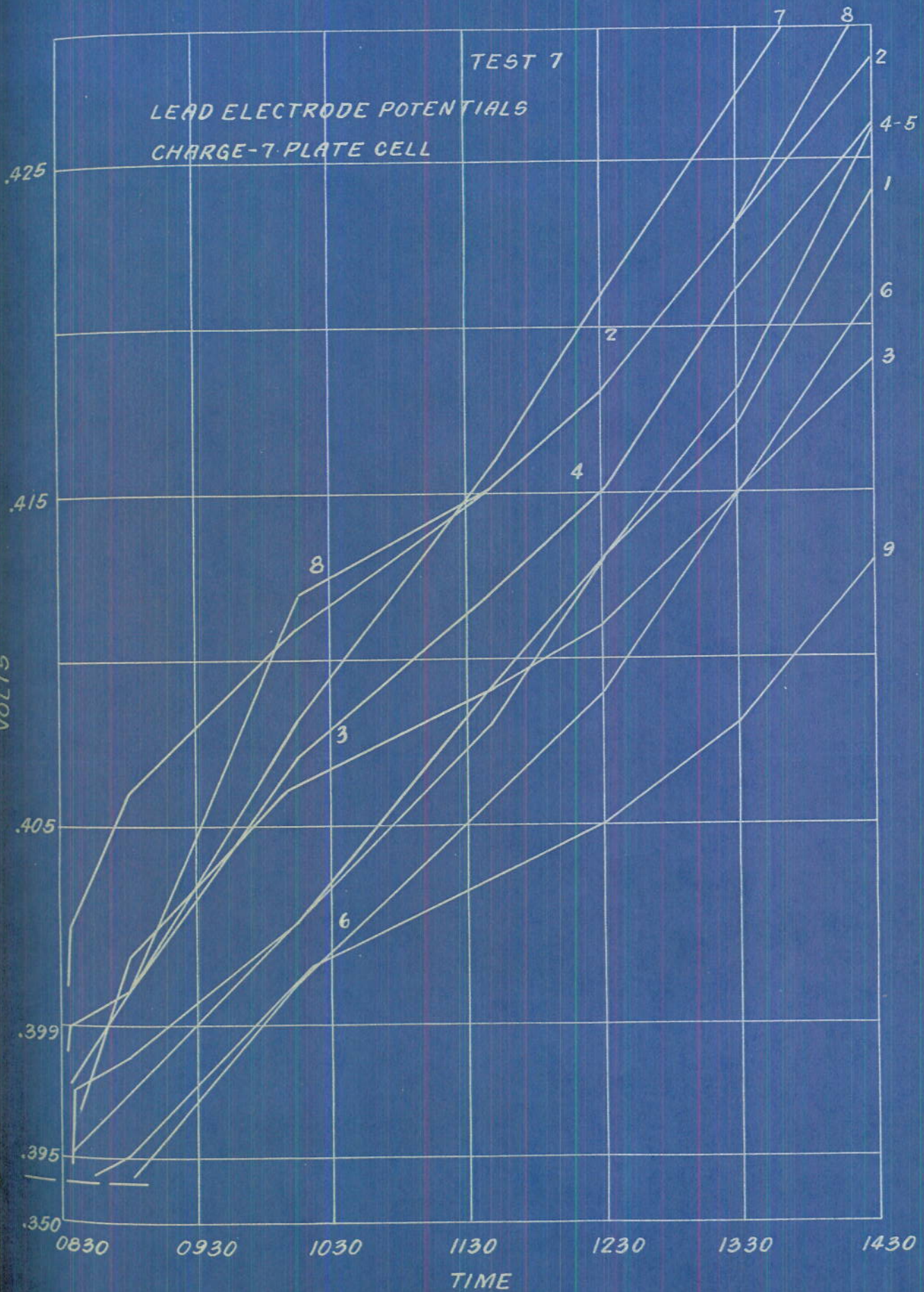


LOCATION OF REFERENCE ELECTRODES --- TESTS 7-9

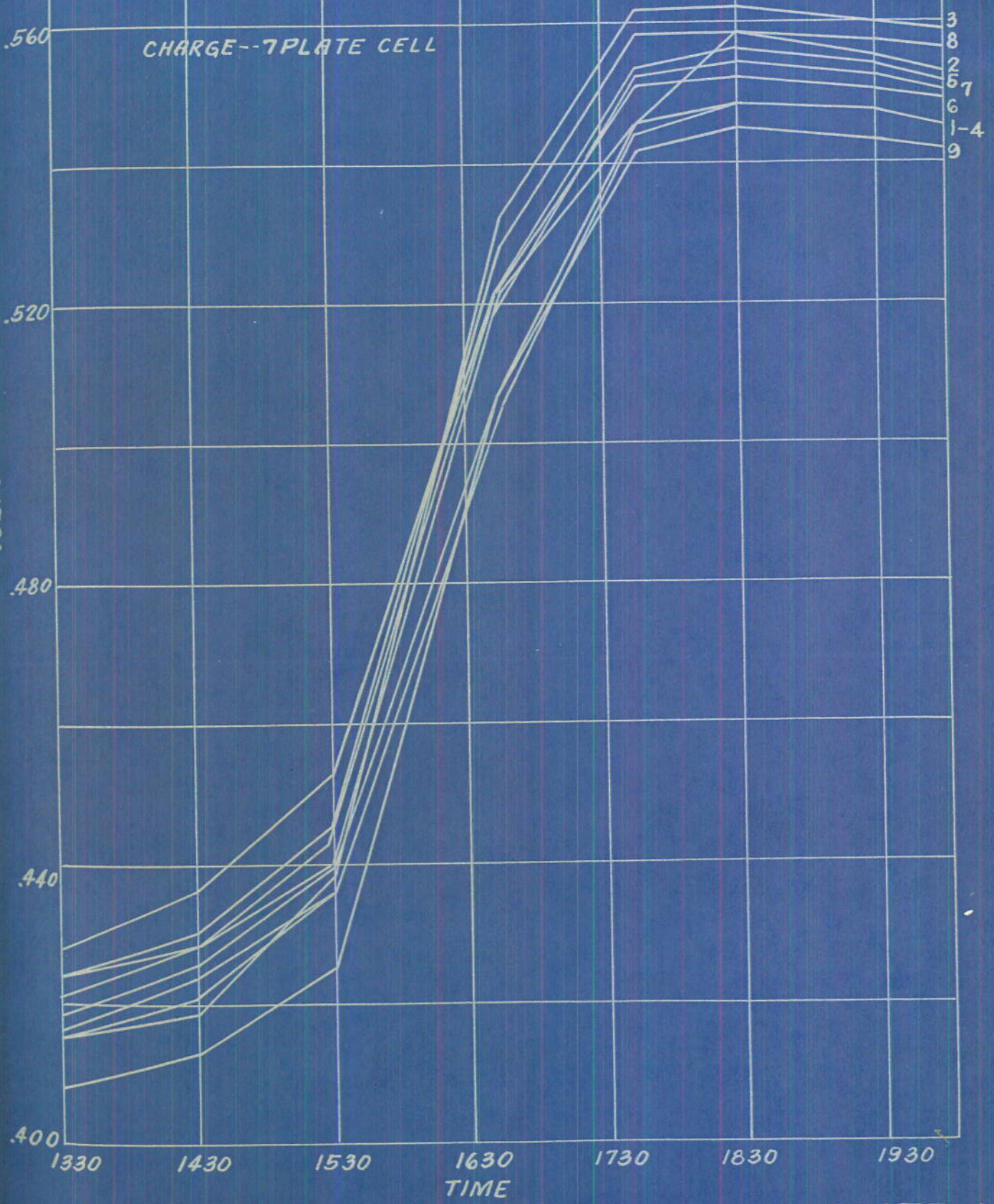


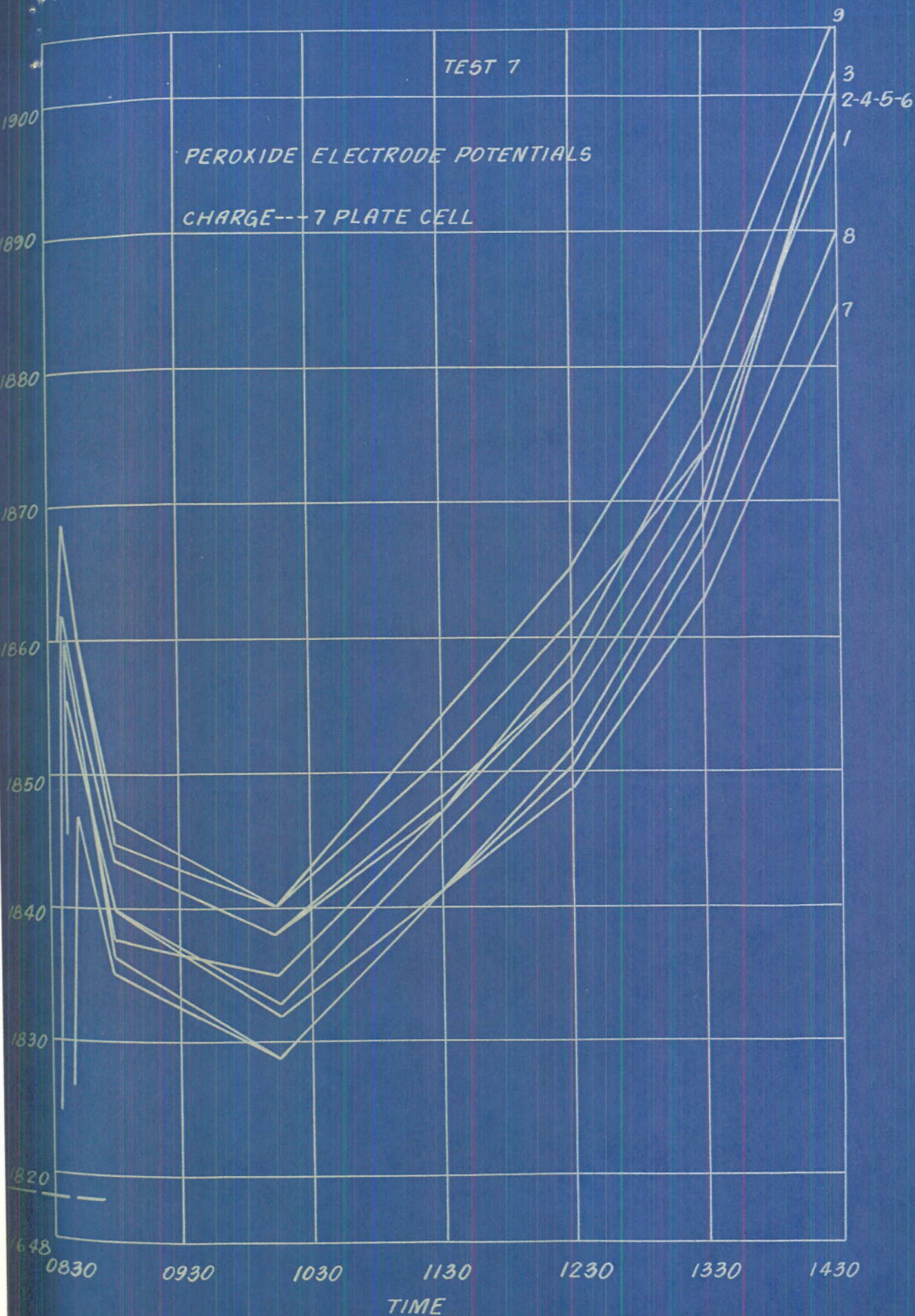
LOCATION OF REFERENCE ELECTRODES --- TESTS 3-6





TEST 7  
LEAD ELECTRODE POTENTIALS





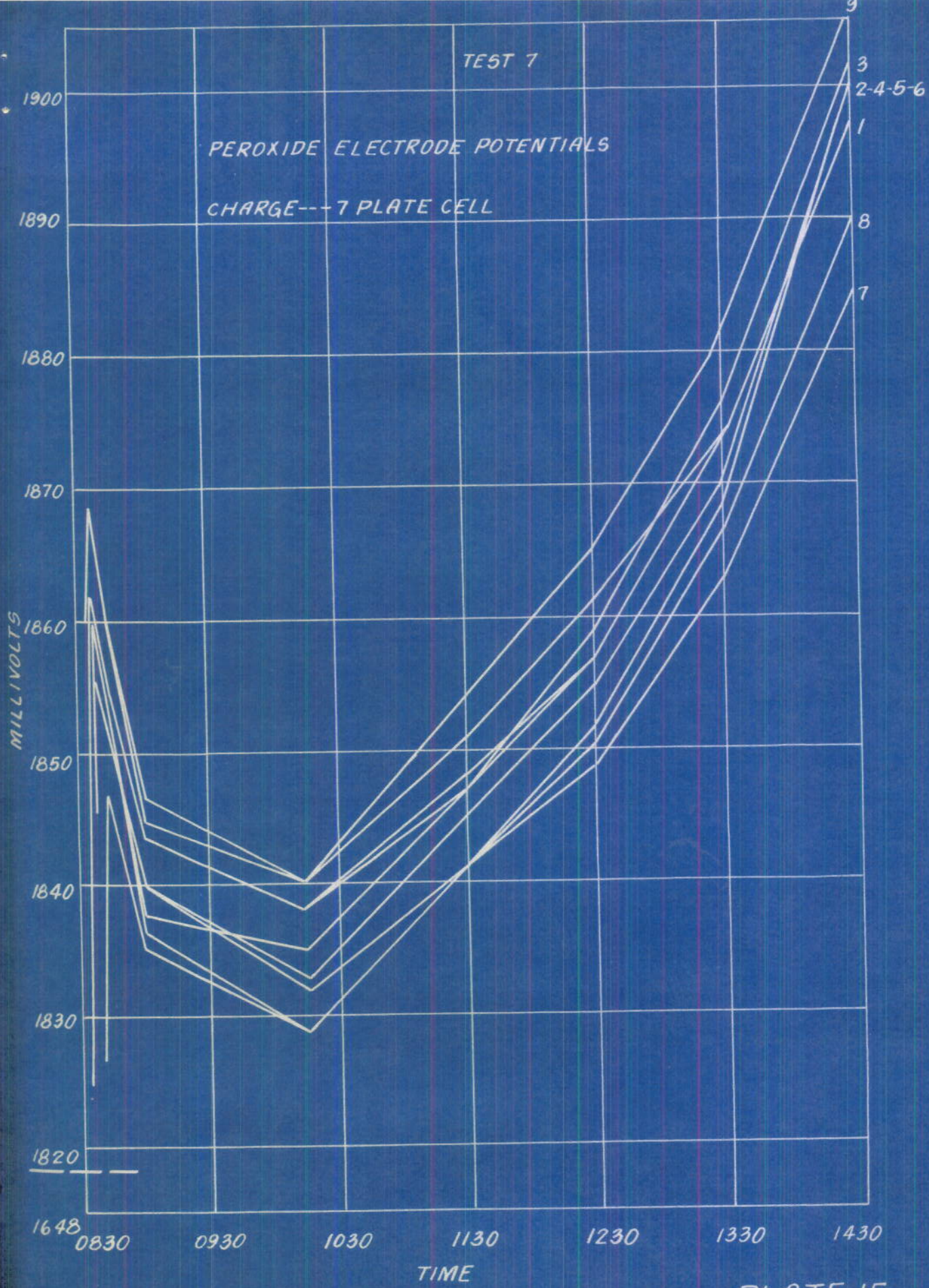


PLATE 15

TEST 7

PEROXIDE ELECTRODE POTENTIALS

CHARGE---7 PLATE CELL

2010

9

1-4

6-7

5

2-8

3

1960

1910

1860

1330

1430

1530

1630

1730

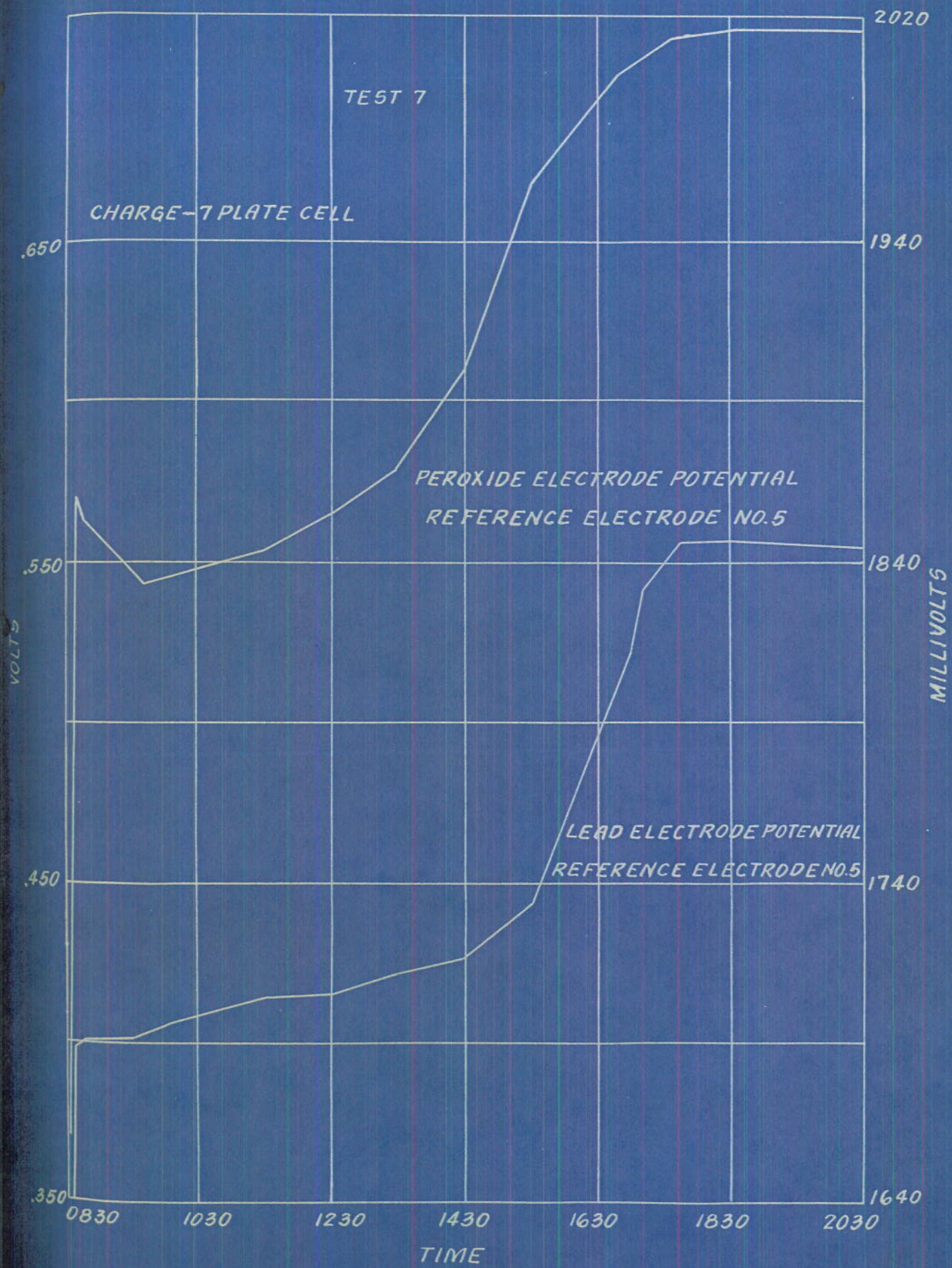
1830

1930

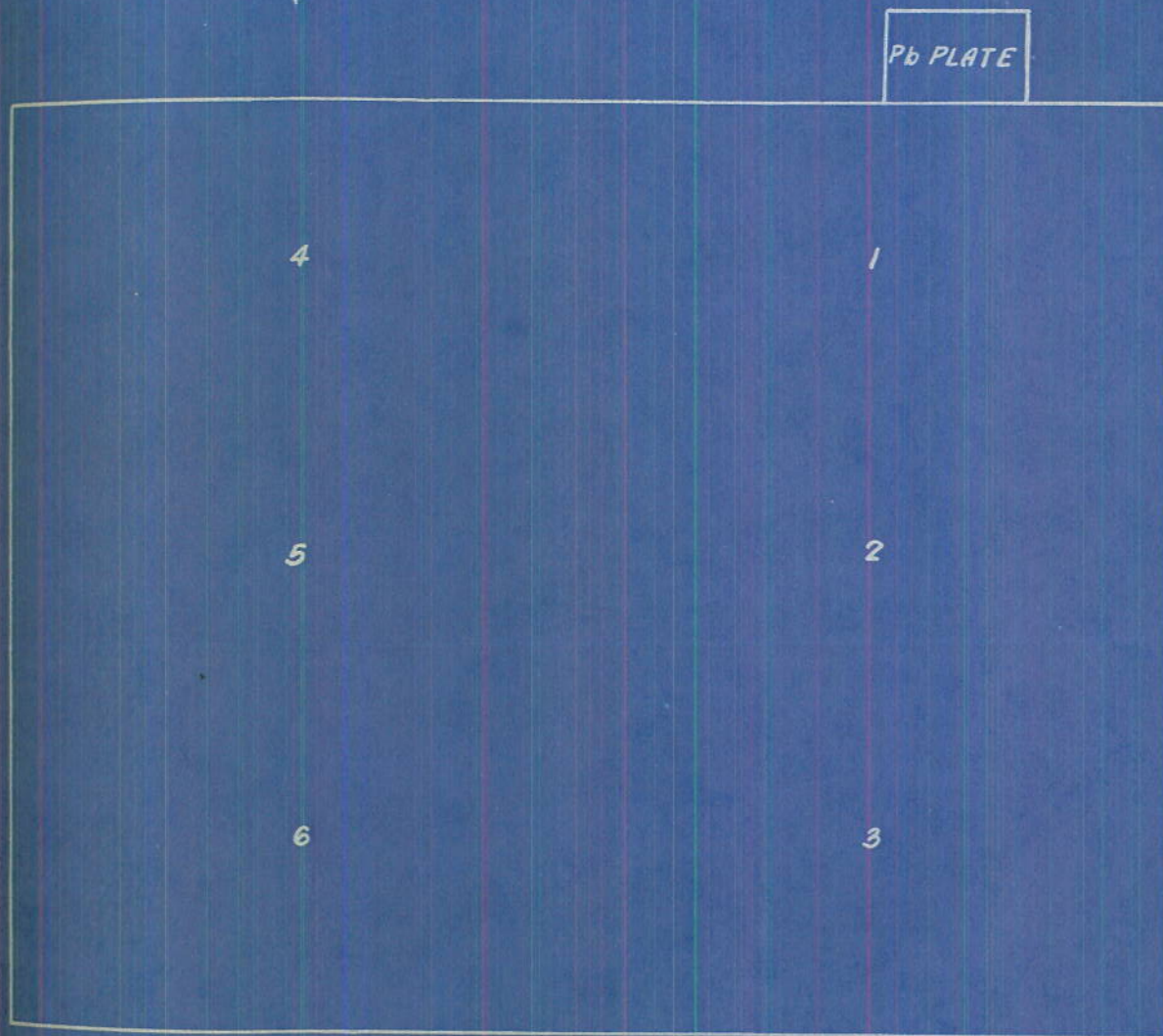
TIME

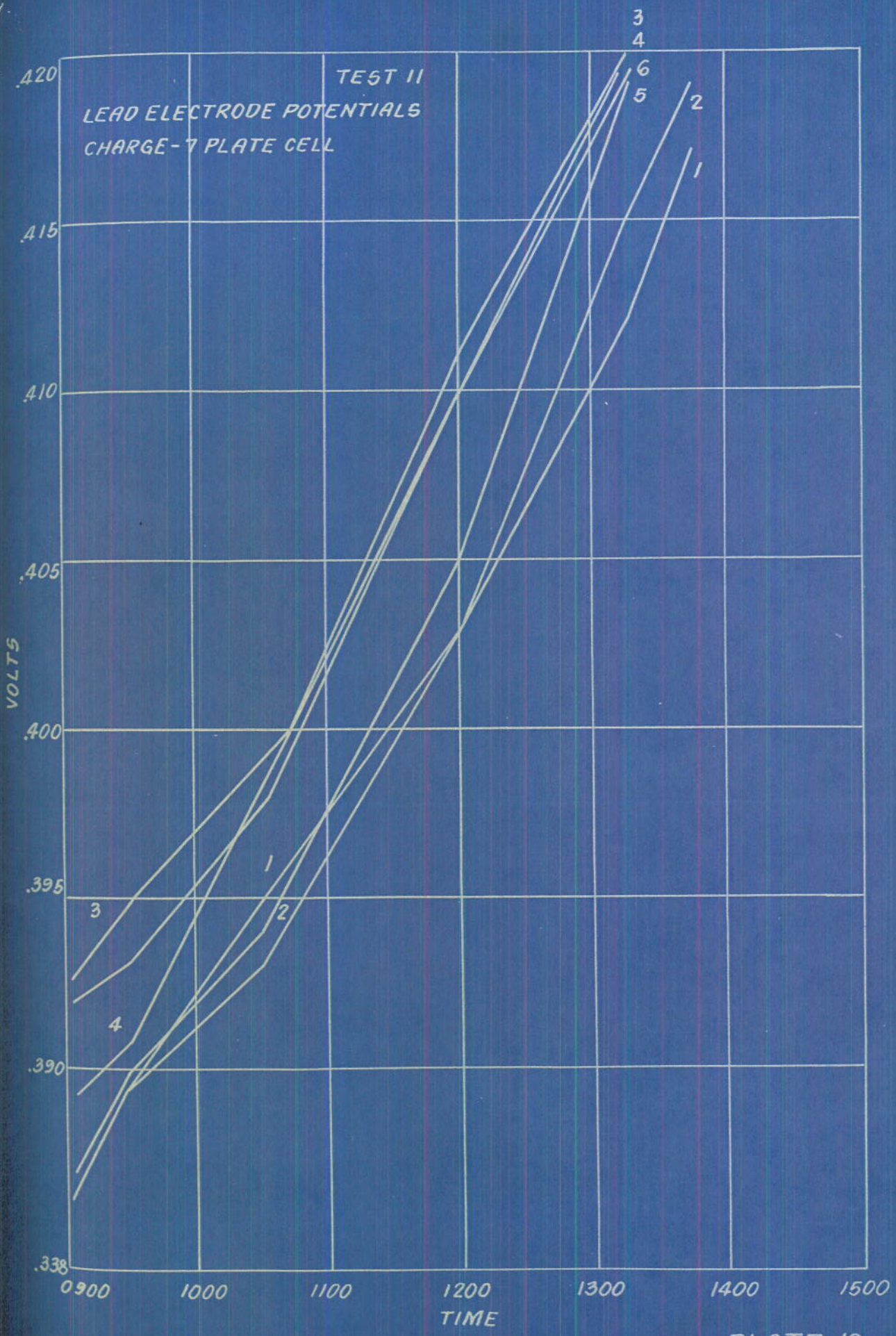
PLATE 16

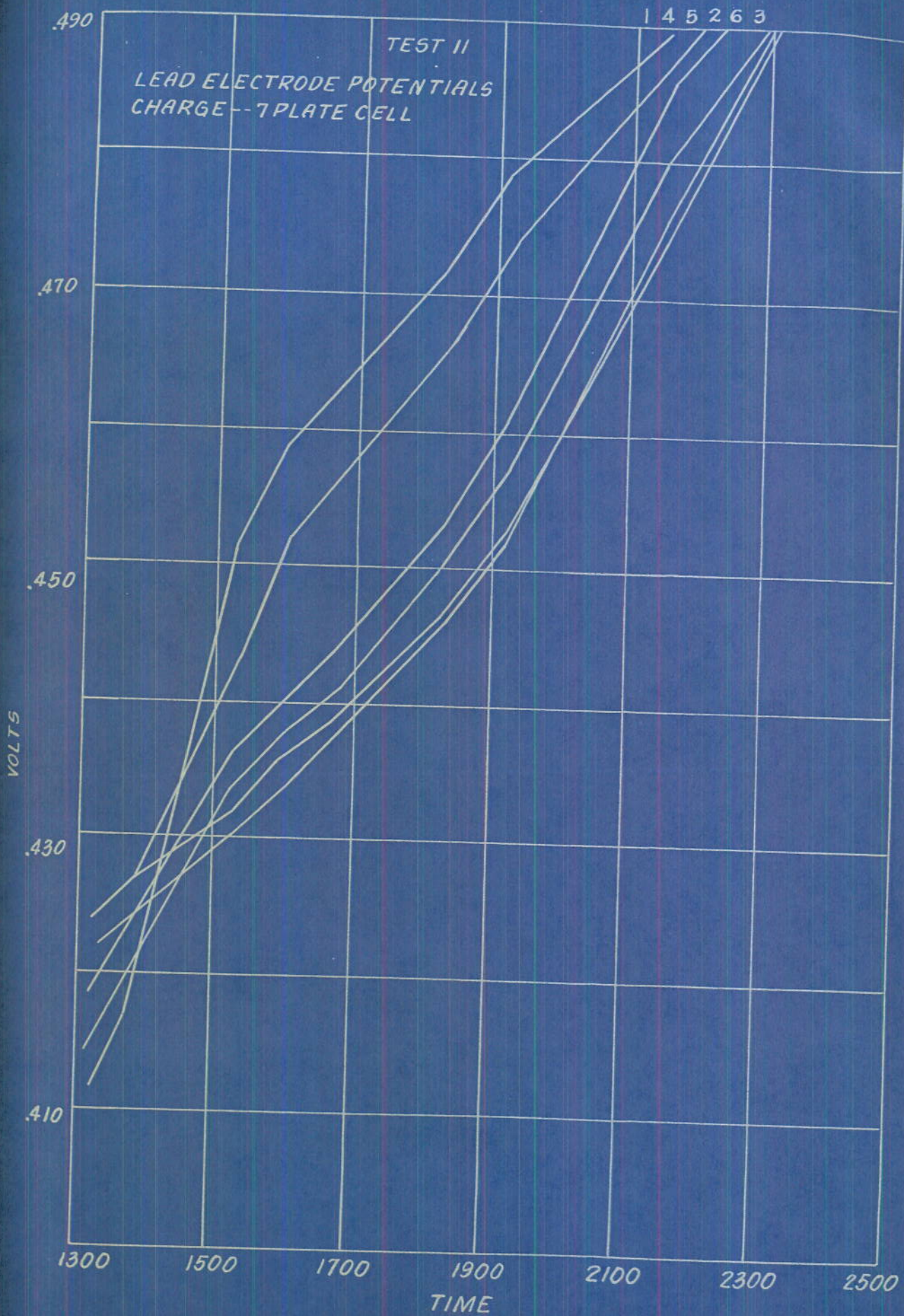
MILLIVOLTS



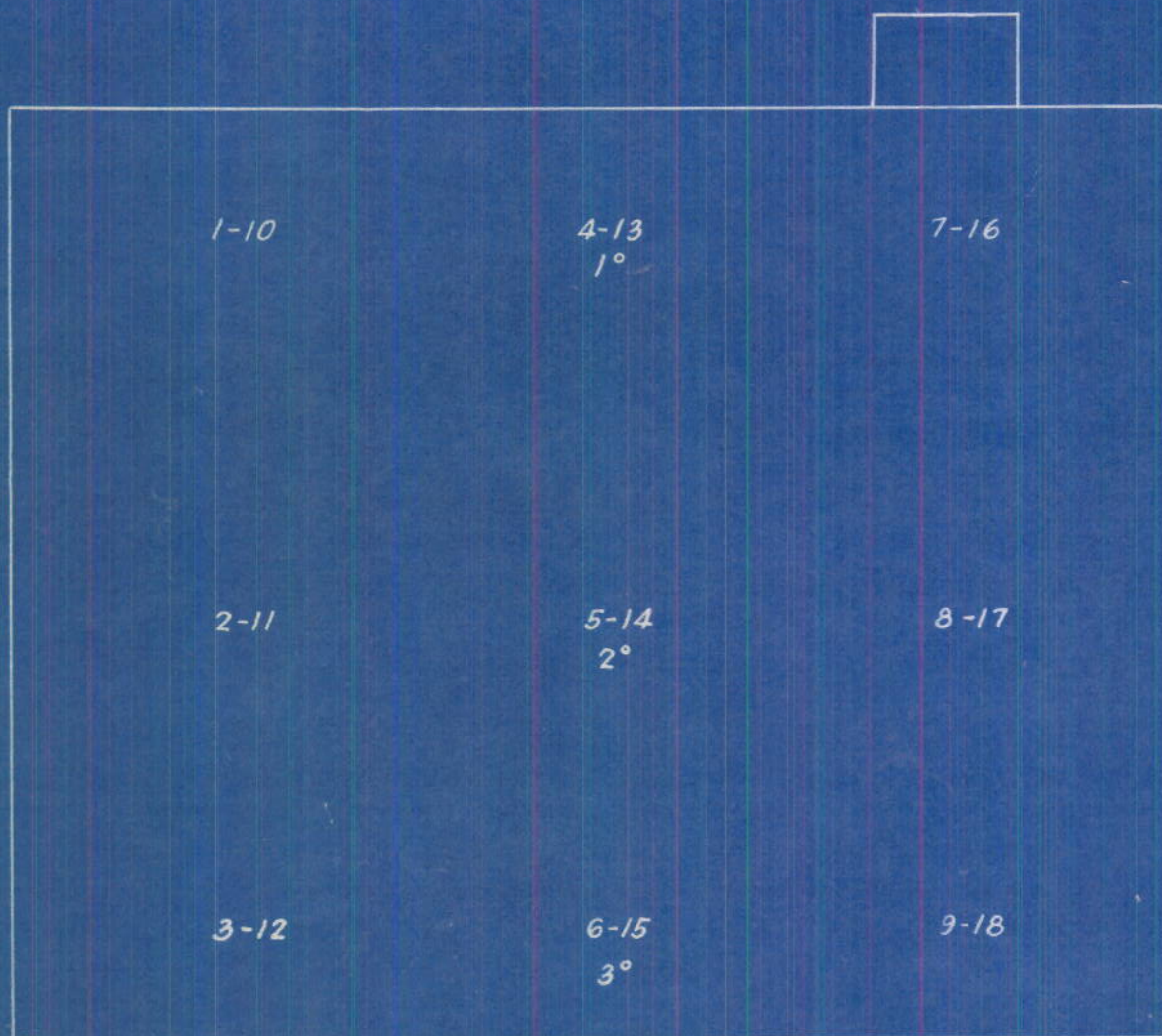
LOCATION OF REFERENCE ELECTRODES---TESTS 10-11







LOCATION OF REFERENCE ELECTRODES --- TEST 14



°---MERCUROUS SULPHATE REFERENCE ELECTRODES  
1-18--SOLDERED LEADS

RESISTANCE OF LEAD GRID

	225	219	208	192	177	160	148	161	168
	226	237	231	215	208	197	188	194	189
	232	241	237	230	225	219	224	218	210
	237	235	231	226	226	222	223	226	228

VALUE GIVEN  $\times 10^{-5}$  = RESISTANCE IN OHMS FROM STRAP TO POINT TAKEN

RESISTANCE OF PEROXIDE GRID

187	182	176	171	163	154	147	153	156
184	178	177	173	170	x	159	162	163
180	185	180	173	175	164	168	169	165
184	185	182	180	178	174	174	173	171
186	184	183	183	184	181	182	179	179
189	187	188	189	188	183	185	186	185
192	194	191	190	189	186	188	187	188

READING GIVEN  $\times 10^{-5}$  = RESISTANCE IN OHMS FROM STRAP TO POINT TAKEN