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NUCLEAR WASTE TANK AND PIPELINE EXTERNAL LEAK DETECTION SYSTEMS

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ABSTRACT

The development of two external waste tank and pipeline leak detection systems based on the electrical potential fields is reviewed. The Boeing system measured the distortion of an imposed a.c. potential field. The Battelle-Northwest system measured the change in the magnitude of the existing d.c. potential field generated by the cathodic protection system and the local electrochemical potential near the electrodes in the sediment. It was found that in a dry area the systems can detect as low as 200 liters of leakage. The engineering assistance to the tank farm managment in assessing the suspected leakers is also presented.

NUCLEAR WASTE TANK AND PIPELINE EXTERNAL LEAK DETECTION SYSTEMS

INTRODUCTION

The subsurface high-level radioactive waste storage tanks and associated pipelines at the Energy Research and Development Administration's Hanford Plants (200 Areas) have developed leakage into the surrounding sediments. The leak detection devices thus far available are the in-tank Food Industries Corporation (FIC) liquid level gauge, the gamma radiation monitoring of dry wells surrounding the tanks, and, in some cases, the radiation monitoring of laterals beneath the tanks. Except where laterals were available, the detection of small leakage of approximately 5,700 liters (1,500 gallons) was impossible. This was due to the volume of the tank [a reading of 2.54-cm change with the FIC gauge represents 10,220 liters (2,700 gallons) for a 22.5-meter (75-foot) diameter million gallon tank] and the incessant foaming and caking of the liquid waste surface rendering the measurement by the FIC gauge inaccurate. The dry well radiation monitoring detects the leakage of liquid waste only after it reaches the proximity of the well monitored. In certain situations, depending on the soil characteristics (as in Tank 104-A), a bottom leak of 5700 liters may not be detectable by the dry wells. Hence improved techniques for earlier detection of leakage are highly desirable.

The original need for a sediment interstitial solution detection system stemmed from the desire to pattern the effectiveness of a grout around a tank or trench. With the advent of a detection system that could possibly measure an increase in 950 liters of salt solution between two well casings 30 meters apart, the emphasis shifted to a more immediate problem of measuring a high-level waste tank leak. The goal of the research program was to develop an external leak detection system capable of detecting a leakage much less than 5700 liters. Similar equipment could be used to note the effectiveness of a subsurface radionuclide affixation.

SUMMARY

Three systems were deemed worthy of testing in the simulated tank site in a pristine area. These systems were (1) Boeing Aerospace Company conductivity system, (2) Holosonics, Inc., acoustical system, and (3) Battelle Pacific Northwest Laboratories (BNW) high-frequency radio system. The tests showed that the Holosonics and BNW systems were not applicable and the Boeing system required further testing. Battelle-Northwest developed a different approach to soil conductivity measurements which was successful in the pristine area tests.

The Boeing and Battelle-Northwest systems were then tested in operating tank farms, but the interference in the tank farms necessitated modifications of both systems. The Boeing system adopted a series of tank exciters that isolated a tank in question and generated around it an alternating current (a.c.) potential field. The Battelle-Northwest system utilized the direct current (d.c.) field generated by the cathodic protection system and the electrochemical potential of the soil in its d.c. readouts. The dry wells surrounding the tanks were used as electrodes to measure the distribution of the potential field and its distortion for both systems.

The results indicated that in a dry area a 200-liter leak from a tank could be discerned readily with decreasing sensitivity as the moisture content of the earth increased. Water leaks from pipelines could be detected within 40 liters. However the Boeing system was not able to respond to pure water leakage.

It was concluded from the series of tests and experience gained in assisting the tank farm management that the two leak detection systems would be useful in the waste tank surveillance. Comparison was made of the Boeing and BNW systems. The Boeing system was more expensive, was difficult to tune at times, and was subject to breakdown. However the data obtained are easier to interpret. The BNW system is less expensive. Tuning was not necessary, but the data interpretation requires further refinement. It is recommended that to optimize the systems for routine operations further research is desirable on the second generation tank circuit exciter and the use of segmented electrodes for determining leakage pattern in three-dimensions. Development of a portable Boeing system in conjunction with the use of a BNW system was deemed plausible on the cost-effectiveness basis.

PRELIMINARY SIMULATION TESTS

CONCEPTS OF THE SYSTEMS

The Boeing concept for detecting leaks of an underground waste storage tank and connecting piping was based on the leak from such tank or pipe altering the potential electric field surrounding the tank or pipe when the conducting fluid enters the soil. Specifically the system comprised two rings of buried electrodes surrounding the tank or pipe. An alternating current source provided an a.c. potential between the conductive surface of the tank or pipe and the outer ring reference electrodes. A detector system comprising a half-bridge circuit sensed any changes in soil potential between the tank or pipe surface and the sensor electrodes as compared with the applied reference potential.

The BNW system measured the impedance of the soil between the sensor electrodes and the inner ring electrodes and between the sensor electrodes and the center electrode.

SIMULATED TANK TEST CONFIGURATION

The simulation test configuration is shown in Figure 1. A series of dry wells was sunk to depths of 9 to 15 m by a vacuum drilling operation and cased with 10.2-cm black iron pipe. Wells were laid out in cylindrical patterns to simulate the tank wall (Wells 51-67), tank farm Dry Wells (68-75), and the surrounding tank farm ground. Wells 51 through 67 were strapped together with AWG #1 wire to form an equipotential representation of the tank, and Wells 76 through 83 were similarly strapped to represent the surrounding tank farm. The wells drilled for the test were completed as follows:

Location	Depth Meters	Purpose
1 in center	9	Middle-of-tank leak addition
16 at 11.4 m radius	9	Simulate tank capacitance
8 positioned:		Sensor wells
3 at 13 m radius	12	
3 at 16 m radius	12	
2 at 14.5 m radius	12	
8 at 28.3 m radius	9	Remainder of tank farm capacitance simulation

The wells had all black iron casings. On nine of the wells the bottom 3 m of the case was perforated and a polypropylene perforated screen added. The wells with perforations and screens were drilled 3 m deeper and pulled 3 m to avoid flow into the well of the fine dry sand. The well in the center and four wells in the simulated tank circle were perforated for leak additions. Four wells in the sensor ring were perforated for later grouting studies.

Figure 2 depicts the pipe/electrode configuration used in determining a subsurface leak from transfer piping. The reference electrodes were the combined inner and outer tank ring electrodes discussed previously. The a.c. potential was impressed between the buried pipe and the combined tank electrodes. The eight electrodes (depicted in Figure 2) were bridged to the pipe and the effect of a simulated leak injected at Tube A could be detected by the eight electrode systems. The two systems were employed simultaneously in monitoring the leakage simulation.

TEST RESULTS

Boeing System

Simulated Tank Tests. A power amplifier connected between the simulated tank and tank farm provided 10 volts excitation at 3 kilohertz. The potential of each Dry Well (68-75) was compared with a half-bridge connected between inner and outer rings, and the difference applied to an amplifier and phase-sensitive detector.

Center Leak Simulation. A leak from the center of the tank was simulated by valving various amounts of 3*M* sodium nitrate solution into Well 51, the center well. Response of typical sensor well electrodes is shown in Figure 3. Note that although the initial response was very sensitive (responding to as little as 3.78 liters), the sensitivity degraded rapidly with increase in leak volume. As the response was quasi-logarithmic, the sensitivity, or response slope was inversely proportional to leak volume. Thus sensing a new leak in a previous large leak may be difficult. Response level of the system to 1.27 cm rainfall is shown for reference.

Figure 4 shows a polar plot of sensor electrode response to the simulated center leak. Note that the response was approximately inversely proportional to the distance of the sensor electrode from the leak. Note also that as the solution migrated into surrounding soil, spreading in volume and surface area, the response continued to increase with time.

Side Leak Simulation. Response of the leak detection system to a simulated salt solution leak at one of the tank side wells is shown in Figure 5. The position of the salt solution insertion was readily apparent from the electrode response; and response to small leak quantities was dramatic.

Response to a raw water leak is shown in Figure 6. As this leak was immediately adjacent to sensor electrode #69, its response was very sensitive. Taking into account the relative positions of electrodes in Figures 5 and 6, the response of the system to a water leak in a previously dry, unsalted situation was estimated to be roughly 20% of the response to a 3*M* salt solution.

Figure 7 shows system response to further addition of water followed by leak cessation. After the leak was stopped, the response increased for a while as the plume spread, but eventually the peak response decreased as the water concentration decreased at the insertion electrode. The continued increase of the farther electrodes at 14 hours may be attributed to migration of other salt solution additions in the simulation site.

Simulated Transfer Pipeline. A short section of transfer pipe was simulated as shown in Figure 2. Ten volts at 3 kHz were applied between the pipe and the tank simulation electrodes. Response of the electrodes to small leaks was immediate and dramatic, as shown in Figure 8.

Battelle-Northwest System

Simulated Tank Tests. The methods and instrumentation selected were a high radiofrequency probe, a vector impedance measurement, and one kHz impedance bridge. Only the impedance bridge was found to be successful in monitoring the simulated leakage. The General Radio Impedance Bridge was used to collect the bulk of the data. The absolute value of the resistance and capacitance values were compromised due to circuit component values added to the system by the Boeing equipment and due to the lack of time required to add external components to the bridge in order to obtain a true null. However the stability and repeatability of the measurements appeared to be good and therefore the data were believed to represent changes in impedance within the precision and repeatability of the instrument with, of course, an allowance for human error in operating the manually balanced bridge.

Center Leak. Figures 9 and 10 represent the relationship between the resistive impedance component and the quantity leaked and capacitive component and the quantity leaked, respectively. The empirical relationships are of the forms:

$$R = -K_r \log Q + C_r$$

and

$$C = K_c \log Q + C_c$$

where R = resistance

K_r, K_c, C_r, and C_c = constants

Q = quantity leaked.

Over the test the value ΔR appears to be more constant then $\frac{\Delta R}{R}$. This implies that solution introduced was more uniformly distributed than the original moisture content. The capacitance between electrodes increased after the test site stood dormant for three days, suggesting that the water was diffusing between the electrodes faster than was the salt.

The magnitude of the resistance change over the addition of 4920 liters was on the order of 60 to 70 ohms with the initial value from 167 to 110 ohms before any addition. Change in capacitance was less certain due to a dramatic change in capacitance after the second day both in quantity and dissipation factor. The slope implies a capacitive change of about 20 nanofarads for the above addition.

Side Leak Simulation. Figure 11 shows the depreciation of resistivity of soils between center to wells around the simulated tank for center additions as well as side additions. As shown in Figure 12, the tank ring-to-probe impedance was less dramatic due to the lack of values available before the addition to the side wells. The experiment proceeded on a schedule which did not allow for equilibrium conditions to be established; therefore the repeatability of measurements was not ascertained.

TANK FARM LEAK SIMULATION

TANK FARM GEOMETRY

The primary difference between actual tank farm conditions and the preliminary simulation test site, other than the continuity of tank walls, is the interconnecting piping and surface access to electrical connections to the tanks. All the tanks in a farm are connected with heavy gauge steel piping, making the establishment of significant potential differences between tanks rather difficult. In addition, the steel risers which come to the surface from each tank were not designed to make intimate metal-to-metal contact with each other or with the steel tank liner. Large sections of reinforced concrete serve as the metallic joining matrix. Representative cross sections of portions of the tank are shown in Figure 13. Typical tank farm piping interconnections are shown in Figure 14.

Because of this geometry, a method to electrically isolate the tank in question was devised for the Boeing system. A compensating and resonant circuit was used to isolate the tank and raised an a.c. potential difference of one volt between the tank selected and the tank farm. A field test revealed that the BNW system of impedance measurement was not feasible for detecting leakage in a tank farm. A method was adopted which utilized the effects of the d.c. field generated by the cathodic protection system and the electrochemical potential of the soil.

BX TANK FARM LEAK SIMULATION

Boeing System

Tank 101-BX Field Mapping

Equipotential contours derived from initial measurements on Tank 101-BX are shown in Figure 15. Equipotential values are root mean squares (rms) a.c., normalized to 1 volt average value at the feedback terminals of the 101-BX Tank drivers, with all other drivers in the shorting conditions. Contours are as expected for a corner tank except for the 0.70 volt equipotential which is distorted by the old leak plume from Tank 102-BX. Effects of the wet backfilling operation shortly prior to this measurement are not obvious. Another measurement 2.5 months later reveals changes in the potential field (Figure 16) which has shrunk inwardly toward the tank. Changes are demonstrated more vividly (Figure 17) by a plot of incremental potentials.

Tank 102-BX Field Mapping and Simulated Leak Test

Initial equipotential contours for Tank 102-BX, obtained with the 101-102, 102-103, and 102-105 drivers active and the other two drivers in shorting operation, are shown in Figure 18. When compared with similar plots obtained from Tanks 101-BX and 103-BX, a large gradient exists at the tank surface, implying poor contact with the soil and thus dry soil conditions.

Subsequent data show the equipotential lines to expand and contract with changes in conditions of adjoining tanks (*i.e.*, dry-out of 101 backfill, injection of 200 liters of water by 103). Plots are shown in Figures 19 and 20 for one month and four months later. Field increment plots for this type do not appear to reveal anything of significance.

Two dry wells to the concrete dome of Tank 102-BX were available and appeared attractive for conducting simulated leak tests. Three hundred eighty liters of 3*M* sodium nitrate solution were injected into Well 02-05A without observable change in field pattern. The proximity of Well 02-04 with its apparent deep contamination precluded further liquid insertion in this location.

Tank 103-BX Field Mapping and Simulated Leak Tests

Initial equipotential contours for Tank 103-BX are shown in Figure 21. Drivers 102-103 and 103-106 were operating at the 1-volt level, and all others shorting. Here a relatively small portion of the total potential drop occurred near the tank. This indicated the tank to have good contact with the surrounding soil and with the old leak plume from Tank 102-BX. The equipotential lines of Figure 20 suggest a direct conduction path proceeding southeast from Tank 103-BX.

Two simulated salt solution leak tests were made by insertion of 265 and 379 liters of quantities of 3*M* sodium nitrate into Well 03-05A, which terminates at the tank footing. Response to the first 265-liter test was not recognized at first, owing to low response of nearby wells. Subsequent view of data, however, produced the plot of Figure 22, which indicates consistent increase of electrical conduction from Tank 103-BX after the test. Negative values of field increment indicate greater current flow.

The response to this salt solution insertion was observed to decay over a period of about one week, as shown in Figure 23, where the positive value increment contours indicate a lowering of current conduction.

The next test on this tank was the insertion of 757 liters of raw water to Well 03-05A. During an appreciable interval of this test, the nearby hydrant was turned on only partially, allowing an unknown amount of water to be dumped into the nearby soil. The resulting potential changes are plotted in Figure 24. Note that the field increment contours are positive, indicating a lowering of electrical conduction from Tank 103.

Day-to-day monitoring of the field from Tank 103-BX shows fluctuations of 0.01 to 0.05 incremental magnitude in voltage. No cause for these fluctuations was apparent. Plotting of the incremental fluctuations as in Figure 25 reveals a pattern aligned with the hydrant water supply line.

The second addition of salt water to Well 03-05A on November 14, 1974, produced no observable consistent results. It is assumed that the soil at the base of the tank is too saturated with water and salt to allow significant reaction to further aqueous addition.

Battelle-Northwest System

Tank 102-BX Simulated Leak Test

Prior to the addition of 379 liters of $NaNO_3$ to Well 02-05, a.c. resistance readings were taken with an Electro Scientific Industry (ESI) Impedance Meter Model 251. Current and potential readings (d.c.) were made with a Fluke 8000A Digital Multimeter (DMM). The measurements were in four groups:

1. Cathodic protection on before addition.
2. Cathodic protection off before addition.
3. Cathodic protection off after addition.
4. Cathodic protection on and a delay of 18+ hr.

The data are presented as follows:

Table I.	Readings of voltages 1, 2, 3, 4 above.
Table II.	Readings of d.c. current 1, 2, 3, 4 above.
Table III.	Percentage changes in values between 2 and 3; also between 1 and 4. Note system changes with cathodic protection on versus off were not made.
Table IV.	Point-to-point resistance.
Table V.	Resistance change for cathodic protection off status 2 and 3. Stability of the reading with cathodic protection is not good enough to allow comparison.
Figure 26.	Voltage change distribution on polar coordinates.

In contrast to the unresponsiveness of the Boeing system, the immediate effects on current and voltage from tank-to-points are indicated.

Tank → 11 is minor as might be expected. Long-term effects under conditions 1 and 4 indicate well-to-well changes but uncertain tank-to-well changes. The added material was located in a region which affected probes 03, 04, 05, and perhaps 07 to a lesser degree.

The impedance changes (a.c. resistance), where detectable, were all lowered. Also the change was about the level of detectability for the system. From previous tests, changes (additions at an electrode) were larger for the circuits involving the addition point.

TABLE I

VOLTAGE READINGS, TANK 102-BX
NOVEMBER 6 AND 7, 1974

Circuit	Well	Voltage (mV) Before Test 1[a]	Before Test 2[b]	Test 1[c]	Test 2[d]
Tank	→ 07	65.5	- 63.3	- 73.3	66.8
Tank	→ 11	-208	-256	-259	-207
Tank	→ 03	164	- 51.3	- 60.2	166
Tank	→ 04	195	118.6	-130.4	199.2
Tank	→ 06	105	- 22.7	- 30.3	102
07	→ 11	-271	-188.5	-185.5	-272
07	→ 03	98.5	15.3	13.2	98.4
07	→ 04	130.2	- 51.9	- 57.3	129.5
07	→ 06	39	44.4	43.1	36.5
11	→ 03	370	204	198.6	373
11	→ 04	401	136	128.3	406
11	→ 06	310	233	229	310
03	→ 04	31.6	- 67	- 70.5	33.2
03	→ 06	- 59.6	28	29.9	- 62.9
04	→ 06	- 91.2	97	100.4	- 92.8

[a]Cathodic protection on before.
[b]Cathodic protection off.
[c]Cathodic protection off, 379 liters $NaNO_3$.
[d]Cathodic protection on 18-hr delay.

TABLE II

SHORT CIRCUIT CURRENT READINGS, TANK 102-BX NOVEMBER 6 AND 7, 1974

Circuit	Well	Current (mA) Before Test 1[a]	Before Test 2[b]	Test 1[c]	Test 2[d]
Tank	→ 07	0.0649	0.0674	- 0.681	0.0661
Tank	→ 11	- 1.806	-10.45	-10.5	1.805
Tank	→ 03	+ 1.548	- 3.33	- 3.83	1.540
Tank	→ 04	1.875	- 8.47	- 9.24	1.865
Tank	→ 06	0.920	- 1.02	- 1.31	0.895
07	→ 11	- 8.44	- 5.85	- 5.79	- 8.44
07	→ 03	4.37	0.133	0.58/0.113	4.35
07	→ 04	6.06	- 0.474	- 0.518	6.17
07	→ 06	1.28	0.370	0.356	1.20
11	→ 03	12.45	1.689	6.75	12.55
11	→ 04	14.28	1.132	4.50	14.36
11	→ 05	8.26	1.815	6.08	8.18
08	→ 04	1.69	- 0.625	- 3.78	1.78
08	→ 06	- 2.15	0.25	1.07	- 2.26
04	→ 06	- 3.42	0.838	3.77	- 3.61

[a]Cathodic protection on before.
[b]Cathodic protection off.
[c]Cathodic protection off, 379 liters $NaNO_3$.
[d]Cathodic protection on 18-hr delay.

TABLE III

COMPARISONS WITH STATED SYSTEM PERTURBATION

Circuit	Well	Addition of 100 gal $NaNO_3$ Volts %	Addition of 100 gal $NaNO_3$ Current %	Addition of 100 gal $NaNO_3$ Plus 18 hr Volts %	Addition of 100 gal $NaNO_3$ Plus 18 hr Current %
Tank →	07	+10.5	-	+ 1.9	+ 1.8
Tank →	11	+ 1.2	+ 0.4	- 0.5	- 0.06
Tank →	03	+17.3	+15	+ 1.2	- 0.62
Tank →	04	+ 9.95	+ 9.1	+ 2.1	- 0.54
Tank →	06	+33.4	+28.4	- 2.9	- 2.8
07 →	11	- 1.6	- 1.1	+ 0.36	0.00
07 →	03	-14	-15.1	- 0.11	- 0.44
07 →	04	+10.4	+ 9.2	- 0.54	+ 1.8
07 →	06	- 3	- 3.8	- 6.5	- 6.2
11 →	03	- 1.7	NA[a]	+ 0.8	+ 0.7
11 →	04	- 5.7	NA	+ 1.2	+ 0.56
11 →	06	- 1.8	NA	0.00	- 0.97
03 →	04	+ 5.2	NA	+ 5.0	+ 5.3
03 →	06	+ 3	NA	+ 5.5	+ 5.1
04 →	06	+ 3.5	NA	+ 1.7	+ 5.5

[a]NA = no analysis.

TABLE IV

RESISTANCE READINGS, TANK 102-BX NOVEMBER 6 AND 7, 1974

Circuit	Well	Test 1[a]	Test 2[b]	Test 1[c]	Test 2[d]
Tank	→ 07	7.32	7.35	7.35	7.28
Tank	→ 11	12.35	12.36	12.35	12.35
Tank	→ 03	5.05	5.17	5.16	15.19
Tank	→ 04	3.5	3.69	3.69	3.35
Tank	→ 06	11.06	11.70	11.68	11.58
	07 → 11	19.03	19.02	19.01	18.95
	07 → 03	11.43	11.42	11.42	11.36
	07 → 04	10.09	10.13	10.13	9.97
	07 → 06	17.73	17.72	17.69	17.58
	11 → 03	16.78	16.82	16.82	16.78
	11 → 04	15.32	15.45	15.43	15.20
	11 → 06	23.4	23.4	23.4	23.3
	03 → 04	7.58	7.62	7.61	7.52
	03 → 06	15.75	15.78	15.75	15.63
	04 → 06	14.38	14.39	14.35	15

[a]Cathodic protection on before.
[b]Cathodic protection off.
[c]Cathodic protection off, 379 liters $NaNO_3$.
[d]Cathodic protection on 18-hr delay.

TABLE V

IMPEDANCE CHANGE - NO CATHODIC PROTECTION
ADDITION OF 379 LITERS $NaNO_3$
TANK 102-BX
NOVEMBER 6 AND 7, 1974

Circuit Well	% Change
Tank → 07	Not determined
Tank → 11	-0.08
Tank → 03	-0.19
Tank → 04	Not determined
Tank → 06	-0.17
07 → 11	-0.053
07 → 03	Not determined
07 → 04	Not determined
07 → 06	-0.17
11 → 03	Not determined
11 → 04	-0.13
11 → 06	Not determined
03 → 04	-0.14
03 → 06	-0.19
04 → 06	-0.28

Tank 103-BX Simulated Leak Tests

Three hundred seventy-nine liters of $NaNO_3$ solution were added to a well-type addition point located at Tank 103-BX. Voltage, short circuit current, impedance (a.c. resistance) were measured one day prior to the test, immedately prior to the addition, and both 5 and 15 minutes after the conclusions of the addition. The addition period was 15 minutes in duration. The measurements were made between all combinations of tank-to-well and well-to-well with points taken two at a time. Instruments used were an ESI Model 560 for a.c. resistance and a Fluke 8000A for d.c. potentials and current.

Data regarding the measurements are presented as follows for tank-to-well and well-to-well combinations:

Table VI.	Potential Differences in Millivolts.
Table VII.	Short Circuit Current in Microamps or Milliamps.
Table VIII.	1 kHz Resistance Values.
Table IX.	Percent Changes in Potentials and Short Circuit Currents as well as Algebraic Changes in the Magnitudes of Potentials and Currents.
Figure 27.	Voltage Change Distribution on the Polar Coordinates.

The large effect on measurements involving Well 03-05 is obvious from the plot in Figure 27. Positive voltage changes accompanied by negative current changes suggest that the effects are due to d.c. field potential changes resulting from the cathodic protection which overlays the electrochemical potential differences.

The analysis of a.c. resistance changes was not made due to the slight changes noted and the instability of the readings.

The data obtained from addition of water are presented in Figures 28 and 29. The circle-dot data are for the probe 180° from the point where addition of water was made. The relative stability of these data brings forth the significance and the relationship of the variation in the readings of the probe with the proximity of the probe relative to the location of water addition; *i.e.*, the percent change in measure quantities changes cumulatively with time and the closer the probe to the water addition, the more severe the change. Point 3 represents the reversal effects of the cessation of dynamic leakage. This effect reflects the re-equilibrating process in the soil.

Hence, if a small steady-state leak exists and the transport of material through the monitored domain is sufficiently great, cumulative effect might not be observed.

TABLE VI

VOLTAGE READINGS
ADDITION OF 379 LITERS OF $NaNO_3$ TO TANK WELL 03-05A
TANK 103-BX
NOVEMBER 14, 1974

Circuit			Voltages (mV)			
	Well		Test 1[a]	Test 2[b]	Test 3[c]	Test 4[d]
Tank	→	03-12	67.9	64.3	64.8	64.5
Tank	→	03-03	136.3	132.5	133.2	134.4
Tank	→	03-05	38	36.2	42.9	53.9
Tank	→	02-01	24.8	21.6	22.7	24.8
Tank	→	02-11	-	-206	-206	-206
	03-12 →	03-03	68.3	68.2	68.4	68.8
	03-12 →	03-05	- 30.0	- 28.1	- 21.3	- 11.5
	03-12 →	02-01	- 43.3	- 42.7	- 42	- 40.8
	03-12 →	02-11	-	-270	-270	-271
	03-03 →	03-05	- 98.3	- 96.3	- 89.2	- 80.2
	03-03 →	02-01	-111.5	-110.8	-110.3	-109.6
	03-03 →	02-11	-	-339	-339	-339
	03-05 →	02-01	- 12.9	- 14.6	- 21.8	- 29.5
	03-05 →	02-11	-	-242	-251	-259
	02-01 →	02-11	-	-228	-229	-230

[a]November 12, 1974.
[b]November 14, 1974, prior to addition.
[c]November 14, 1974, 12:50 p.m., addition of salt 12:30 → 12:45 p.m.
[d]November 14, 1974, 1:00 p.m.

TABLE VII

SHORT CIRCUIT CURRENT
ADDITION OF 379 LITERS OF $NaNO_3$ TO TANK WELL 03-05A
TANK 103-BX
NOVEMBER 14, 1974

Circuit			Current (μA)			
		Well	Test 1[a]	Test 2[b]	Test 3[c]	Test 4[d]
Tank	→	03-12	66.9	63.4	64.1	64.7
Tank	→	03-03	133.7	130.1	131.1	132.1
Tank	→	03-05	37.5	35.8	45.3	53.8
Tank	→	02-01	24.5	21.6	22.9	19.3
Tank	→	02-11	-	- 8.31 mA	- 8.34 mA	- 8.28 mA
03-12	→	03-03	66.1	66.1	65.5	66.3
03-12	→	03-05	- 29.3	- 27.4	- 18.1	- 10.4
03-12	→	02-01	- 42.1	- 40.8	- 40.6	- 39.0
03-12	→	02-11	-	- 7.08 mA	- 7.1 mA	- 7.12 mA
03-03	→	03-05	- 95.2	- 92.8	- 82.6	- 76.8
03-03	→	02-01	-107.9	-104.8	-106.1	-104.4
03-03	→	02-11	-	- 7.93 mA	- 7.95 mA	- 8.05 mA
03-05	→	02-01	- 12.9	- 14.1	- 23.2	- 28.9
03-05	→	02-11	-	- 6.26 mA	- 6.5 mA	- 6.71 mA
02-01	→	02-11	-	- 5.78 mA	- 5.82 mA	- 5.84 mA

[a]November 12, 1974.
[b]November 14, 1974, prior to addition.
[c]November 14, 1974, addition 12:30 → 12:45 p.m. measured at 12:50 p.m.
[d]November 14, 1974, at 1:00 p.m.

TABLE VIII

POINT-TO-POINT RESISTANCE
ADDITION OF 379 LITERS OF $NaNO_3$ TO TANK WELL 03-05A
TANK 103-BX
NOVEMBER 14, 1974

Circuit		Well	Resistance (ohms/1 kHz) Test 1[a]	Test 2[b]	Test 3[c]	Test 4[d]
Tank	→	03-12	12.4	12.46	12.2	12.2
Tank	→	03-03	15.73	15.75	15.3	15.3
Tank	→	03-05	13.14	13.16	12.9	12.9
Tank	→	02-01	13.20	13.21	12.9	12.9
Tank	→	02-11	-	15.54	12.4	12.4
03-12	→	03-03	27.1	27.1	27.1	27.0
03-12	→	03-05	24.7	24.7	24.6	24.6
03-12	→	02-01	24.8	24.8	24.8	24.8
03-12	→	02-11	-	24.2	24.2	24.2
03-03	→	03-05	27.7	27.9	27.8	27.8
03-03	→	02-01	28.1	28.1	28.0	27.0
03-03	→	02-11	-	27.3	27.3	27.2
03-05	→	02-01	24.9	25	24.9	24.8
03-05	→	02-11	-	24.7	24.7	24.6
02-01	→	02-11	-	24.8	24.8	24.8

[a] November 12, 1974.
[b] November 14, 1974, prior to addition.
[c] November 14, 1974, addition 12:30 → 12:45 p.m. measured at 12:50 p.m.
[d] November 14, 1974, at 1:00 p.m.

TABLE IX

PERCENT CHANGE OF VOLTAGE AND CURRENT
ADDITION OF 379 LITERS OF $NaNO_3$ TO TANK WELL 03-05A
TANK 103-BX
NOVEMBER 14, 1974

Circuit Well			% Change Voltage	Δ mV	% Change Current	Δ μA
Tank	→	03-12	1.66	1.2	2.05	1.3
Tank	→	03-03	1.43	1.9	1.53	2.0
Tank	→	03-05	48.9	17.7	50.2	18.0
Tank	→	02-01	14.8	2.2	- 10.6	- 2.3
Tank	→	02-11	- 0.5	1.0	0.37	30
03-12	→	03-03	0.87	0.6	0.3	0.2
03-12	→	03-05	- 51.9	16.6	- 62	17
03-12	→	02-01	- 4.45	1.9	- 4.41	1.8
03-12	→	02-11	0.37	1	0.56	- 40
03-03	→	03-05	- 16.7	16.1	- 17.2	16
03-03	→	02-01	- 1.1	1.2	- 0.38	0.4
03-03	→	02-11	0	0	1.51	-120
03-05	→	02-01	100.2	-14.9	104.9	- 14.8
03-05	→	02-11	7.2	-17	7.18	-460
02-01	→	02-11	0.87	- 2	1.03	- 0.60

TANK 102-TY LEAK SIMULATION

Boeing System

A total of 3520 liters of salt solution were injected into Well 02-11 which was drilled for this purpose. The tank farm condition was such that only about 0.65 volt and 0.76 volt could be maintained between Tanks 104 and 102 and between Tanks 101 and 102, respectively (1 volt is the desired value). No shorting operation was installed as it was found from the experience in engineering assistance to the tank farm management that such omission entailed no significant change in potential distribution. Figure 30 shows the variation of potential with time of each well. The same data were plotted on the polar coordinates. Oral communication from tank farm management indicated that Tank 102-TY is an old dry salted area. This type of soil condition is not conducive to rapid depreciation of potential readings after the injection of the salt solution. Figure 31 shows the distribution of the potential readings normalized by reading at 04-03, and Figure 32 shows the distribution of the percentage of potential drops biased in the direction of 02-11.

Battelle-Northwest System

As was indicated by the Boeing system, the BNW system also showed the definite bias in the changes of potentials in favor of the direction where the salt solution was injected. Figure 33 depicts the same characteristics as in the Boeing system. Notice, however, the dry salted sediment in the vicinity of Tank 102-TY has prevented great erosion in the potential readings outside the NE quadrant where the effects of salt addition were kept to a minimum.

B TANK FARM LEAK SIMULATION

Boeing System

Tank 110-B Simulated Leak Test

The driver arrangement was made such that approximately 1 volt difference was maintained between Tanks 111-B and 110-B and between 107-B and 111-B. Figure 34 shows the variation of potential with time of each well surrounding Tank 110-B, along with the points in time when the injection of set quantities of salt solution was completed. It is to be noted that the readings of the wells close to the location of the solution addition displayed depreciation rates which were directly proportional to the quantities added. Most dramatically, the readings on Well 10-12, which is closest to the addition location showed a definite and pronounced response. Figure 35 indicates a "bulge" on the polar plots in the 12 o'clock direction where the additional well was located. This pattern exemplifies what a side leak should resemble.

Tank 101-B Simulated Leak Test

Tank 101-B was selected to test the hypothesis of "cold finger" effect, and later leakage in a wet and salted soil at the tank footing. The hypothesis is that the temperature variation in the atmosphere is a significant factor to cause moisture migration and condensation and thus affects the measurements taken by the Boeing and BNW systems. An additional observation is to determine whether a dribbling dome leak due to pumping operation would follow the tank geometry and not diffuse into the soil. It was believed by the tank farm management that the leakage at the piping connection at the tank dome to the pump may follow the tank geometry. When it reaches the points of curvature change, such as the junctions of dome and tank wall, and tank wall and tank footing, the leakage then plumes out. This is the hypothesis to account for the "blips" detected at some wells at the dome level and at the tank bottom level, rather than to attribute these "blips" to the leakage from the tank proper.

A test well designated 01-06 was drilled to the footing of the tank and a dome well was provided on top of the tank about 3 m from Well 01-06. The rate of injection of salt solution into the dome well was limited to 0.25 liters per minute. The injection was made in two consecutive days, with 26 liters on the first day and 32 liters on the second. Figure 36 represents the variation of potentials at each well against time and Figure 37 represents the corresponding polar plot. It is to be noted that the dynamical effect of the leakage manifests itself in the graph. A jump in potential reading is noted for all wells when a quantity of as low as 2.5 liters was introduced. After about 18 hours before the second injection was made, the potential readings had recovered to essentially the values as when the test began. This appreciation in the potential readings might have pointed out the important characteristic difference between leakage at the dome and leakage at the bottom level of the tank where only depreciation of the potential readings on the outset of leakage was recorded. This phenomenon repeated itself on the second day when an additional 32 liters were introduced. It can be inferred that the geometry of the equipotential surfaces were distorted differently for the dome leak than for the bottom level leak. Judging from the uniformity of variations in the potential readings, it is concluded that the solution added has diffused into the soil above the dome. No evidence of side pluming has been detected by the Boeing system. However, although the neutron well logging data indicated that the moisture in Well 01-06 at the 12.2 m level (tank footing) increased by about 3% one day after the dribbling test, the increment was too small to support the side-pluming contention.

Three batches of 22.7 kg of dry ice each were dumped into Well 01-05 eight, twelve, and fourteen days after the dome leak simulation. Neither the neutron well logging indicated any increase in moisture at Well 01-05, nor can any correlation be deduced from the data collected by the Boeing and BNW systems.

The second stage of testing of Tank 101-B involved the injection of 2271 liters of salt solution at Well 01-06. The length of the well is 10.7 m below the surface reaching the tank footing level. The well was perforated between the 9.8 and 10.7 m level and was shorted to Tank 101-B to simulate its integrity with the tank. Figures 38 and 39 show the results of the test. It is evident that the lack of great depreciation of the potential readings even after the 2271-liter injection signifies the influence of the moistness of the sediment. No further addition was made, as some radioactivity was detected in the area and further addition might cause its migration.

Battelle-Northwest System

Tank 110-B Simulated Leak Test

The reversal effect at the cessation of dynamic leakage mentioned in the Tank 103-BX test is also evident in Figure 40. The data were collected with an automatic data acquisition system. The sinusoidal characteristic is most pronounced with Well 10-12 which is next to the injection point. The closer peripheral wells, 10-02 and 10-09, also show the same effect in a more subdued and synchronous fashion. Figure 41 shows on the polar coordinates the individual readings of the wells before and after the addition of 1893 liters of salt solution. This plot and Figure 35 complement each other and display the characteristic side leak "bulge". Figure 42 shows the plot of ΔmV. The lopsided effect in the 12 o'clock direction is quite pronounced.

Tank 101-B Simulated Leak Test

The BNW system was not installed for the first stage of the dribbling test at the tank dome. Figure 43 is a plot of the distribution in potentials of the peripheral wells for the 2271 liters simulated leakage. A strong bias in the direction of Well 01-06 is to be noted. The changes in potentials range from 0.5 to 16.6 mV.

IN-FIELD PIPELINE LEAK SIMULATION

WATER LINE LEAKAGE SIMULATION

A section of water line 91.5 m in length was selected for this test. Thirteen electrodes of 0.6 cm x 1.5 m metal rods were placed alternately on either side of the pipeline. The electrodes on each side were 12.2 m apart from each other and were 3 m from the water line. A water well was driven just above the water line at its midsection. For the test 189 liters of water were added at the water well. Figure 44 shows the configuration of the arrangement.

Boeing System

A transformer was mounted on each end of the section of the pipeline selected. A McIntosh driver driving at 200 Hz was coupled to the pipeline at each end, maintaining 156 to 160 V, 157 mA at one end and 158 to 162 V, 206 mA at the other. The 189-liter addition did not produce any changes of reading of the electrodes. It was concluded that the system could not detect any leakage from the water line.

Battelle-Northwest System

Contrary to the Boeing system, the BNW system readily displayed changes in potentials on all the probes. Figure 45 is the plot of the potential changes between the readings before the water injection and the readings five days later. Notice, however, the almost-zero change at probe 7. The reading at probe 7, which was directly opposite the addition well, was gradually increasing with time when water was first introduced. In an effort to obtain better contact for monitoring by the Boeing system, the addition well pipe was manhandled. Probe 7 reading abruptly dropped to its original value. The cause of this phenomenon needs to be explained.

WASTE LINE LEAKAGE SIMULATION

The set-up for water line leak simulation was also used for waste line leak simulation, which was conducted in two stages. In the first stage a 208-liter salt solution was added to the well provided for the water addition in the previous test. In the second stage, three quantities of salt solution were injected at three different locations along the pipeline. Three holes were dug by the vacuum system opposite probes 2, 6, and 10. The designated liters of salt solution for addition at each hole were 19, 38, and 114, respectively. These holes were then refilled with dirt in preparation for the "blind" test.

Boeing System

Figure 46 represents the potential distributions along the pipeline when the salt solution addition was 7.6, 30.3, and 208 liters. It is seen that probe 7, which was closest to the addition point, underwent the greatest depreciation in potential readings. A drop in the potential reading of 47 mV was experienced by probe 7; while the next nearest probes, 6 and 8, experienced only about a 10 mV change. The results of the second-stage simulation are presented in Figure 47. The addition of the three quantities was made four days after the first stage was performed. The progression with time of the potential distribution is also shown in this figure. It was estimated that the system could detect with 1.5 m where the leakage has occurred. A quasi-logarithmic relationship also exists between the potential changes and the quantities added.

Battelle-Northwest System

The BNW system was used for the first-stage simulation only. Figure 48 is a plot of the potential-time variations for each probe. The points in time of quantities of solution added were noted on the graph. The logarithmic relationship between the quantities of addition and potential changes also manifests itself.

ENGINEERING ASSISTANCE TO TANK FARM MANAGEMENT

Subsequent to the BX Tank Farm simulation and prior to the final scheduled tests, engineering assistance was rendered to evaluate and to pattern suspected leakers. The tanks in question were 105-C, 104-A, 102-AX, 106-TX, and 110-U. Assistance was rendered in that order before the last scheduled tests began in TY and B Farms. In addition, these evaluations were made in the absence of baseline readings for reference. Hence the interpretation of the data obtained was dependent on the experience accumulated and other supporting evidence. The assistance then served as a trouble-shooting device. The routine monitoring of these tanks by both systems also revealed their inherent characteristics and idiosyncrasies, which might be helpful in the final assessment of the systems. The various conditions and interferences under which these systems operated also provided some insight into the capabilities of the systems.

TANK 105-C

Tank 105-C was wired and monitored for a period of six months. Figure 49 is the plant layout of the underground structure associated with tanks 105-C and 104-C. Notice that there is an overflow cascade line between 105-C and 104-C and four fill-line connectors at Tank 105-C in the 8 o'clock direction. Three of the fill lines were plugged and the remaining one is connected to a 7.6-cm Purex supernatant line. The 20.3-cm sleeve pipe encases a 7.6-cm pipe which extends into Tanks 105-C and 104-C as shown in Figure 13. The 20.3-cm sleeve pipe has packing glands at its entries to the tanks. The packing glands are subject to leakage.

The potential difference of approximately 1 volt is maintained between 105-C and 104-C, 102-C, 106-C, and 108-C, respectively, for the Boeing system. Both systems utilized the same peripheral wells for monitoring.

The data obtained by both systems for Tank 105-C were quite stable. Initial data plotted in polar coordinates indicated lower potentials in the 8 o'clock direction corresponding to the sector containing overflow cascade line and the fill-line connectors for Purex supernatant line (Figures 50 and 51). Information revealed that this area between 104-C and 105-C was flooded in the past from the overflow of the cascade line, and thus its salt content is quite high. As shown in Figure 52 for the Boeing system and Figure 53 for the BNW system, there was one period of time (from late March to early April) during which wide variations were detected. However later readings showed a great stability after a period of upward trend. Figure 54 shows this effect on the polar plots. This could be caused by the dewatering of the hydrant into the soil during normal tank farm operations. The moisture then plumed out into the soil and caused the changes in potential readings.

TANK 104-A

Because of the existence of the laterals underneath the Tank, 104-A provides the only situation in actual tank farm conditions where the correlation between the bottom leak and the potential readings of the peripheral wells can be made. Tank 104-A was a confirmed leaker and the first sign of possible leakage occurring there came from the routine radiation analysis of the laterals beneath the tank. The locations and dates of high peaks detected in the laterals are shown in Figure 55. The peripheral wells did not and still do not register any radiation counts higher than background. This is one example where the bottom leak can be such that the detection cannot be made from the dry wells. Were it not for the laterals, greater leakage would have to occur before the existing detection device, such as an FIC gauge, could render significant changes.

The 1-volt potential was maintained between Tanks 104-A and 105-A and between 104-A and 101-A for the Boeing system. Figure 56 shows the initial and subsequent patterns of the potential readings. Two days after installation of the Boeing system a situation was encountered in which the drivers, which were used to maintain the potential differences, had been excessively draining off current. A check of resistance of soil between 104-A and the laterals under 104-A revealed a substantially low reading (0.3 ohm), indicating that the the moisture had bridged the tank and the laterals--thereby draining current away from 104-A. The implication was that the moisture had traveled outward and downward beyond the laterals. This was confirmed by other studies; *e.g.*, gamma directional measurements.

The overall low potentials from the Boeing system mutually confirmed the distribution of activity presented in the geologist's map, Figure 55. The later expansion of the potential plot was due to the increase in the leakage volume; and the direction was easterly. It is to be noted that the polar plots displayed the combined effect of the activity due to leakage from 104-A. Figure 57 shows the results of the BNW system. It indicates a similar pattern. The low reading at 4 and 5 o'clock were due to the electronic interferences from neighboring tanks and piping. Figure 58 is the comparison of data taken five months later; no great change is seen.

TANK 102-AX

A leak detection sump pit for Tank 102-AX, located at 10 o'clock direction, was found to have accumulated moisture. Radiation analysis showed a substantially higher count than the background. Communication with the tank farm management revealed that all wells surrounding 102-AX had a moisture reading of 14 to 15%. Tank 102-AX was suspected to be a leaker.

Boeing and BNW systems were installed and monitored for two weeks. During this period the measurements were very stable. On the Boeing system the potential readings were all very high. As the Boeing system did not readily respond to water, it was evident that no salt solution was present in the soil to distort the potential field. The 14 to 15% reading on the moisture was then primarily due to the presence of water. As shown in Figure 59, two wells had lower potentials than the rest of the wells. These were 11-02-11 and 11-01-05 located on either side of the 50.8-cm vapor header connecting Tanks 101-AX and 102-AX vapor spaces. This implied that the section between Wells 11-02-11 and 11-01-05 had higher salt content than other sectors. The reading of one of the newly drilled wells, 11-02-23, although showing slightly higher reading than either Wells 11-02-11 or 11-01-05, also supported this contention. Judging from the overall high potentials around the tank, it was concluded that Tank 102-AX was not leaking solution into the soil. This conclusion was also borne out by the directional lithium drifted germanium [Ge(Li)] detector employed in Well 11-02-23. The results were as follows:

Level m	Radionuclide	Direction of Maximum Reading
3	^{137}Cs	East
4.6	Ru, Co	Northeast
10.6	Ru (concentrated 3.7 Cu/liter)	East

The evidence that ^{137}Cs showed up at the 10-m level from east of Well 11-02-23 and the distortion of the potential fields was most pronounced in the Wells 11-02-11 to 11-01-05 sector indicates that the leakage could come from underground piping close to Tank 102-AX. It was deduced that the most logical candidates for a leak were the Dresser couplings which apparently connected several sections of the header assembly. Dresser couplings are a common structural unit for allowing thermal expansion-contraction in piping assemblies. It would appear that the elastometric seals in these couplings had lost their sealing capacity from the service. Figure 60 shows the measurements from the BNW system. It is to be noted that the BNW system rendered a different configuration from that of the Boeing system. This was due to the presence of the 14 to 15% moisture content in the sediment. As was mentioned before, the Boeing system did not respond readily to water addition; its potential configuration reflected this characteristic.

TANK 106-TX

The evaluation of Tank 106-TX was initiated by sudden drops of liquid level indicated by the hand-operated liquid level gauge. The position of the tank was similar to Tank 105-C; *i.e.*, a center tank. The tank has no bottom laterals. The other available alternative for detection was the radiation analysis of the surrounding dry wells. As was shown in the case of Tank 104-A, large quantities of solution could leak out of the tank without being monitored by the dry wells. Hence, the external leak detection was desirable to assess the soil condition around the tank. Information from tank farm management indicated that the soil surrounding Tank 106-TX was unsalted. For the Boeing system, four drivers were set up to maintain the potential difference of 1 volt between Tanks 106-TX and 102-TX, 105-TX, 110-TX and 107-TX, respectively. Tank 106-TX was monitored for about two weeks. Figure 61 shows the progression of the polar pattern and the distribution of the potentials. It is to be noted that the polar pattern is lopsided in the southwestern quadrant. This effect is especially magnified by the curves connecting the potentials of the outer wells. In comparing with the polar plot obtained with the data of Tank 104-A, a conclusion could be drawn that certain small quantities of salt solution existed beneath Tank 106-TX, has not reached the dry wells, and was causing the more or less circular patterns similar to Tank 104-A. Toward the end of the second week the potentials on the wells were seen to have stabilized. Further confirmation on the assessment is needed. Figure 62 shows the potential distribution from the Battelle system. It displays the same characteristics as the plot for the Boeing system. No outer well readings were plotted, as those wells were too close to the neighboring tanks to render any direct relationship.

TANK 110-U

The investigation of Tank 110-U was prompted by the dropping of the liquid level detected by the FIC gauge and the subsequent increase in radiation in Well 10-07. Tank 110-U was a corner tank. As such, only two drivers for the Boeing system were needed to maintain potential difference between Tanks 110-U and 107-U and between Tanks 110-U and 111-U. With the substantiation from the external leak detection systems, Tank 110-U was later declared to be a leaker.

The results acquired by the Boeing system are presented in Figure 63. The initial overall readings for the inner wells were quite low, with the lowest readings registered at Wells 10-07 and 10-05. This suggested that the source of leakage existed in the southern quadrant. Two outer wells, 11-05 and 00-06, which also displayed relatively low potentials, support this contention. The leakage was seen to be diffusing in the northeasterly direction, as evidenced by the subsequent readings. Judging from the overall readings, it was concluded that a lens leak might have occurred.

The BNW system had acquired some useful data before difficulty developed in the circuit. Figure 64 shows the potential distribution. The parallel between BNW and Boeing data is clearly delineated. The assessment of leakage was further substantiated.

DISCUSSION

CHARACTERISTICS OF DATA

Boeing System

Depending on the sediments surrounding the tank, the interconnecting piping and the relative location of the tanks to each other, it was sometimes difficult to maintain a potential difference of one volt at the tank in question from the surrrounding tanks. For example, in the case of Tank 102-AX, the voltage between 101-AX and 102-AX was maintained at about 0.85 volt and the voltage between 104-AX and 102-AX was at about 0.3 volt. However this represents an extreme case. A special treatment of the data then was required to render significance to that obtained. The highest value of the wells surrounding Tank 102-AX was taken as reference. Each well reading then was divided by this value, after which the result was plotted and compared. This treatment had been effective for use in comparing data from different dates, as the highest value always occurred at the same well.

In the case where the potential difference was in the neighborhood of one volt, a different procedure was adopted. In this case the feedback voltages (*i.e.*, the maintained voltages) were averaged and used as a reference voltage. Each well reading then was divided by this value. This treatment of data made it possible not only to compare data of the same tank on different dates, but also data on different tanks. In this fashion assessment of a tank can be evaluated based on previous experiences. This is the normalization process.

There was, however, some variance from this normalization process. In the test tank areas such as 102-TY and

101-B where the sediment was wet and/or salted, the normalized values of the potential were not as discernable as the raw data. The normalization was done at each injection point by the average of the feedback voltage at that time. Figure 64 shows the comparison between the normalized and unnormalized values for Tank 102-TY. As the feedback voltage change amounted to only 1.5% of the original voltage and dynamic leakage was in progress, the realignment of the potential field had not been stabilized to render as meaningful the normalized data. Hence it is suggested that within the period of time when the addition of the salt solution (or leakage) is in progress, raw data should be used to evaluate the condition of the soil.

Battelle-Northwest System

As the data acquired by the BNW system depend on the combined effect of d.c. field imposed by the cathodic protection system and the local electrochemical potential of the soil, no reference range is yet available for evaluation purposes. The polarity also gives no definite indication. On the other hand, the changes from the baseline data, either positively or negatively, do indicate the responsiveness of the system. Figure 33 for Tank 102-TY and Figure 41 for Tank 110-B provide the example. The readings at Well 02-11 of Tank 102-TY changed from positive to negative during the salt solution injection, while the readings at Well 10-12 of 110-B changed from negative to positive. The day-to-day variation of the system in operation was within 10 mV to 15 mV, which is quite stable. However in wet areas where response is relatively smaller, this type of variation could mask a small leakage. [Note: The change in voltage at Well 10-12 during the test at Tank 110-B was in excess of 125 mV.] The day-to-day variation could originate from different sources. For instance, the readings at Well 05-08 of Tank 104-A showed a cyclically sinusoidal variation, beginning to drop at about 9:30 a.m. and staying low until 11:30 a.m. when the readings began to rise. A check with tank farm operations revealed that water had been sprayed in the vicinity of Well 05-08 during this period of time. To evaluate any tank in question by the BNW system it is essential that more emphasis should be put on the near wells. As the well becomes further from the tank, interference from other tanks and pipelines would render the assessment of the reading inconclusive. It is also to be noted that the cyclical variation has a weekly period. The daily potential standard deviations calculated for the period from May 22 to May 28, 1975, indicated that during the period (Saturday, Sunday, and Monday) of relative inactivity in the tank farm, lowest variations were registered. The highest variations were encountered on Thursday and Friday. This tank farm activity-related variation also manifested itself in the standard devaitions calculated for a 24-hr period for May 31 and June 1, 1975. It is suggested that the variations encountered could be eliminated by utilizing regulators on the cathodic protection system.

General Observations

One apparent question was the number and position of wells that would render best results for the external leak detection system. From experience in analyzing data, the minimal optimum number and position of wells appears to be eight, situated within approximately 1.5 m of the tank wall and 45° apart. This arrangement is desirable because the closer the well to the leakage point, the greater the response. If the wells were too far apart, locating leakage would be more difficult. The parallel between the Boeing and Battelle-Northwest systems was brought forth when comparisons were made of the polar plots of percent change for Boeing data and voltage change for Battelle-Northwest data. This comparison is shown in Figures 32, 66 (Tank 102-TY), 67, 42 (Tank 110-B), 68, and 69 (Tank 101-B).

Data plotted on the polar coordinate had not been corrected for the distance of the wells to the tank. The development of the polar plot was intended for a cursory assessment of the tank in question. For a more detailed and precise evaluation, distance correction and soil condition and distribution should be taken into consideration. This and other features, such as the significance of the slope of ΔQ (quantity leaked) versus ΔP (potential change), will be studied as the need arises.

To date both systems lack routine objective data interpretation. A method which was developed for this purpose required further refinement.

As was pointed out previously, both systems displayed a reversing trend when the injection of salt solution ceased. This dynamic characteristic should be taken into account when comparison is made between real and simulated leakages and when data are processed.

The characteristic difference between the two systems brought forth in the water line leakage test might be useful in discriminating the water leakage from salt leakage in an unsalted area. For example, in the case of Tank 102-AX the effect of the 14 to 15% moisture content was registered in the BNW system as evidenced by the area enclosed by the curve connecting the more or less evenly distributed potentials (see Figure 60). In contrast, the data acquired by the Boeing system, which does not respond well to water, showed a small area (less salted) biased in the 12 o'clock direction (see Figure 59). Incorporation of the two systems would have the advantage of distinguishing the nature of the leak in an unsalted area. This assertion requires further confirmation.

The tanks that were selected for experiment were based on the best information available. The tanks were so chosen that their sediment would represent conditions of wet and unsalted, dry and salted, and dry and unsalted. The responses of the external leak detection systems would then be correlated accordingly. However the degree and the extent of salinity and wetness that the sediment was subjected to deviated from that which was estimated, and the funding and time were limited. As a result, the experiment provided only the outcome for the original plan; *i.e.*, the feasibility of applying the systems in the operating tank farms. In retrospect, a better understanding and optimization of the system could be obtained through a better definition of the baseline conditions. This could involve at each tank the sediment sampling for salinity, neutron probing for moisture content, and injection of known quantities of salt solution to simulate any desired baseline condition.

It was noted in the course of the experiment that the area of the polar plot for the Boeing system can be used to assess the salinity of the sediment surrounding the tank. For instance at Tank 102-AX all the peripheral wells showed a 14 to 15% moisture content by neutron probe but the polar plot indicated a small area enclosed by the curve connecting the potentials (see Figure 59). Tank 102-AX is a nonleaker, as are all the surrunding tanks. Hence the sediment can be assumed to have low salinity and the moisture is attributed to water. On the other hand, the dribbling test at

Tank 101-B had definitely rendered a wet and salted baseline condition for the subsequent leak-at-the-footing test. The area of the polar plot and the response noted for the leak-at-the-footing test underscored the influence of the sediment salinity to the response of the Boeing system. A technique of analysis using the correlation between salinity-moisture and polar plot area will be further studied as need, time, and funding permit. A tank farm scale model is available for initial investigation of the technique.

ASSESSMENT OF THE SYSTEMS

The series of tests and the experience gained in the assistance to tank farm managemen do exhibit the viability and desirability of both systems. In a sense, these systems seemed to complement each other. However both systems, as of this date, suffer some difficulties inherent with the principles upon which these systems are based. With improvements in the hardware and equipment, some of these difficulties are correctable--some are not. The discussions that follow provide a more detailed look into the systems in question.

The systems are based on the distortion or the magnitude of the potential fields. The Boeing system measures the distortion of an imposed a.c. potential field and the Battelle-Northwest system measures the change in the magnitude of the existing d.c. potential field generated by the cathodic protection system and the local electrochemical potential near the electrodes in the soils. Both systems then require the "pluming" of conductive material from the tank before it is detectable either by a leaking salt solution or by leaking water in a very dry area or in a previously salted-then-dried area. The change in potentials in reacting to the pluming, which in turn is related to the quantity leaked, is quasi-logarithmic in nature. This implies that both systems will not have a rapid response in detecting leakage in a highly salted area, as in the BX Tank Farm. Also, as the leak quantity increases, the rate of decrease in potential decreases.

Against this backdrop, and with the experience in the series of tests and pattern determination, the assessment of the systems can then readily be made.

Boeing System

The Boeing system can be used to:

1. Pattern tanks for pre-existing conditions. This has been done with every tank encountered--displayed either through the contour plots or the polar plots developed by the Environmental Engineering Section for cursory evaluations.

2. Detect and differentiate center or side leaks as demonstrated in the test at Tank 110-B.

3. Detect new leaks in old salt areas. This was done in Tanks 103-BX and 102-TY, albeit the effect was small and the response slow.

4. Determine transfer line leak. This was tested in a water line in 200 West Area. Quantities of less than 3 liters can be detected within 1 m.

5. Detect tank leak before it can be seen by gamma probe. This was the case in patterning Tank 104-A. The leakage distorted the totality of the field pattern, and thus remotely affected the probes (wells) around the tank.

6. Discriminate against normal rainfall. This was proven in the rain test at the simulated tank site.

The Boeing system developed so far cannot:

1. Detect tank leaks which do not plume from the tank surface, as it requires certain conductive volume in contact with the tank to distort the imposed potential field.
2. Detect water leaks unless the soil is extremely dry.
3. Detect tank leaks in a wet salted area as rapidly as in unsalted or dry areas. The case in point was Tank 103-BX. The response was rather slow and took about a week to accumulate discernable data.
4. Profile tank leak vertically without segmented electrode. Leak localization in a horizontal plane is readily accomplished. As the probe (dry wells) averages the potential along its length, the measurements taken represent only the horizontal projections of the vertical probe readings. Hence a dome leak may generate a similar pattern as a bottom leak. However this may be differentiated by data analysis, moisture probe, augering, and piping plan studies. One other problem is to distinguish a genuine side leak from a cascade line overflow. This was believed to be the case in patterning Tank 105-C. This should not present too much of a difficulty, for if the system is used as an early warning system. structural plan studies, FIC gauge, and other monitoring will be sufficient to make the differentiation.

Battelle-Northwest System

The Battelle-Northwest system can be used to:

1. Evaluate the existing soil condition around the tank. The observation that wells about tanks are negative with respect to the tanks suggests that corrosion may be accelerated in these regions. Therefore the system appears to be useful in determining the presence of conditions which may be precursors to tank failure, which is of prime concern to tank farm operations.

2. Assess a pre-existing static leakage. This was done in the assistance to the tank farm management. The wrap-around plots of measured magnitude of potentials and their signs were used to determine areas of possible leakage. High conductivity implies leakage might exist.

3. Detect dynamic tank leakage. For leakage in progress, the potential measurements responded vividly.

4. Evaluate the effectiveness of cathodic protection system. The theory is that if in a dry area the probes around a known nonleaker display negative quantities, the cathodic protection system may not be functioning as intended. This theory needs to be evaluated.

5. Detect water line leak and transfer line leak. This was demonstrated in tests in 200 West Area.

The Battelle-Northwest system cannot:

1. Locate vertically the leakage from the tank.

2. Be used to provide contour plots for leakage distribution.

3. Distinguish normal rainfall and water usage in normal tank farm operations.

COMPARISONS OF THE SYSTEMS

Both systems have their own pros and cons. The Boeing system is more expensive. It requires a longer period for installation. Their electronic equipment is rather delicate, difficult and tedious to tune at times, and subject to breakdown. In hostile environs, high heat may render the equipment inoperable. However data obtained via the Boeing system are easier to interpret. In highly salted wet areas the Boeing system does not respond as well as the Battelle-Northwest system in a dynamic leak detection test. Even for the extent of coverge and data generated, the BNW system is quite inexpensive and is easy to install. No tuning is necessary and it is virtually not subject to breakdown. In addition, BNW equipment can be purchased as shelf items rather than custom-designed.

One advantage that both systems have is that if baseline measurements can be made, redundancy may not be required for leak detection.

CONCLUSIONS AND RECOMMENDATIONS

The series of tests and experience in assisting the tank farm management has proven the soundness of the principles. In order to reduce the systems for routine operations, certain aspects of the systems are recommended for further development.

Because of its low cost and good promise, further developments in the Battelle-Northwest system are recommended, including an installation of regulators on the cathodic protection system to stabilize the d.c. potential field generated, and an a.c. carrier on the cathodic protection system to investigate the utilization of a.c. potential field so imposed.

In order to further optimize the Boeing system, some additional developments may be desirable. These developments can be tested at the existing wired test tank with some costs for consulting expense. Among the items which might need further attention are:

1. Effect of salt or water leaks in a tank farm not electrically connected to the tank being monitored. This involves installation of series resonance circuit to eliminate need for reference tank electronics for single farm monitoring.

2. Determine spacing and number of detection electrodes required. Presently when leakage occurred between two widely separated electrodes, detection by the systems was not as sensitive as desired.

3. Develop and optimize a segmented electrode to allow vertical patterning of the tanks, potential field, and to locate tank leaks in 3-D coordinates. This will be based on the successful demonstrations of vibratory drilling technique using steel pipe up to 7.5 cm in diameter.

4. Optimize railroad track fine-tuning to reduce the coupling between driveline and feedback below 1%. The 1% coupling will produce 10% error in actual tank-to-tank voltage which is the maximum that can be tolerated.

5. Develop a 10 kHz-keyed detector to allow multiple channel digital recording of 10 kHz a.c. electrode potential.

6. Develop junction box coax/split tuning capacitor system for the situation where more than one tank is to be driven by a portable test set. Coax and split tuning are required for each railroad track.

7. Develop second-generation tank circuit exciter. Current breadboard operational amplifiers encounter phase margin problems in some tank installations. Lowering amplifier passband to make them operate reduces regulation capability. A tank circuit exciter design which avoids phase margin problem can be designed to replace the OP amps in the breadboard.

One recommended approach for utilizing the Boeing system would be to develop a portable railroad system and a variable tuning device. With the Battelle-Northwest system set up to monitor any irregularity, the Boeing system can be rushed in for an immediate patterning and subsequent continuous monitor should such a need be indicated by the BNW system. This idea is plausible and warrants further investigation; for on the cost-effectiveness basis, this alternative becomes very attractive.

A scale model currently in existence should be utilized for further investigation in data analysis and some items recommended for further study in this section.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to L. E. Bruns who originated the idea and the program for the external tank leak detection system; and whose support, coordination, and consultation made possible the completion of the program. The contributions from O. H. Koski and J. L. Duce of Battelle Pacific Northwest Laboratories, and W. W. Woods and W. A. Eul of the Boeing Aerospace Company are also recognized. The excellent preparation of this document by Eleanore Earhart is deeply appreciated.

REFERENCES

1. W. W. Woods and W. A. Eul, "Waste Storage Leak Detection System Feasibility Testing, Final Report," Boeing Aerospace Company, Seattle, Washington, Consultant Agreement CA-172, December 5, 1974.

2. K. J. Binns and P. J. Lawrenson, Analysis and Computation of Electric and Magnetic Field Problems, The MacMillan Company, New York, 1963.

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APPENDIX A

SOIL TESTS

Three samples of soil were tested for electrical conduction by insertion as the dielectric in a cylindrical coaxial capacitor. The first two soil samples were recovered from a wet drilling process, and were dried thoroughly before testing. These were tested dry and with the addition of a nominal 5% water content. The third sample, recovered from a dry suction drilling process, was tested as-received with no drying or water addition. Results are summarized in Table A-I.

TABLE A-I
HANFORD SOIL RESISTIVITY

Sample No.	Characteristic	Condition	Resistivity ohm-cm
1	Fine sand	Dry	5.5×10^6
1	Fine sand	+ 5% H_2O	2.8×10^4
2	Coarse sand	Dry	1.3×10^5
2	Coarse sand	+ 5% H_2O	4.4×10^3
3	Test site soil	As-received	1.0×10^5

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APPENDIX B

BX TANK FARM INSTRUMENTATION FEASIBILITY STUDIES

TANK AND RISER IMPEDANCE MEASUREMENT

Typical tank circuit impedances were checked at d.c. and 3 kHz a.c. excitation frequencies in the BX Tank Farm. The purpose of this test was to determine the degree of electrical continuity between tanks and tank risers, and to verify the degree of electrical interconnection provided by underground intertank piping. The precision of measurement with d.c. excitation was approximately ± 0.1 milliohm. The 3 kHz measurement was adversely affected by mutual inductance between leadwires, and had a precision of approximately ± 0.1 ohm.

Measurements of d.c. resistance were affected slightly by tank farm internal potentials, presumably from the cathodic protection system. Resistance values were determined from potential difference readings as a 1 ampere current was applied across the measurement terminals.

TABLE B-I

TANK CIRCUIT IMPEDANCES

Measured Impedances in Ohms	d.c.	3 kHz a.c.
Riser-to-tank		
Large	0.0003	0.1
Small	0.0006	0.2
Tank surface (riser-to-riser)	0.0002	0.1
Tank-to-tank		
In-line tanks (*i.e.*, 101 to 102, 102 to 103, 104 to 105, etc.)	0.0030 ± 0.0007	0.3 ± 0.1
Cross-line tanks (*i.e.*, 101 to 104, 102 to 105, 103 to 106, etc.)	0.008 ± 0.002	0.3 ± 0.3

The measured d.c. resistance indicates that although the tank risers do not make direct contact with the steel liners, an excellent electrical path is formed, presumably through the reinforcing bar in the concrete dome. Tank-to-tank resistances are roughly what was estimated for connecting runs of heavy gauge steel pipe. The tank-to-tank and riser-to-tank continuity is adequate to allow sufficient current injection to produce desired potential differences between tanks.

WELL-TO-TANK RESISTANCE

Measurements of the d.c. resistance between the dry wells and the tank farm complex were made for reference purposes, to expose any major anomalies, and to serve as a reference comparison to ensuing electric potential measurements.

Resistance readings were taken with a Fluke Model 8000A digital multimeter which measures the voltage across the test resistance with an applied current of 1 mA. Major differences in well-to-tank measurements were noted when lead attachments were reversed. Significant drift and instability of readings were also noted. This effect is attributed to the tank farm cathodic protection system. True resistance was taken as the mean of the two readings obtained before and after reversal of multimeter leads.

The resistance readings of the wells varied from 11.8 to 94 ohms, depending upon well position and length of pipe. Resistance value between a given well and a tank riser was essentially independent of the tank or riser chosen. This was to be expected from the results of the tank-to-tank resistance measurements (milliohms). Values of well-to-tank d.c. resistance are plotted in Figure 70 as contours of equal resistance. As the distance from tank to well increases the resistance also increases, as expected. The resistance should increase logarithmically with distance for uniform soil conductivity. Beyond the 50 ohm contour the resistance values deviate drastically from a logarithmic relationship. The rate of change in resistance with distance should be decreasing, but increases instead. This implies that the average soil conductivity in the vicinity of dry wells is decreasing with distance from tanks. This is a logical result if a leak plume extends to this distance.

Dry Wells 02-05 and 02-05A are short in length, extending only to the top dome of Tank 102-BX. Their short length decreases conductance to the soil, thus resulting in a high resistance. Dry Well 02-04, presumably in the old leak plume, has an abnormally high resistance for its position. This anomaly is not readily accounted for.

TANK ELECTRICAL ISOLATION

Tank isolation is obtained by driving current from the tank farm into the test tank, raising its electrical potential above the remainder of the tank farm. To fix the test tank potential, sensing of tank-to-tank voltage is required. The sensing line is magnetically influenced by the aboveground current driving conductor. This will add to the voltage of the sense line, producing an erroneous reading.

This problem is overcome by utilizing a geometry which cancels the mutual inductance between driver and voltage sensing conductors. Precise spacing between conductors is required to achieve zero coupling. This cancellation method was tested in the lawn area of the Boeing Space Center in Kent, Washington, and the proper spacing determined. Wood block spacers were cut to dimension and used to guarantee spacing of supply conductor and sense wire conduits in the BX Tank Farm test system.

The sense wire provides tank-to-tank voltage as feedback to the driver amplifiers. The driver amplifiers compare this feedback voltage with the input signal and maintain a steady voltage difference between tanks. In operation, the drivers are switched to excite each tank in turn. The drivers to the selected tank have their inputs switched to a reference input signal and the selected tank is maintained approximately one volt above the adjoining tanks. Other drivers in the tank farm have their input signals shorted, and with the feedback system, maintain essentially zero voltage difference throughout the remainder of the tank farm. With this arrangement, over 90% of the potential drop in the soil should occur in the vicinity of the test tank.

The inductive load presented by the overland drive current conductor, the tank risers, and intertank piping is tuned by installation of capacitors in parallel with the driver. This decreases the driving current required of the driver by a factor of approximately 10. A tuning capacitance range of four to seven microfarads is required to produce resonance at 10 kilohertz, and indicates circuit inductances of 35 to 60 microhenrys.

Five tank isolation circuits were placed in the BX Tank Farm to allow isolation of Tanks 101, 102, and 103. Satisfactory tank isolation was established for each of the tanks noted. Unexpected large tank riser inductance at the driver produced an increase in feedback signal causing tank-to-tank voltages to be less than the planned one volt. This problem was relieved by alteration of circuitry to allow sensing of tank potential with an adjoining riser. Errors in drive line mutual inductance cancellation and residual mutual inductance between risers produce an error of tank-to-tank potential difference of less than 10%.

A schematic diagram of the mutual inductance cancellation arrangement is shown in Figure 71. Driver layout for a complete tank farm is shown in Figure 72.

Accurate measurement of alternating potentials in a low impedance, physically large inductive circuit such as this is made difficult by inductive coupling of the drive circuit with every nearby electrical conductor. Use of twisted pairs or coaxial cable for cancellation of net coupling is not feasible when the points between which the potential is to be measured are separated by a large distance. Inductive coupling may be reduced by careful layout of wiring, but residual effects will still be appreciable. For this reason one-time mapping of potential fields in a tank farm will show major conduction anomalies, but cannot be used for precise, detailed analyses. Providing that the sensing conductor layout is rigidly maintained, however, small changes of the measured potentials can be utilized to map changes in soil conductance.

The potential sensing electrodes utilized in the BX Tank Farm tests are dry wells ranging from 4.6 to 61 m in depth. Most are approximately 46 m. The wells protrude through widely varying potential contours and will provide an average of a function of soil potential and conductivity over their entire lengths. By extending through these contours, the wells themselves alter the potential fields. As a result, changes in potential produced by localized changes of soil conductance are attenuated by this electrode arrangement both by their averaging and by their ference. The highly conductive layer of the old leak plume from Tank 102-BX, through which many of the wells penetrate, further compounds this problem.

APPENDIX C
CATHODIC PROTECTION SYSTEM

A measurement of cathodic protection system potentials, both d.c. and a.c. (rectified 60 Hz sinusoid) was made in conjunction with tests on Tank 102-BX. Plots of equipotentials from these measurements are shown in Figures 73 and 74. The apparent source of current is southwest of Well 27-06. It is interesting to note that negative potentials were measured with respect to Tank 102 near Tank 103-BX.

The large a.c. potentials generated at the wells by the cathodic protection system are found to affect the voltmeter readings of the 10 kHz potentials. The two voltages are additive according to root-mean square summation, and amount to a 1% increase in some cases. This effect is small, reasonably constant, and will not appear in the output of a keyed demodulator which would be included in any permanent instrumentation system.

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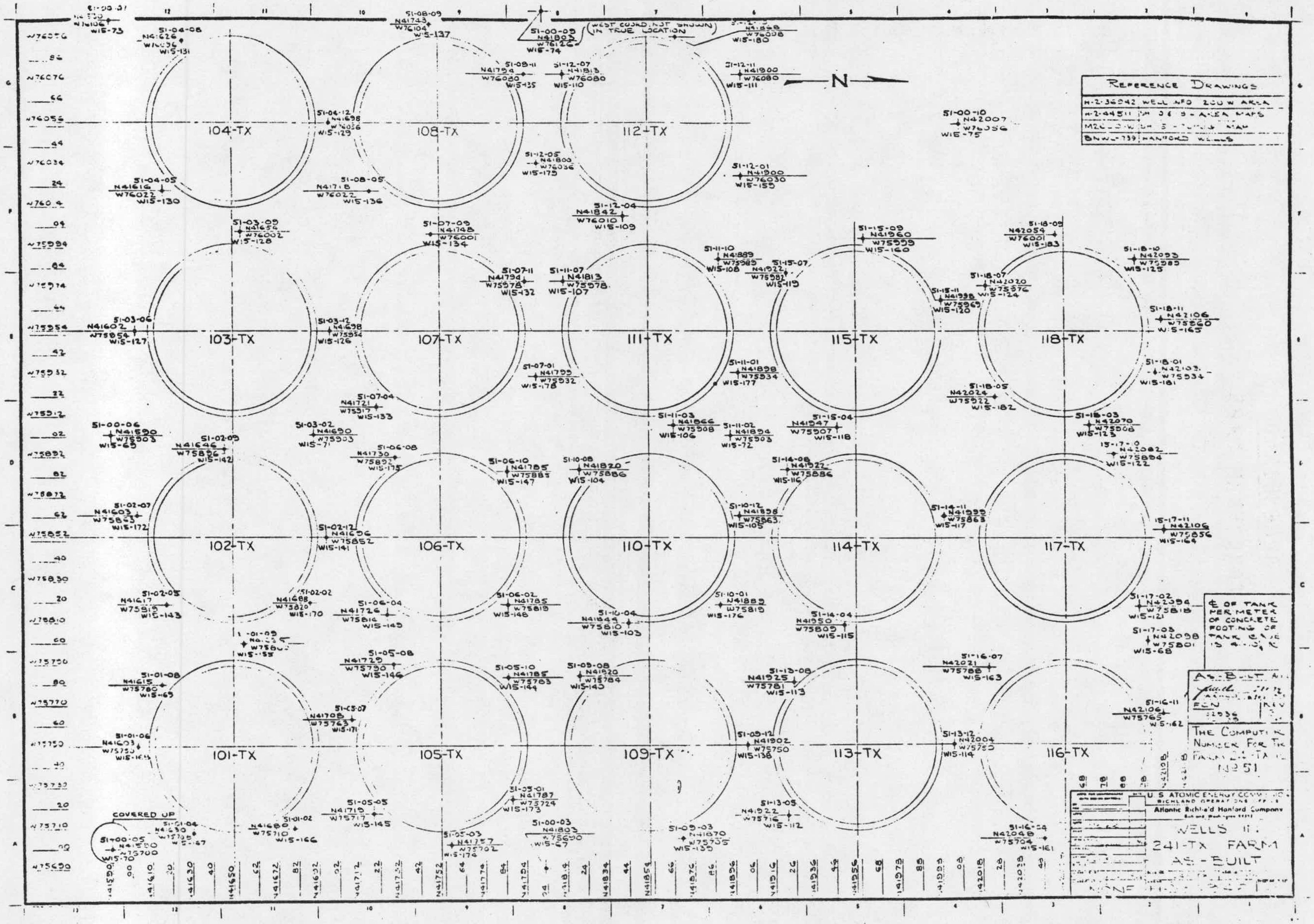
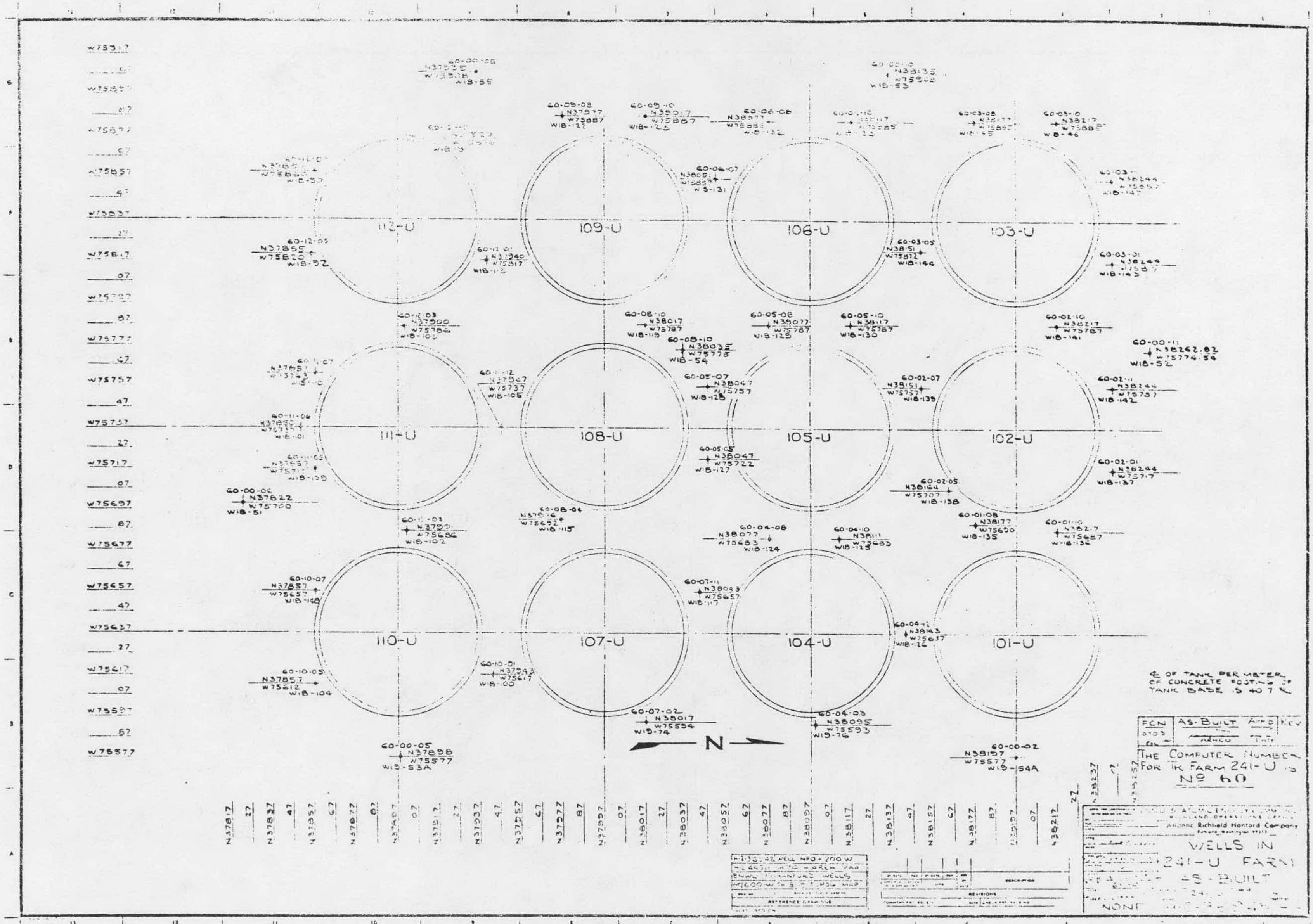
APPENDIX D

TANK FARM MAPS


REFERENCE DRAWINGS
WEST COORD. NOT SHOWN IN TRUE LOCATION
N
104-TX
108-TX
112-TX
103-TX
107-TX
111-TX
115-TX
118-TX
102-TX
106-TX
110-TX
114-TX
117-TX
101-TX
105-TX
109-TX
113-TX
116-TX
COVERED UP
℄ OF TANK PER METER OF CONCRETE FOOTING OF TANK
AS-BUILT
THE COMPUTER NUMBER FOR THE FARM
U.S. ATOMIC ENERGY COMMISSION
RICHLAND OPERATIONS OFFICE
Atlantic Richfield Hanford Company
WELLS IN 241-TX FARM AS-BUILT

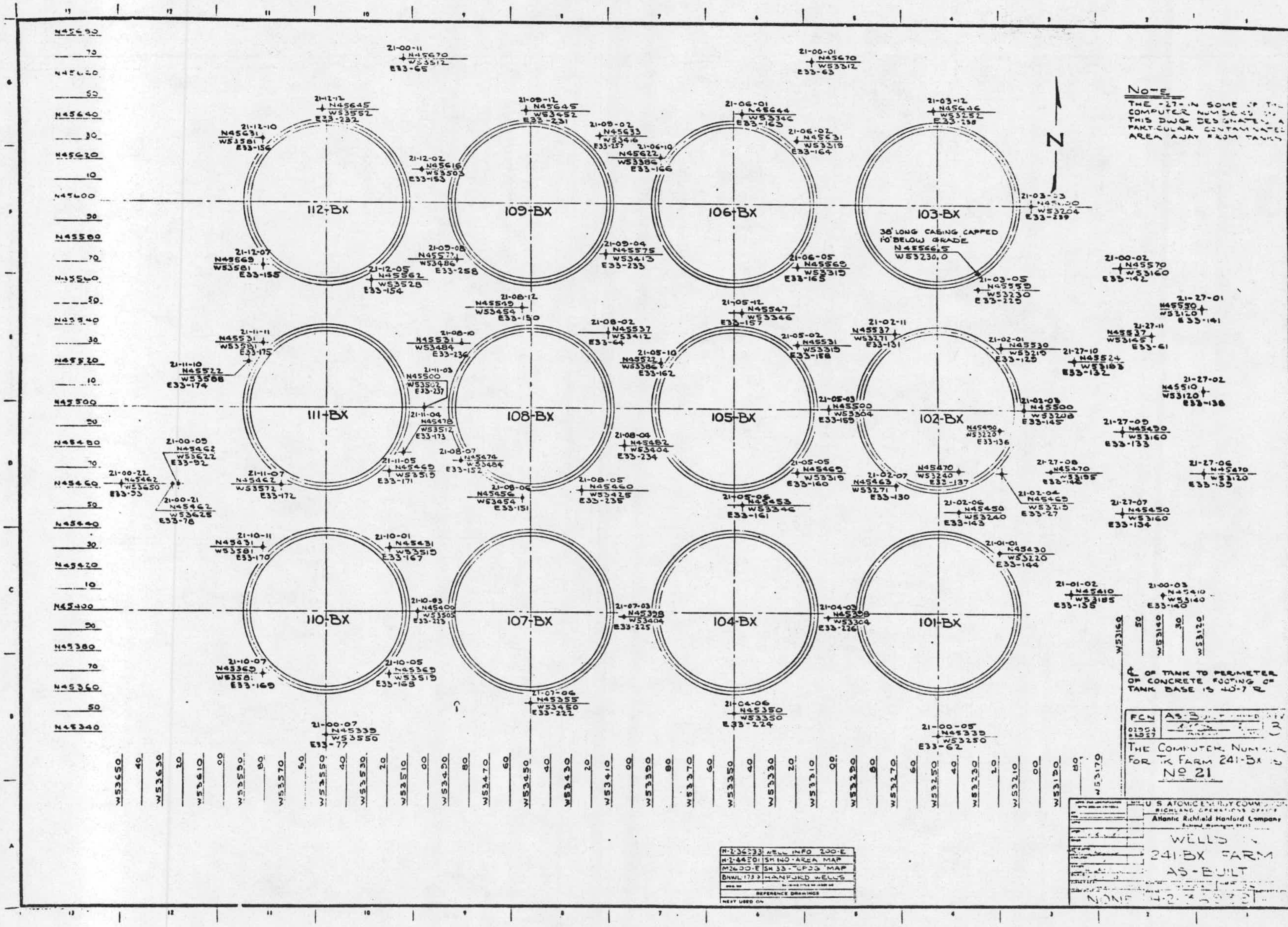
ARH-ST-127



112-U
109-U
106-U
103-U
111-U
108-U
105-U
102-U
110-U
107-U
104-U
101-U
N
℄ OF TANK PERIMETER OF CONCRETE FOOTING OF TANK BASE IS 40.7 R
AS-BUILT
ARHCO
THE COMPUTER NUMBER FOR TK FARM 241-U IS Nº 60
Atlantic Richfield Hanford Company
WELLS IN 241-U FARM AS-BUILT
NONE
REFERENCE DRAWINGS
REVISIONS

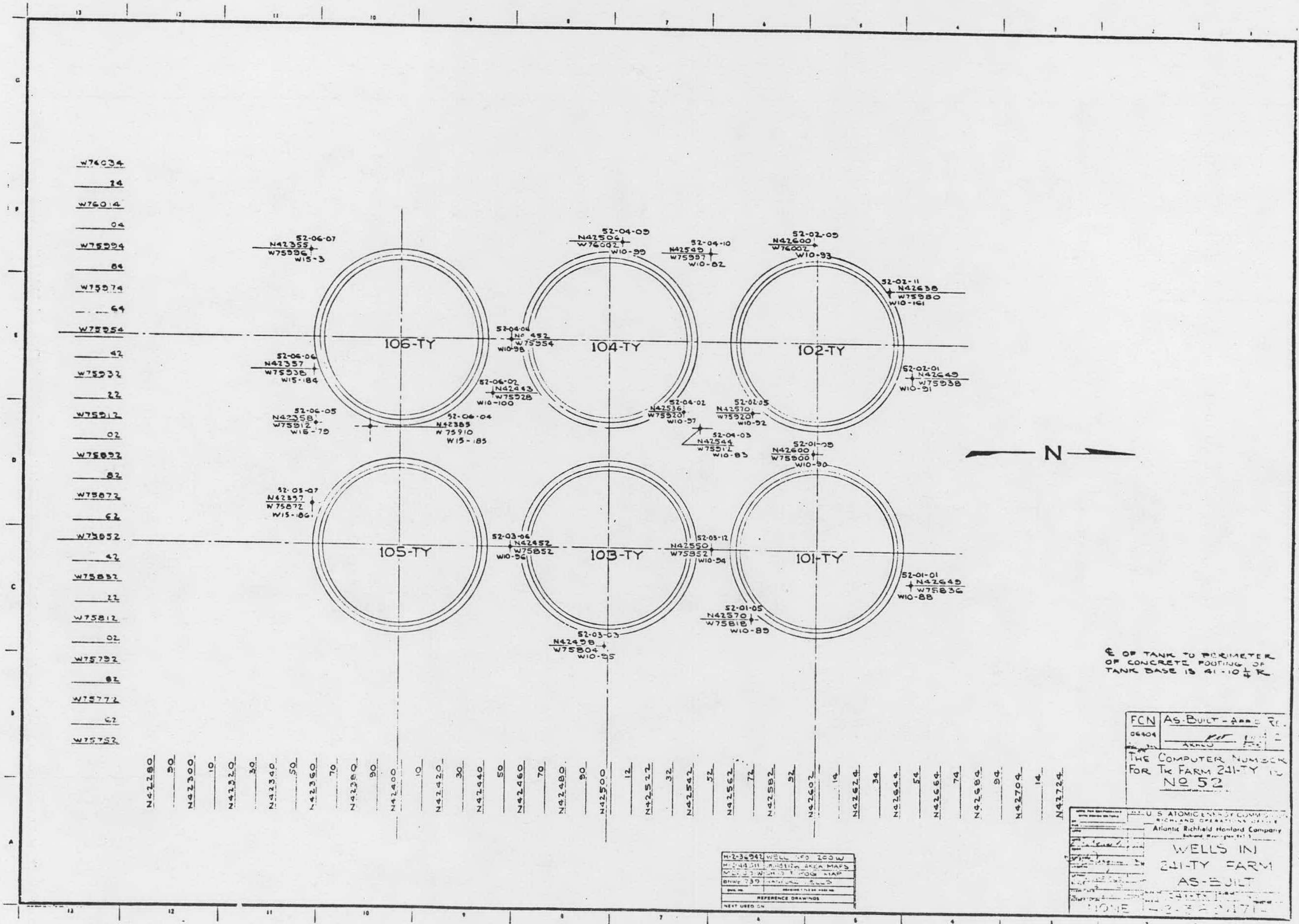
63

ARH-ST-127



112-BX
109-BX
106-BX
103-BX
111-BX
108-BX
105-BX
102-BX
110-BX
107-BX
104-BX
101-BX
N
NOTE
THE "27" IN SOME OF THE COMPUTER NUMBERS ON THIS DWG DESIGNATES A PARTICULAR CONTAMINATED AREA AWAY FROM TANKS
38' LONG CASING CAPPED 10' BELOW GRADE
℄ OF TANK TO PERIMETER OF CONCRETE FOOTING OF TANK BASE IS 40'-7 R
THE COMPUTER NUMBER FOR TK FARM 241-BX IS Nº 21
U S ATOMIC ENERGY COMMISSION
Atlantic Richfield Hanford Company
WELLS IN 241-BX FARM AS-BUILT
REFERENCE DRAWINGS
NEXT USED ON

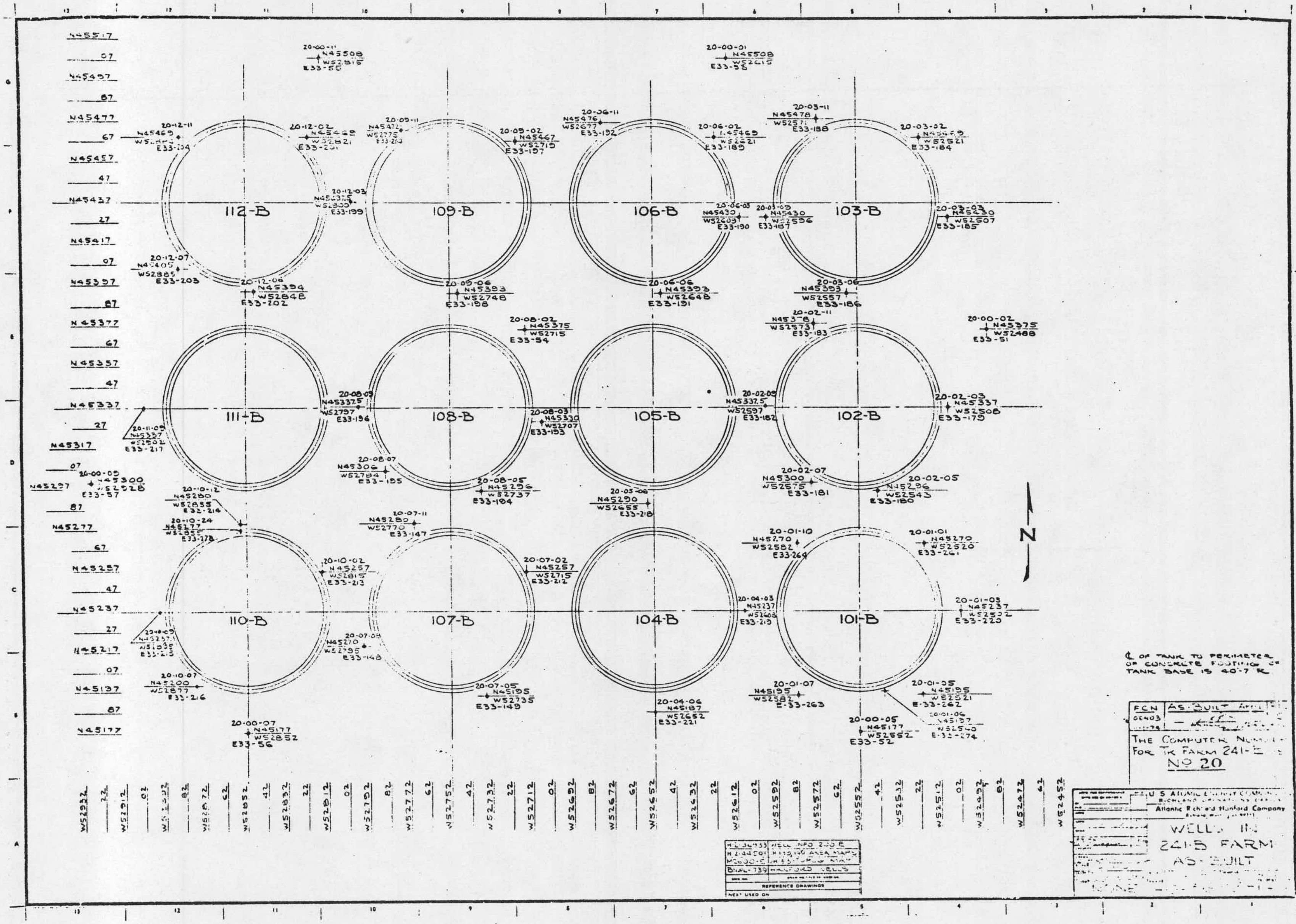
ARH-ST-127



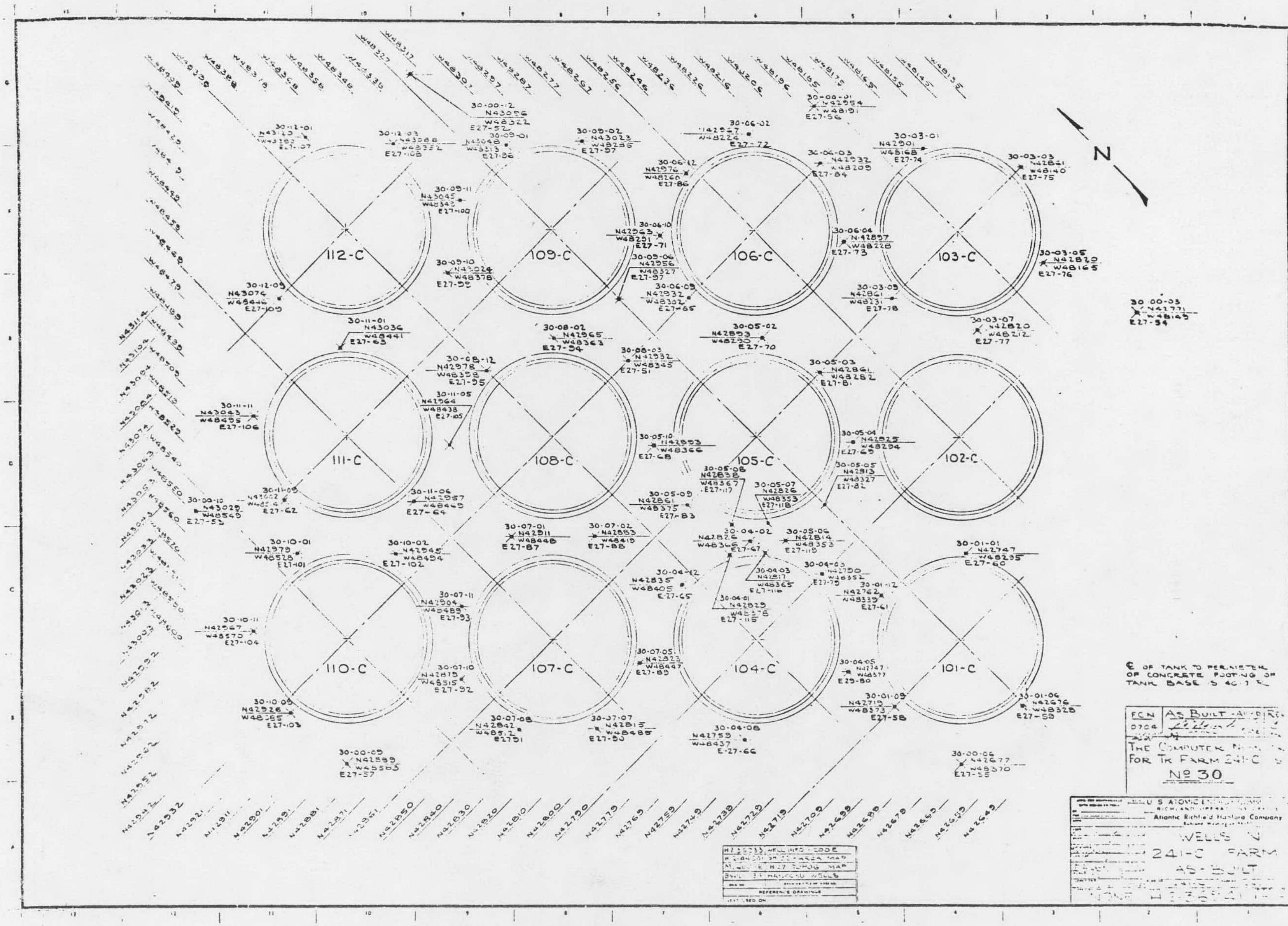
106-TY
104-TY
102-TY
105-TY
103-TY
101-TY
N
52-06-07 N42355 W75996 W15-3
52-04-09 N42506 W76002 W10-99
52-04-10 N42549 W75997 W10-02
52-02-09 N42600 W76002 W10-93
52-02-11 N42638 W75980 W10-161
52-04-04 N° 452 W75954 W10-98
52-06-06 N42357 W75938 W15-184
52-02-01 N42649 W75938 W10-91
52-06-02 N42443 W75928 W10-100
52-04-02 N42536 W75920 W10-97
52-02-05 N42570 W75920 W10-92
52-06-05 N42358 W75912 W15-79
52-06-04 N42385 W75910 W15-185
52-04-03 N42544 W75512 W10-83
52-01-09 N42600 W75900 W10-90
52-03-07 N42357 W75872 W15-186
52-03-04 N42452 W75852 W10-96
52-03-12 N42550 W75852 W10-94
52-01-01 N42649 W75836 W10-88
52-01-05 N42570 W75818 W10-89
52-03-03 N42498 W75804 W10-95
W76034
24
W76014
04
W75994
84
W75974
64
W75954
42
W75932
22
W75912
02
W75892
82
W75872
62
W75852
42
W75832
22
W75812
02
W75792
82
W75772
62
W75752
N42280
90
N42300
10
N42320
30
N42340
50
N42360
70
N42380
90
N42400
10
N42420
30
N42440
50
N42460
70
N42480
90
N42500
12
N42522
32
N42542
52
N42562
72
N42582
92
N42602
14
N42624
34
N42644
54
N42664
74
N42684
94
N42704
14
N42724
℄ OF TANK TO PERIMETER OF CONCRETE FOOTING OF TANK BASE IS 41-10¼ R
FCN
06404
AS-BUILT
THE COMPUTER NUMBER FOR TK FARM 241-TY IS
Nº 52
U S ATOMIC ENERGY COMMISSION
RICHLAND OPERATIONS OFFICE
Atlantic Richfield Hanford Company
WELLS IN
241-TY FARM
AS-BUILT
NONE
REFERENCE DRAWINGS

65

ARH-ST-127

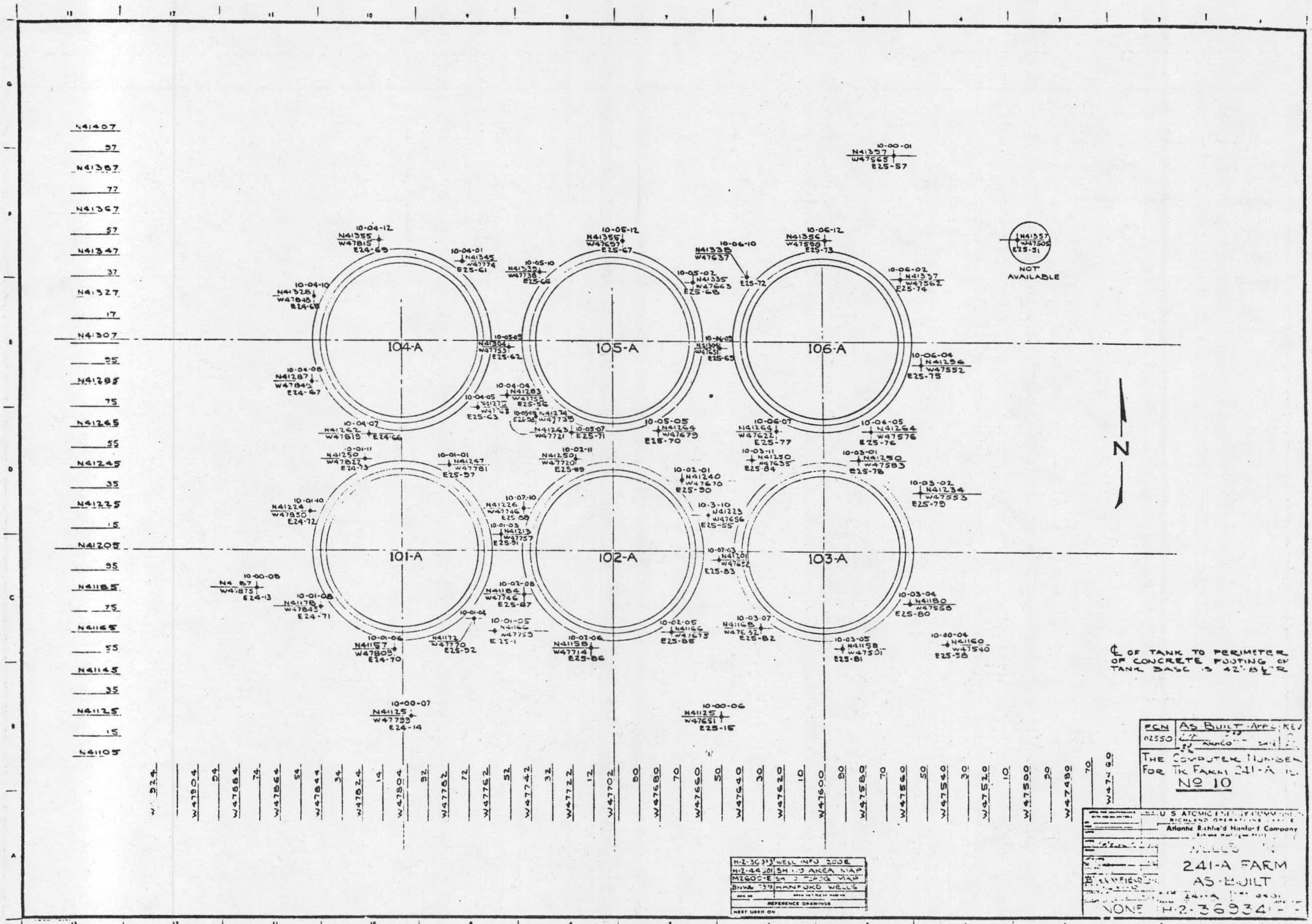

112-B
109-B
106-B
103-B
111-B
108-B
105-B
102-B
110-B
107-B
104-B
101-B
N
℄ OF TANK TO PERIMETER OF CONCRETE FOOTING OF TANK BASE IS 40'-7" R.
THE COMPUTER NUMBER FOR TK FARM 241-B IS
Nº 20
U S ATOMIC ENERGY COMMISSION
Atlantic Richfield Hanford Company
WELLS IN 241-B FARM AS-BUILT
REFERENCE DRAWINGS
NEXT USED ON

ARH-ST-127


N
112-C
109-C
106-C
103-C
111-C
108-C
105-C
102-C
110-C
107-C
104-C
101-C
℄ OF TANK TO PERIMETER OF CONCRETE FOOTING OF TANK BASE IS 40-7 5L
FCN
0704
AS BUILT
THE COMPUTER NUMBER FOR TK FARM 241-C IS
№ 30
U S ATOMIC ENERGY COMMISSION
Atlantic Richfield Hanford Company
WELLS IN
241-C FARM
AS-BUILT
REFERENCE DRAWINGS

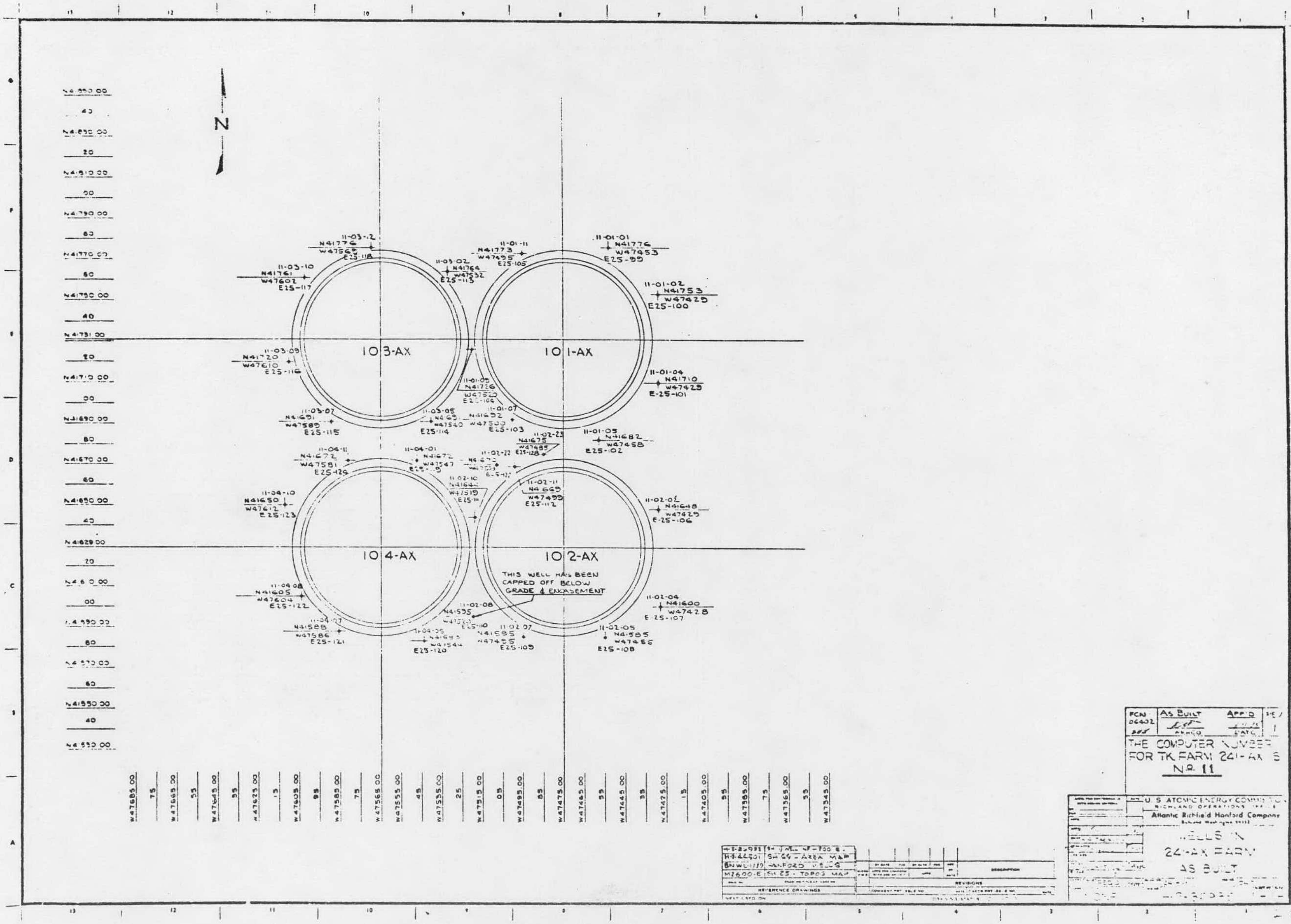
67

ARH-ST-127



104-A
105-A
106-A
101-A
102-A
103-A
N
NOT AVAILABLE
℄ OF TANK TO PERIMETER OF CONCRETE FOOTING OF TANK BASE IS 42'-8½"R
THE COMPUTER NUMBER FOR TK FARM 241-A IS
Nº 10
WELLS
241-A FARM
AS-BUILT
Atlantic Richfield Hanford Company
REFERENCE DRAWINGS
H-2-36934

ARH-ST-127


N
103-AX
101-AX
104-AX
102-AX
THIS WELL HAS BEEN CAPPED OFF BELOW GRADE & ENCASEMENT
FCN 06402
AS BUILT
APP'D
THE COMPUTER NUMBER FOR TK FARM 241-AX IS
Nº 11
Atlantic Richfield Hanford Company
24-AX FARM
AS BUILT
REFERENCE DRAWINGS
REVISIONS

69

ARH-ST-127

WELL NO.	DEPTH	PVC (4")	PERFORATED	COMMENTS
51	40'	20'	BOTTOM 10' PVC	WELL SCREEN
54	40'	20'	BOTTOM 10' PVC	↓
56	27'4"		BOTTOM 7'4"	← LOST 2'8" DUE TO SAND
62	40'	20'	BOTTOM 10' PVC	WELL SCREEN
64	40'	20'	BOTTOM 10 PVC	
69	50'	20'	BOTTOM 10' PVC	
72	50'	20'	BOTTOM 10 PVC	
73	50'	20	BOTTOM 10" PVC	
75	50'	20'	BOTTOM 10 PVC	↓
68	40'			
70	40'			
71	40'			
74	40'			

ALL WELLS 30' UNLESS OTHERWISE NOTED

82,83 ARE 6" WELLS

ALL WELLS PREFIXED BY 299-W21

⊚ PERFORATED WELLS

SCALE

0 FEET 20

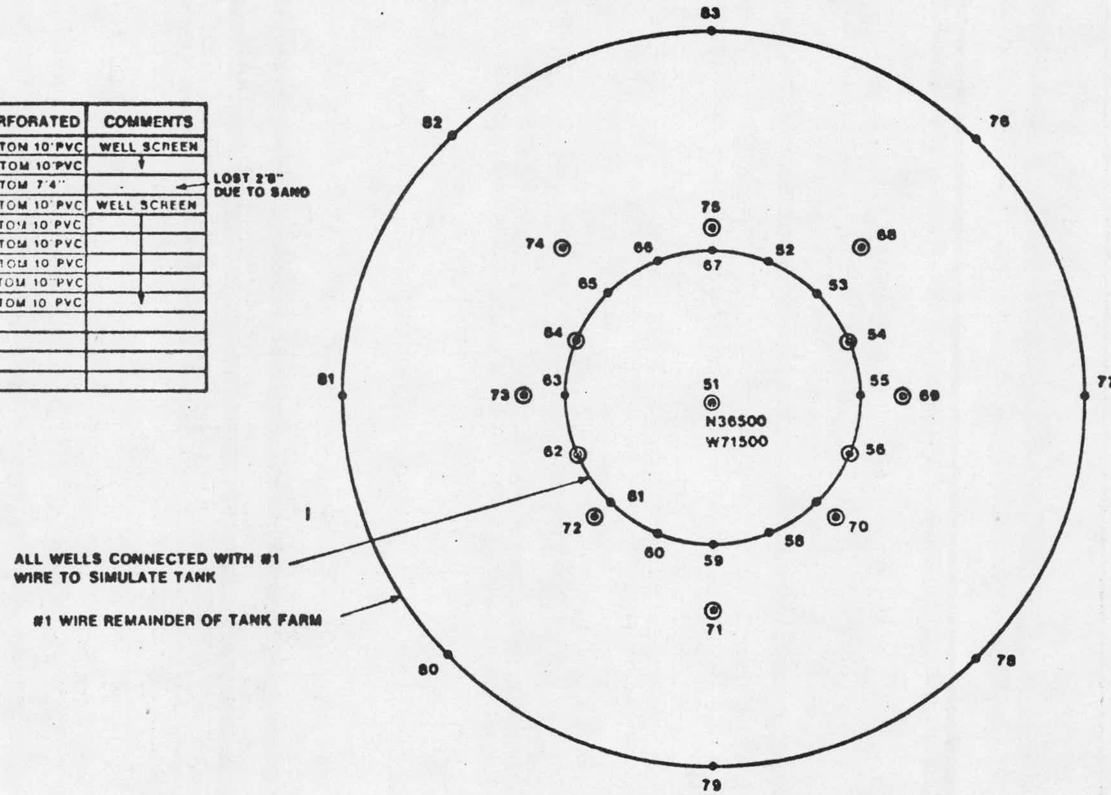


FIGURE 1

PLAN VIEW OF TEST SITE

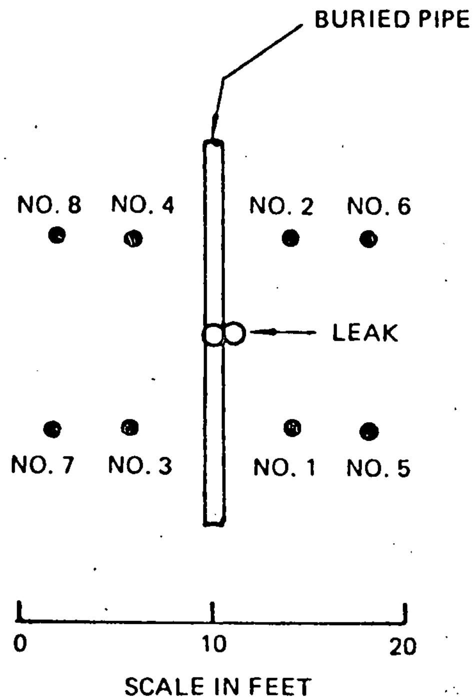


FIGURE 2

PIPE/ELECTRODE CONFIGURATION

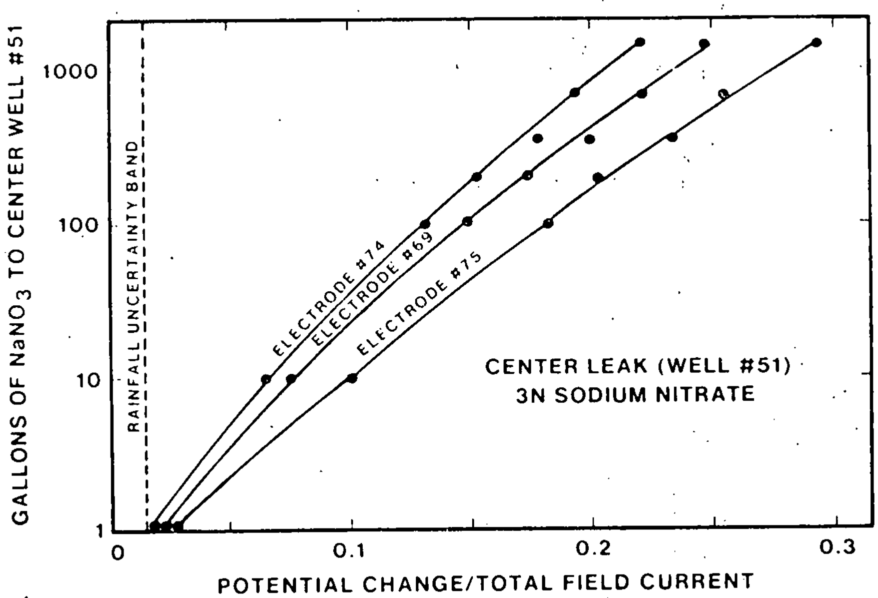


FIGURE 3

TEST SITE CENTER LEAK RESPONSE

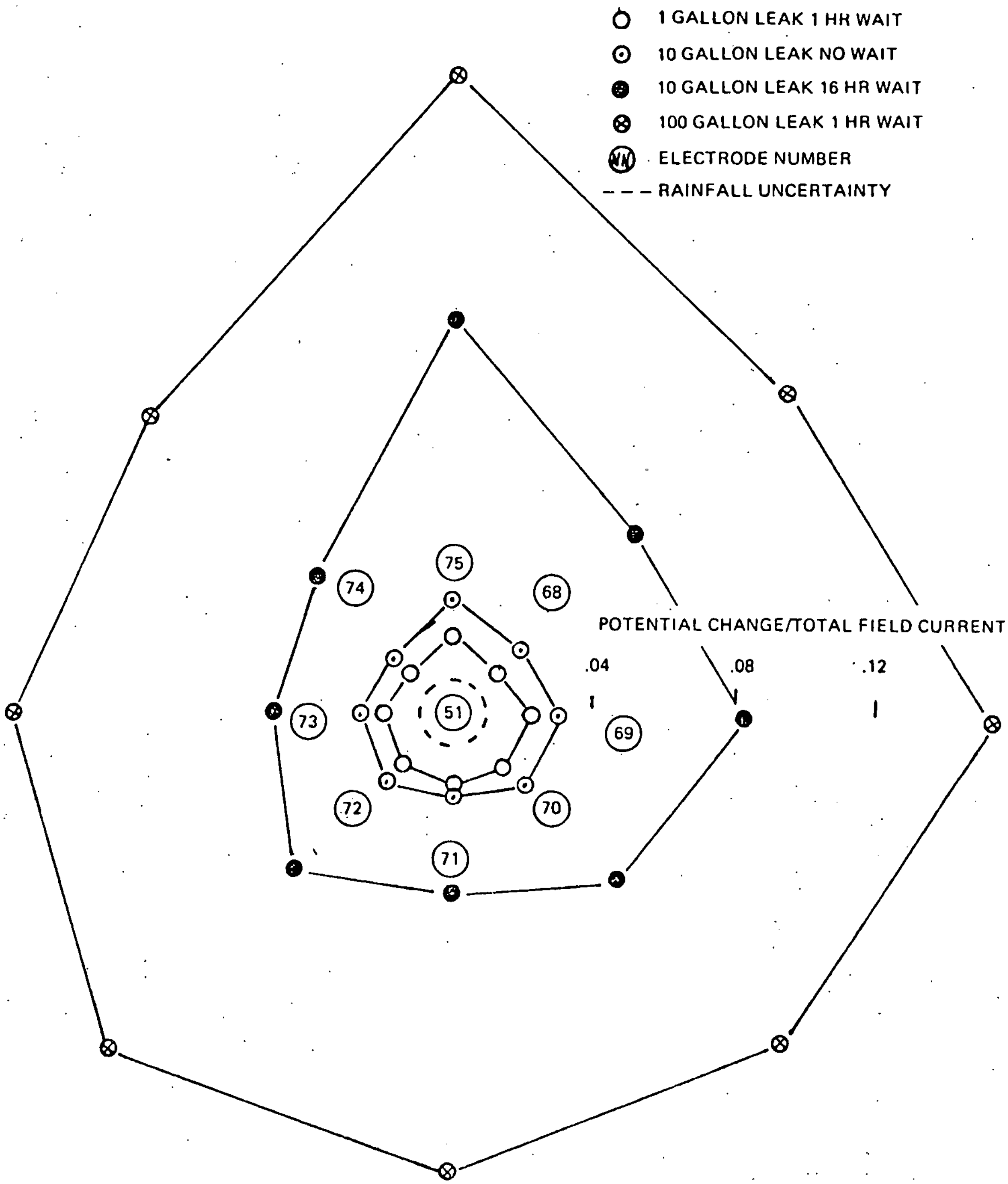


FIGURE 4

CENTER LEAK 3*M* SODIUM NITRATE POLAR FIELD CHANGE PATTERN

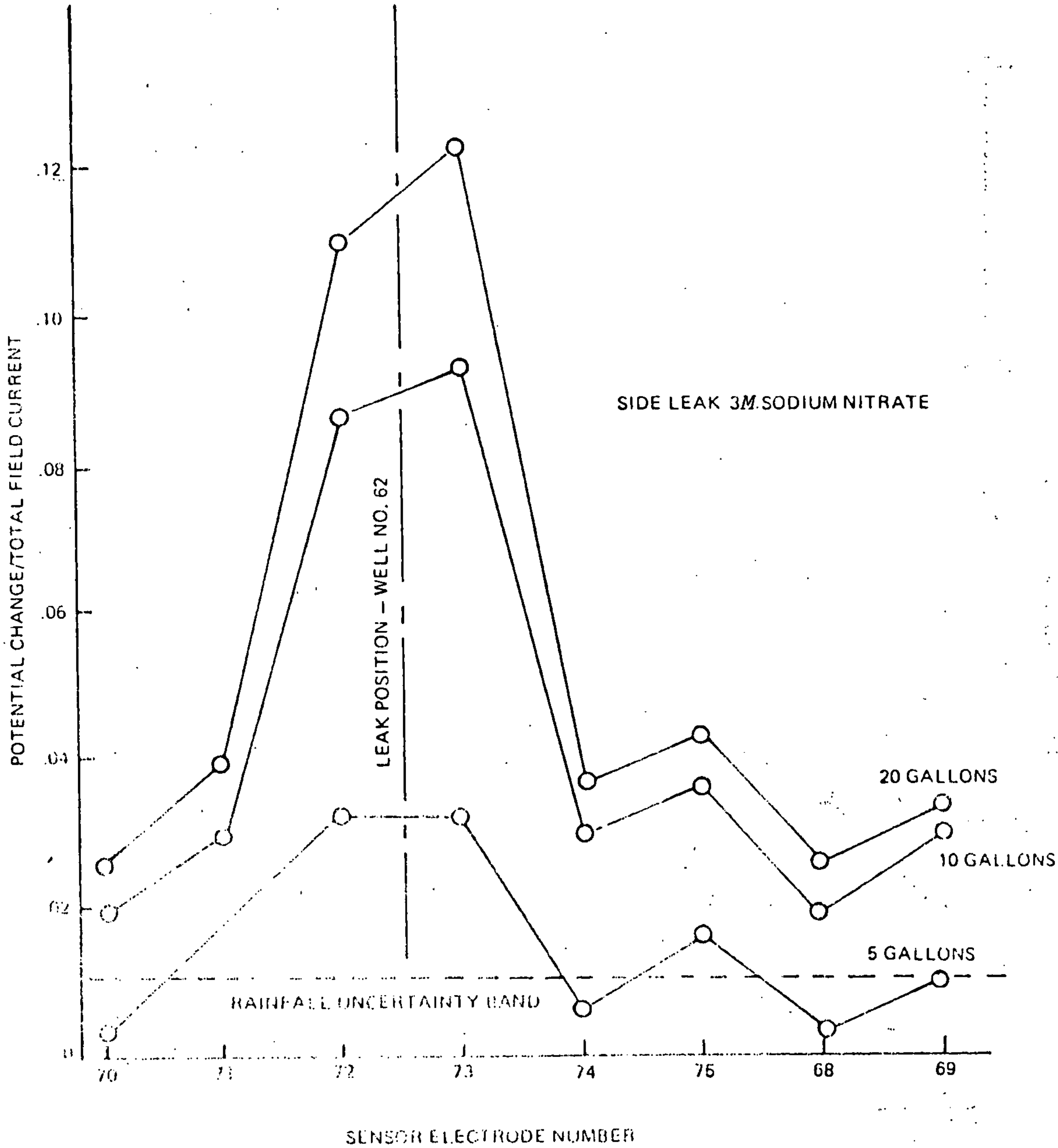


FIGURE 5

SIDE LEAK RESPONSE--SALT SOLUTION

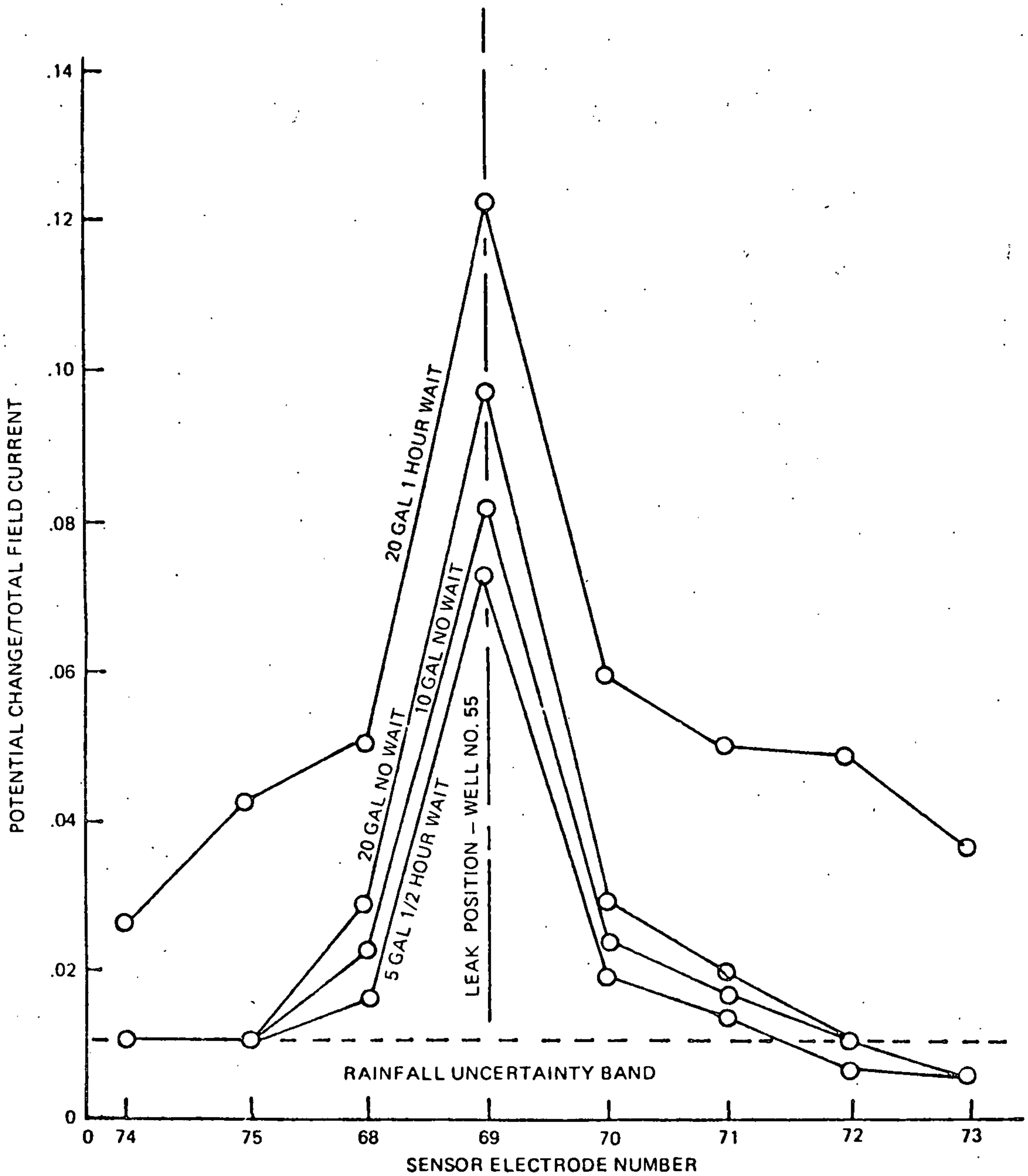


FIGURE 6

SIDE LEAK RESPONSE--RAW WATER

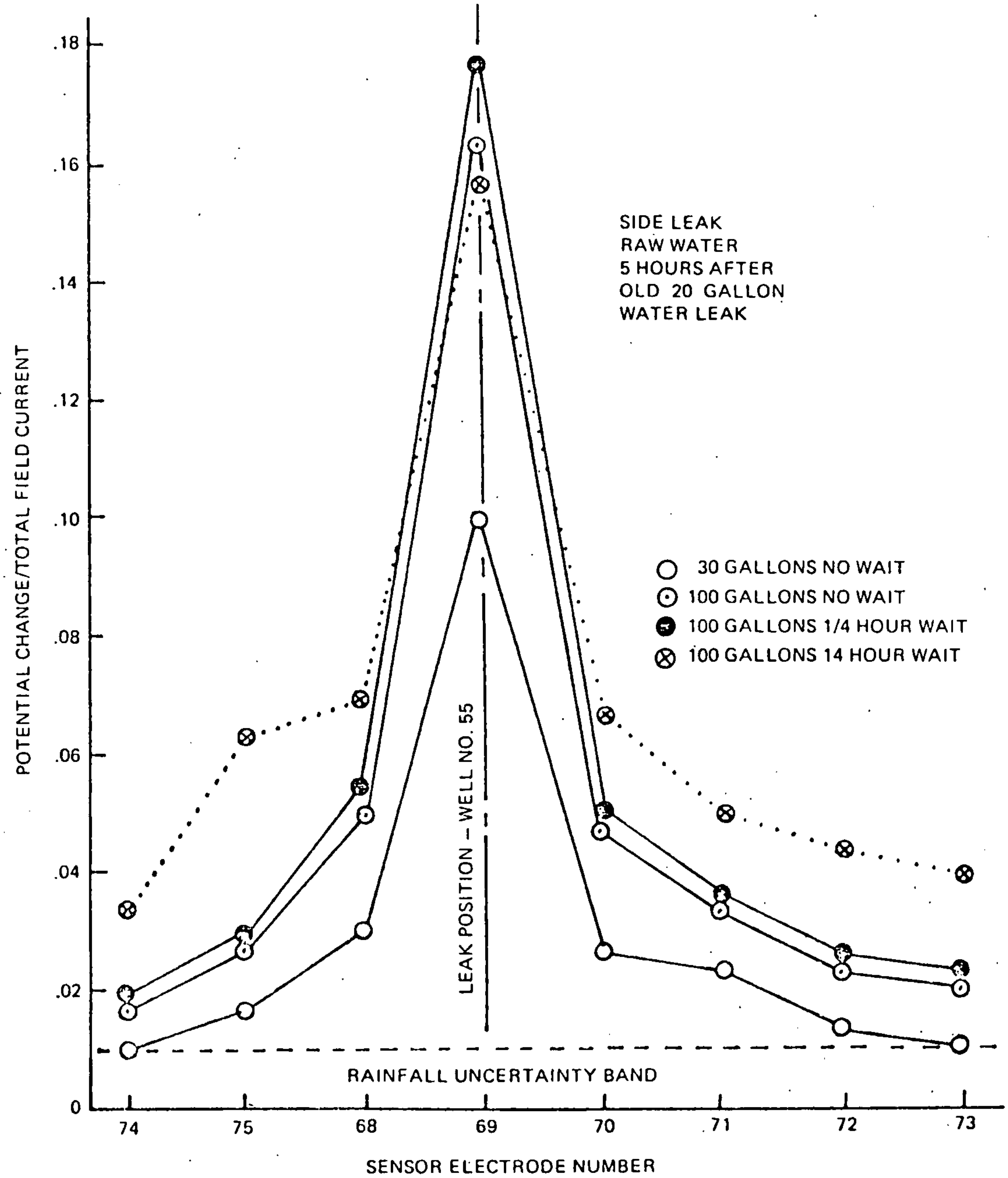


FIGURE 7

SIDE LEAK RESPONSE--ADDITIONAL RAW WATER

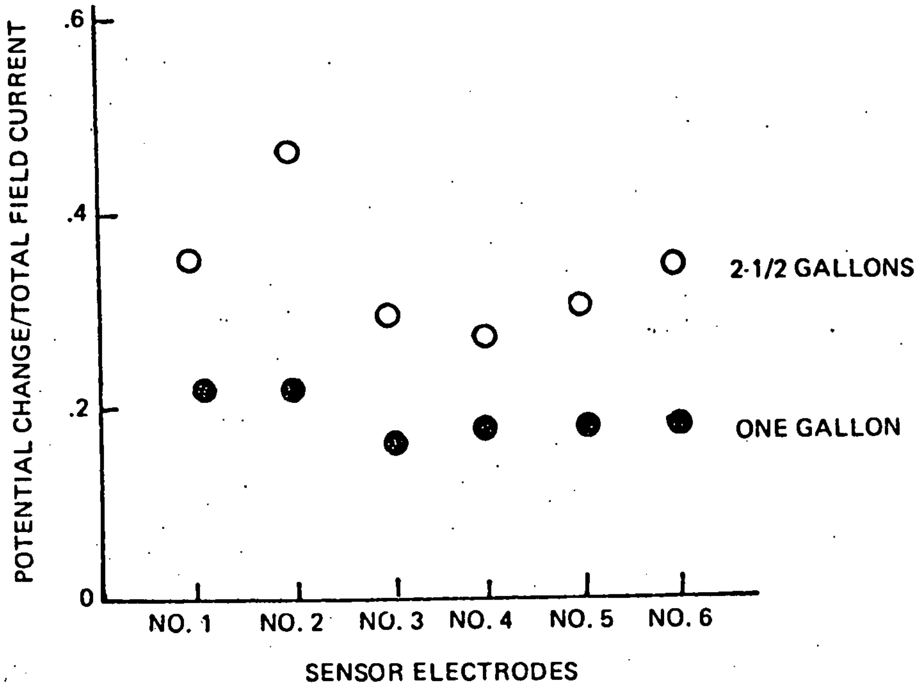


FIGURE 8

LEAK IN BURIED PIPE--3*M* SODIUM NITRATE

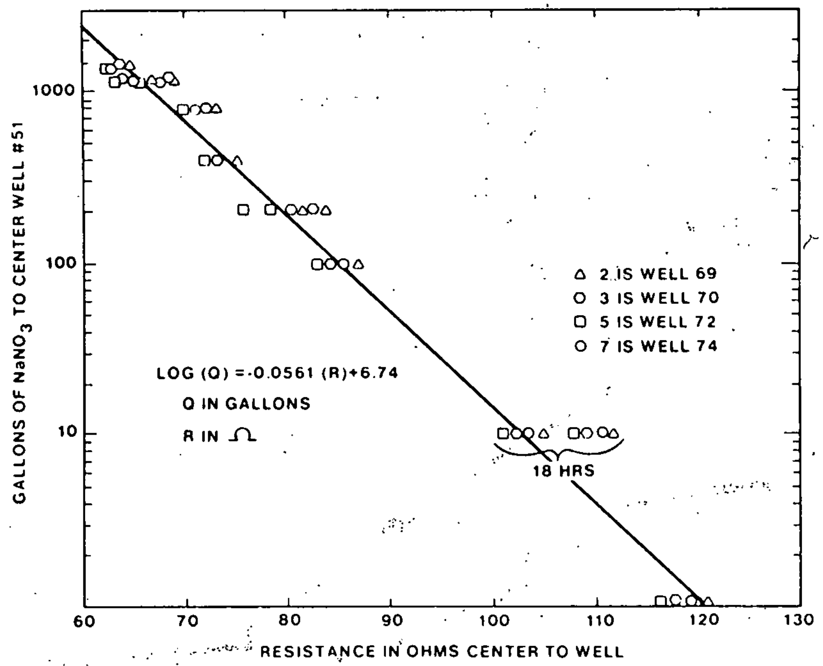


FIGURE 9

BNW TEST SITE RESULTS - RESISTANCE VERSUS GALLONS OF SALT LEAK

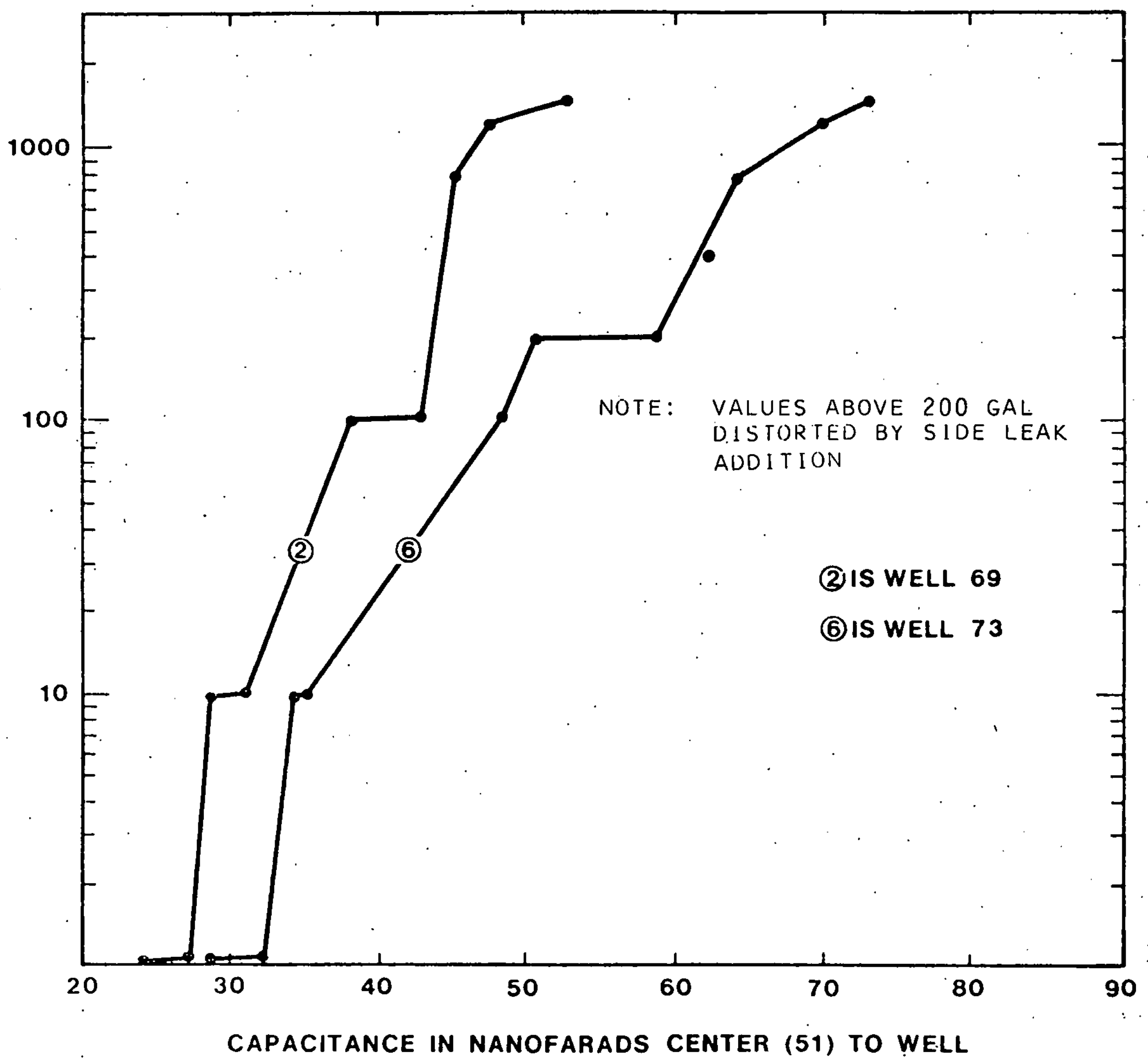


FIGURE 10

BNW TEST SITE RESULTS
CAPACITANCE VERSUS GALLONS OF SALT LEAK

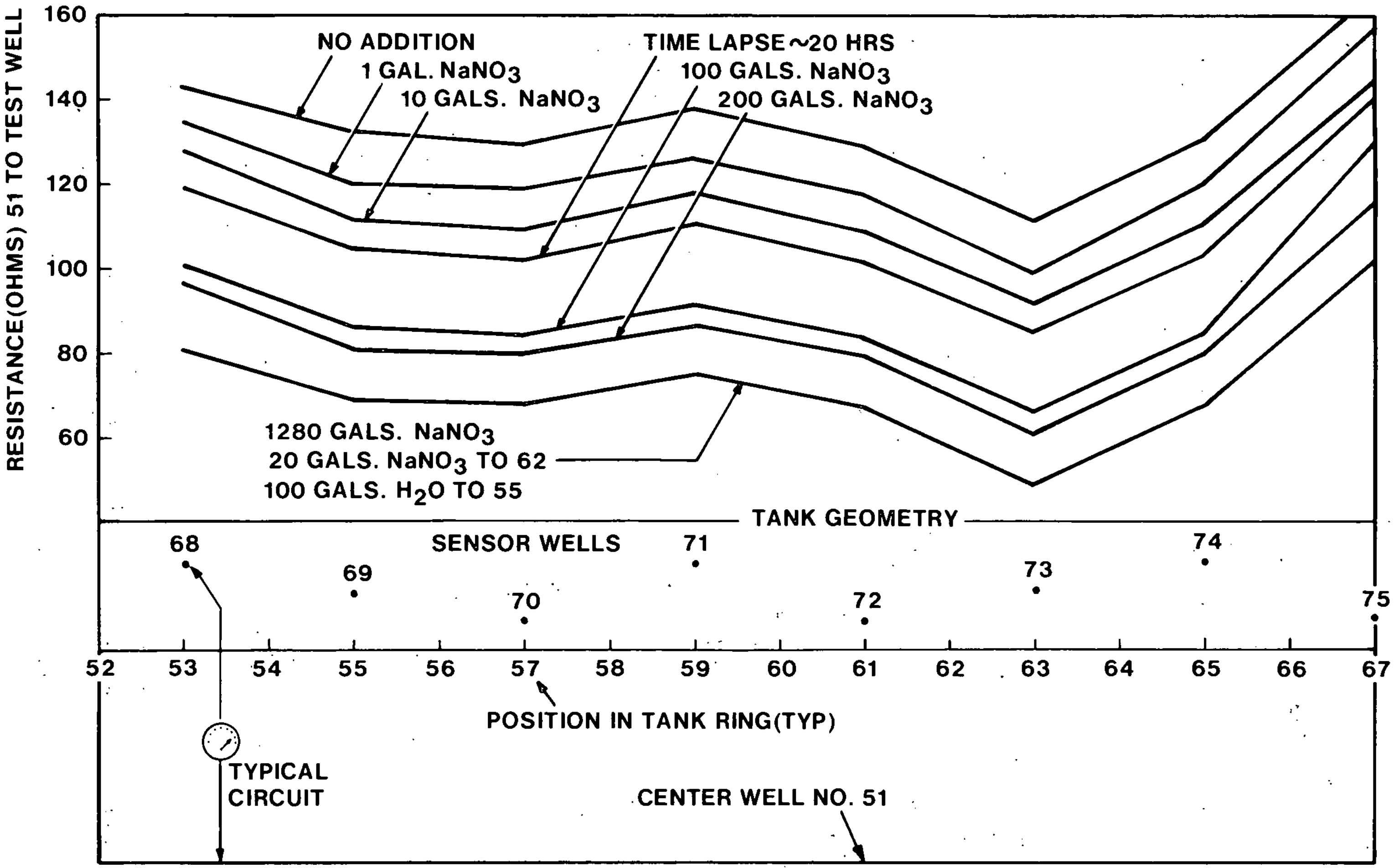


FIGURE 11

CENTER TO PROBE IMPEDANCE

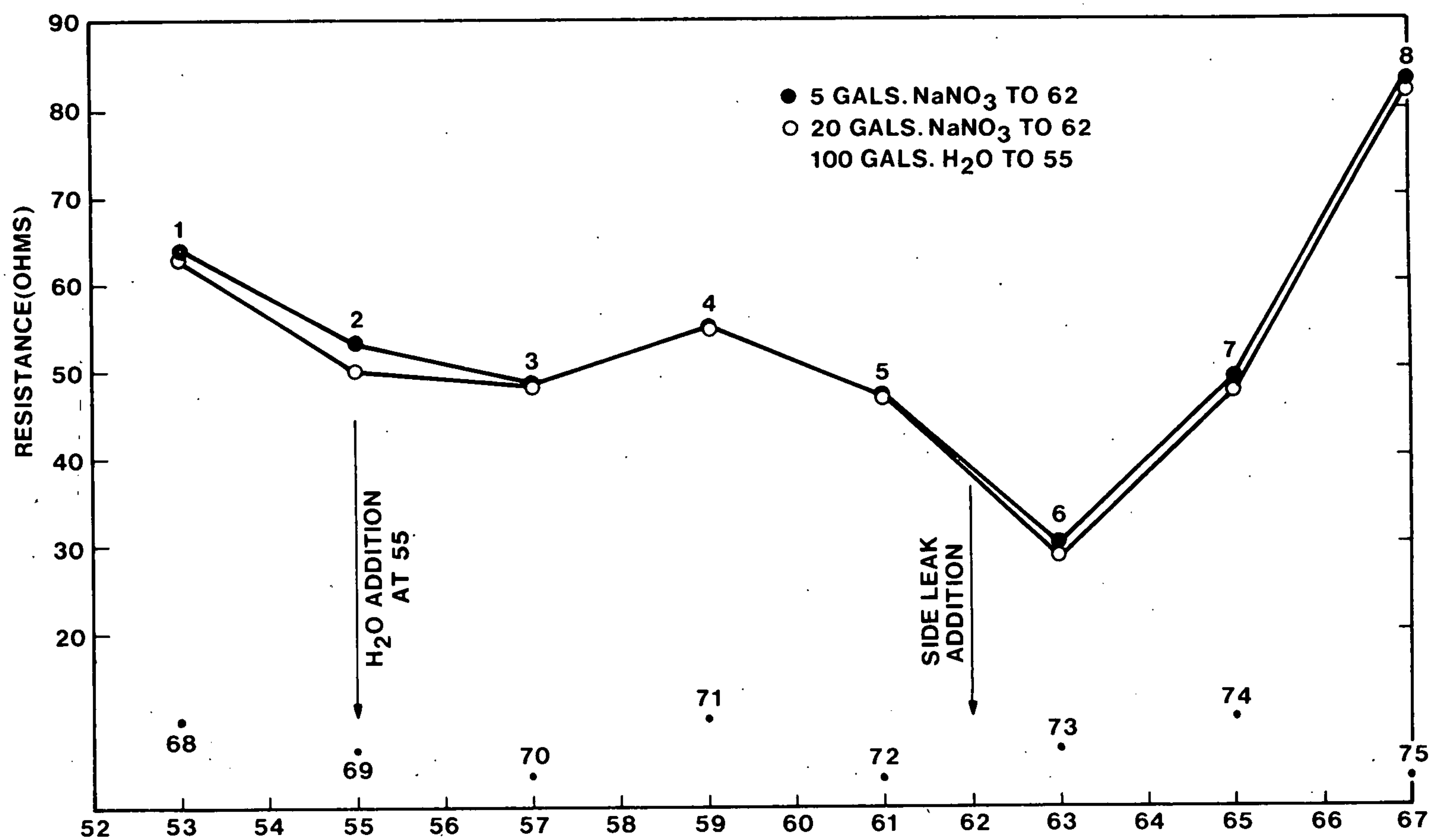
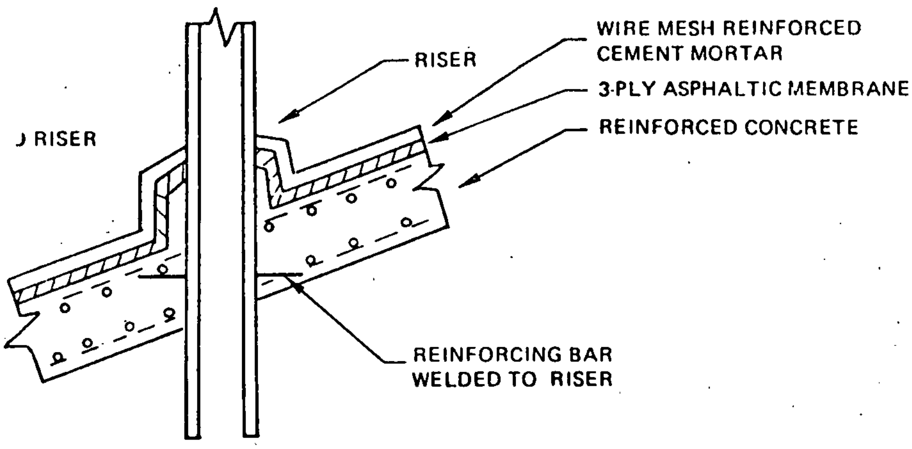


FIGURE 12

RING TO PROBE WELL RESISTANCES



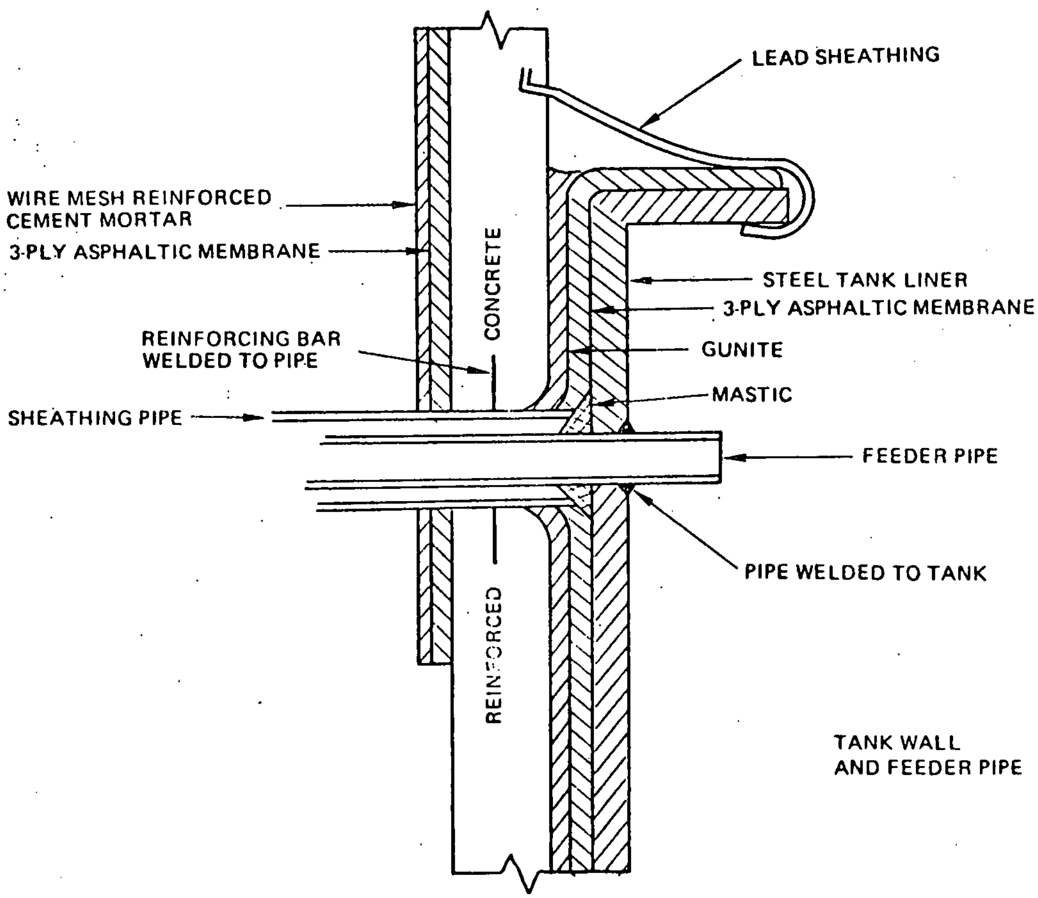


FIGURE 13

TANK WALL DESIGN

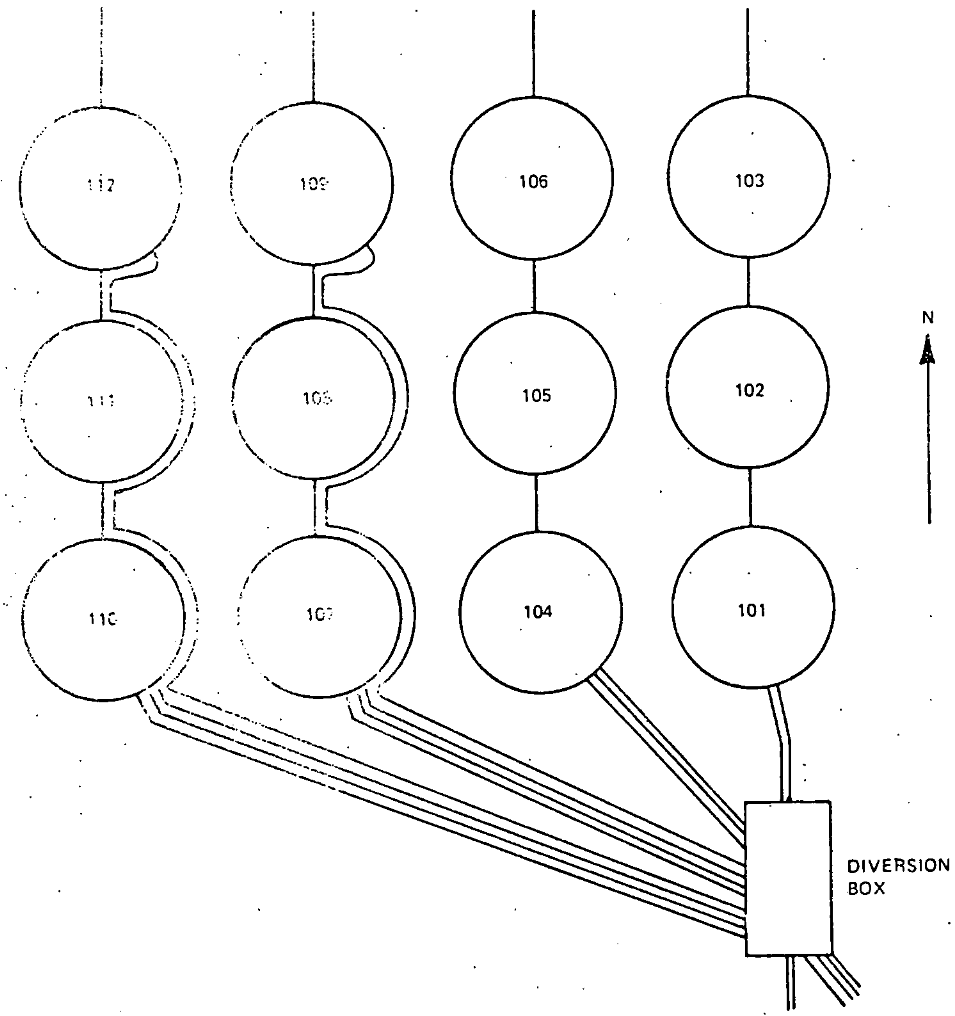


FIGURE 14

TYPICAL TANK FARM PIPING INTERCONNECTIONS

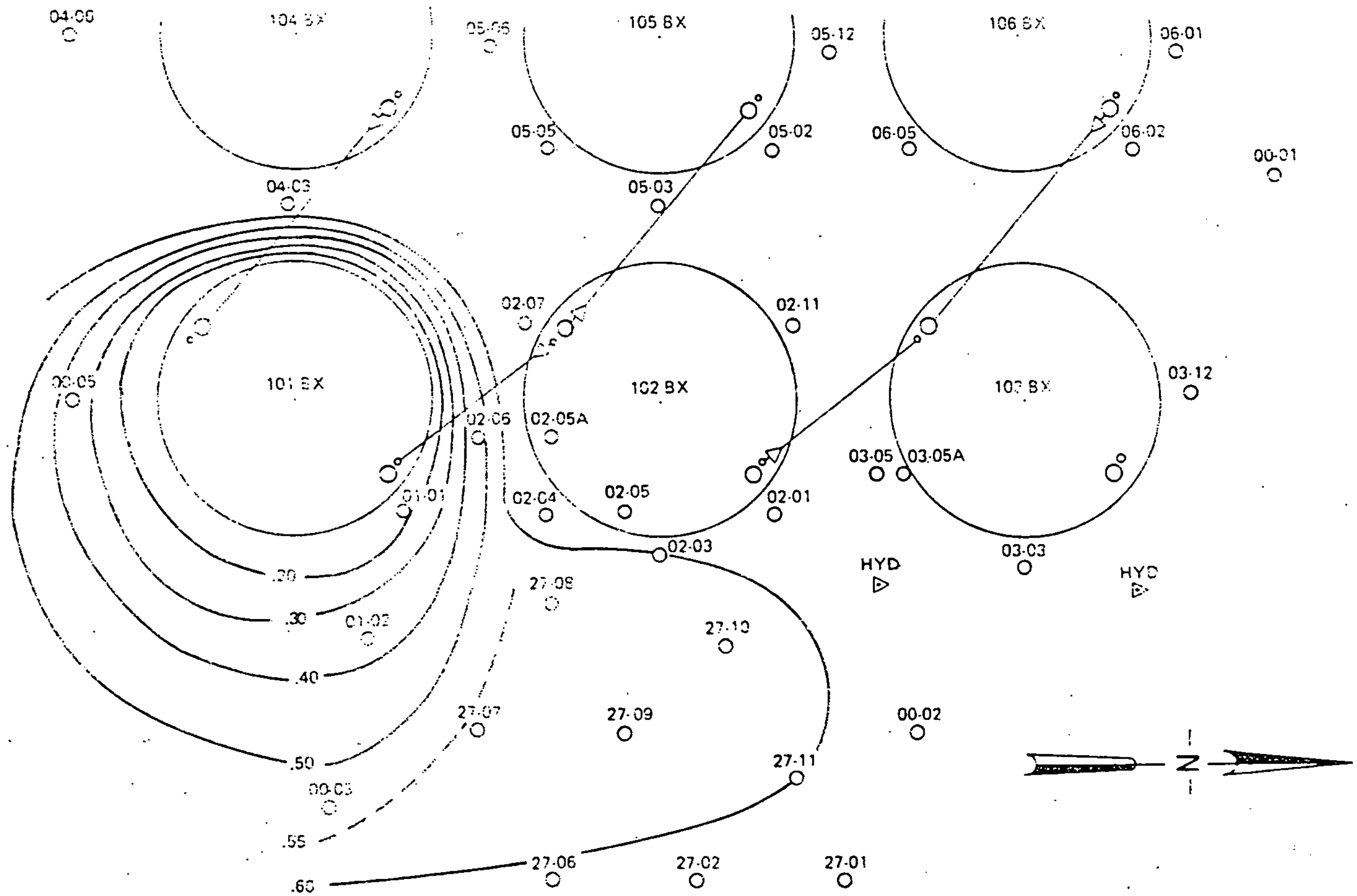


FIGURE 15

TANK 101-BX FIELD PLOT 8/23/74

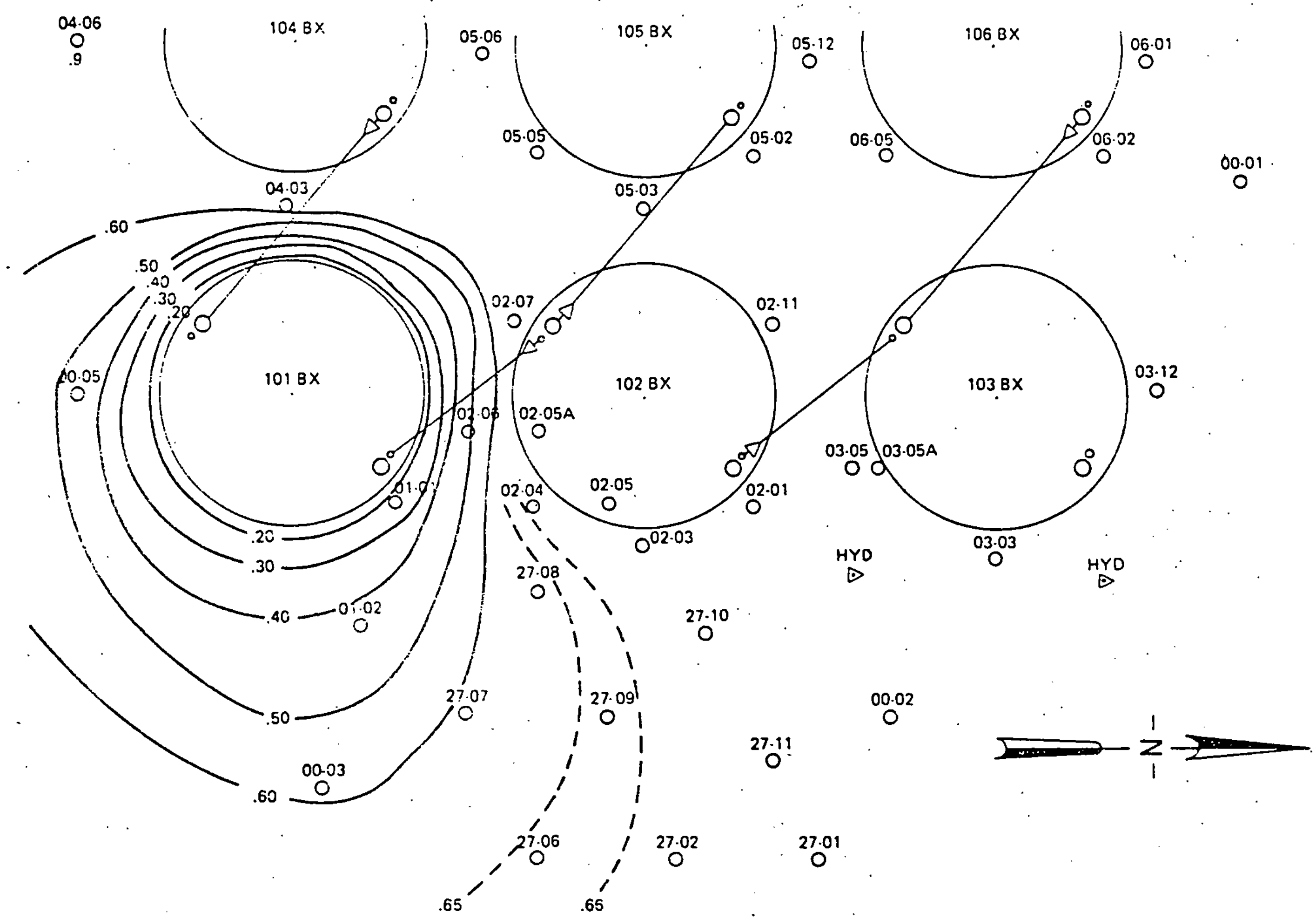


FIGURE 16

TANK 101-BX FIELD PLOT 11/7/74

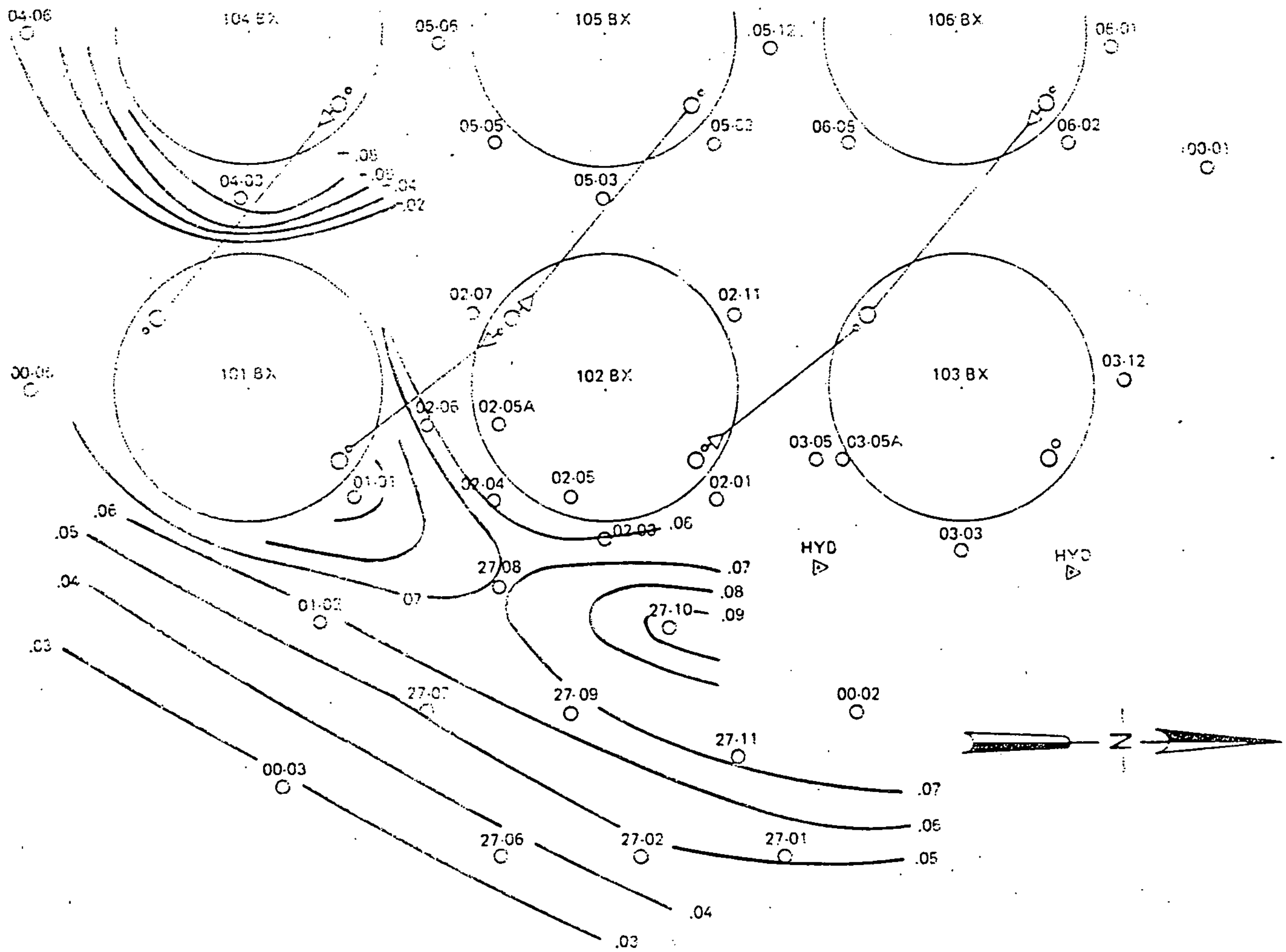


FIGURE 17

TANK 101-BX INCREMENTAL FIELD PLOT 8/23 TO 11/7/74

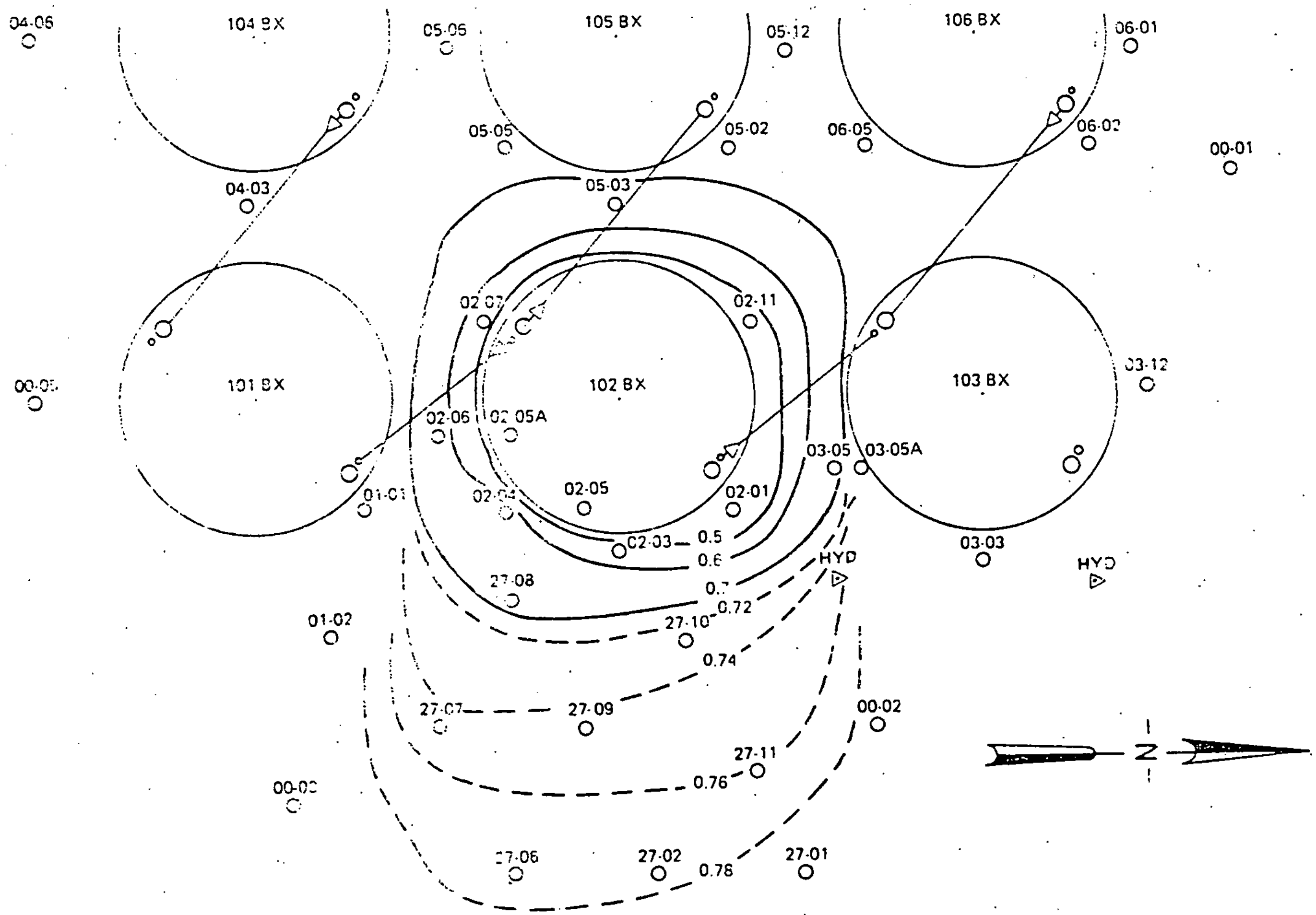


FIGURE 18

TANK 102-BX FIELD PLOT 7/19/74

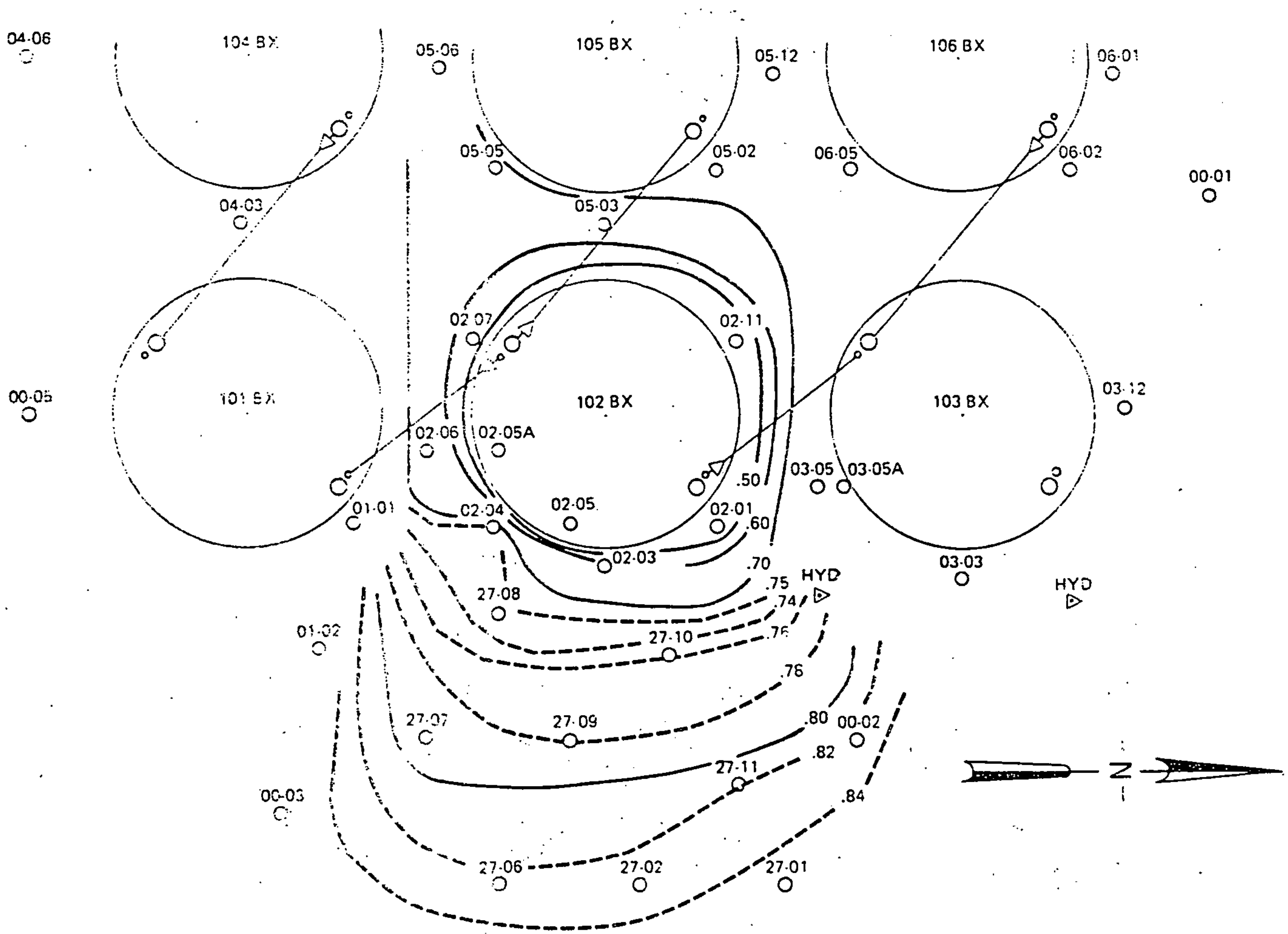


FIGURE 19

TANK 102-BX FIELD PLOT 8/23/74

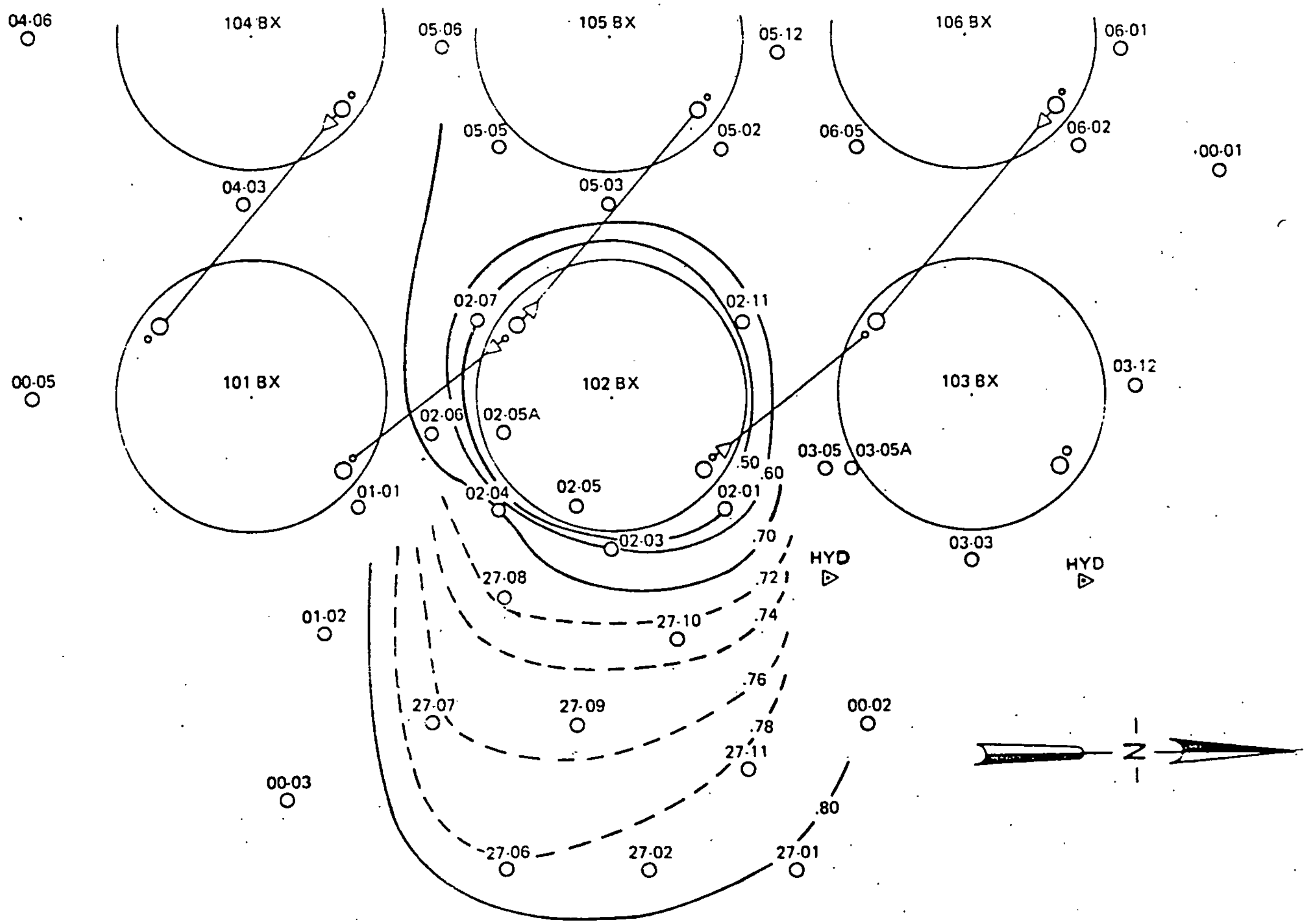


FIGURE 20

TANK 102-BX FIELD PLOT 11/7/74

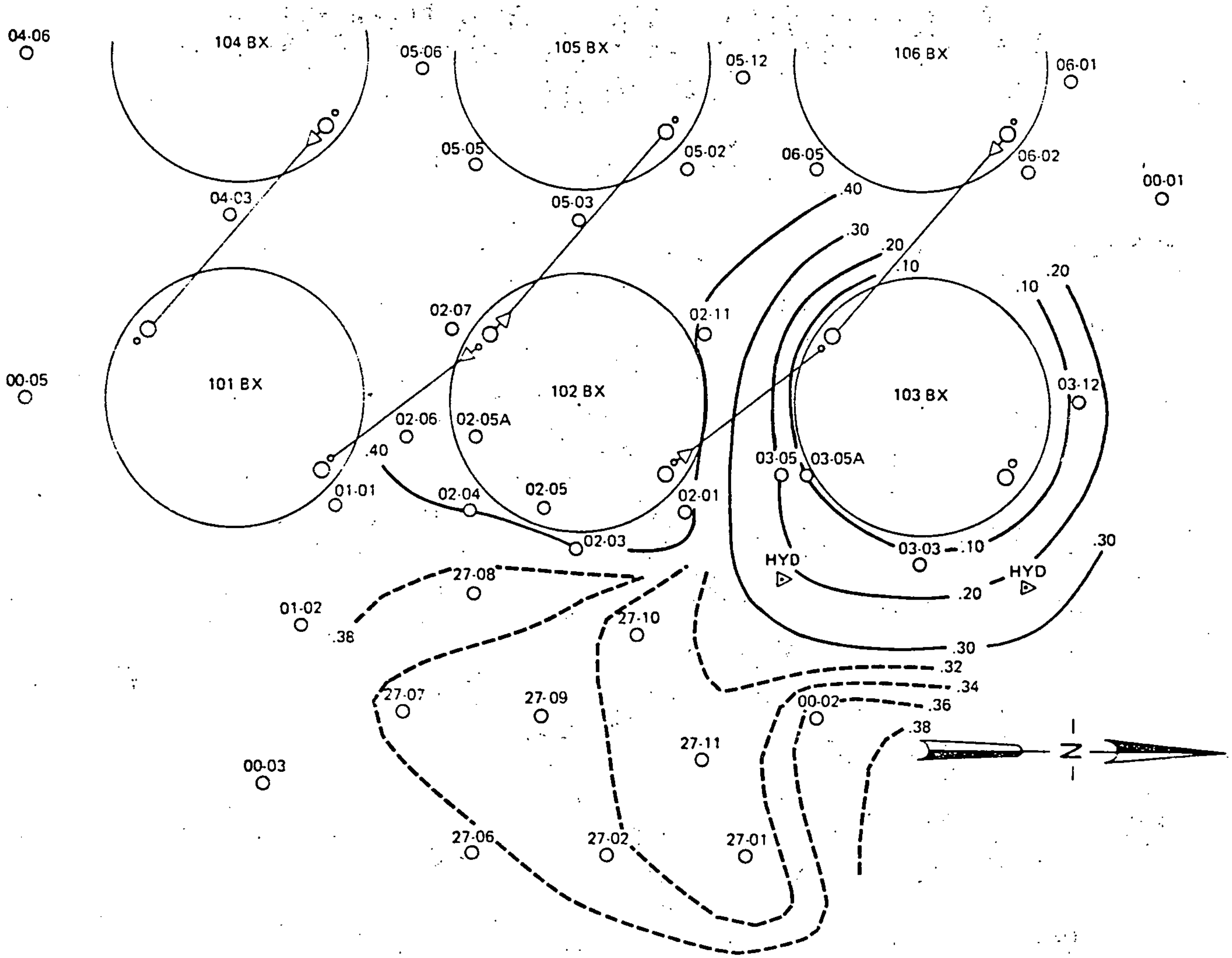


FIGURE 21

TANK 103-BX FIELD PLOT 7/19/74

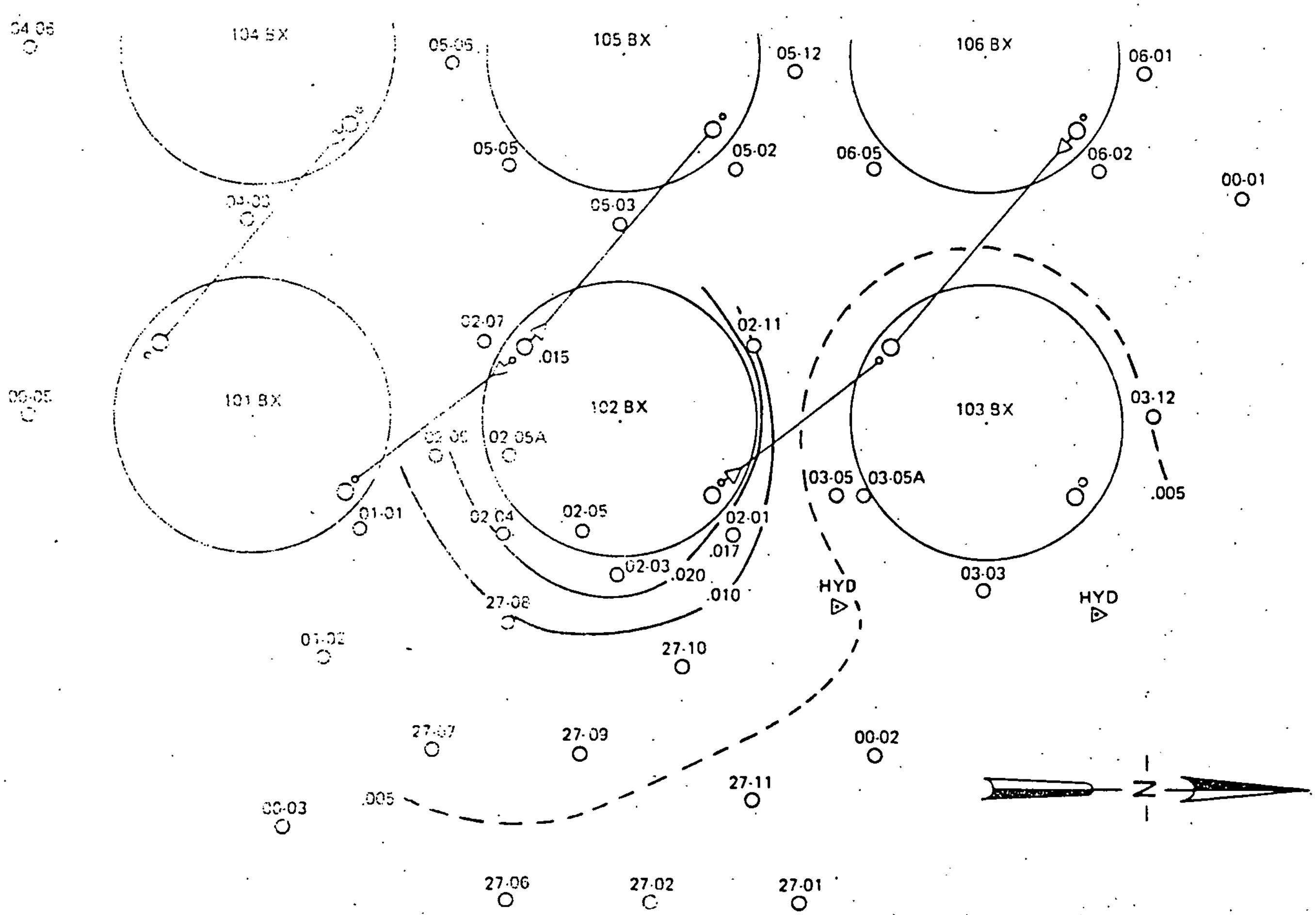


FIGURE 22

TANK 103-BX INCREMENTAL FIELD PLOT 8/22 TO 8/26/74
30 GAL $NaNO_3$ ADDED TO WELL 03-05A ON 8/23/74

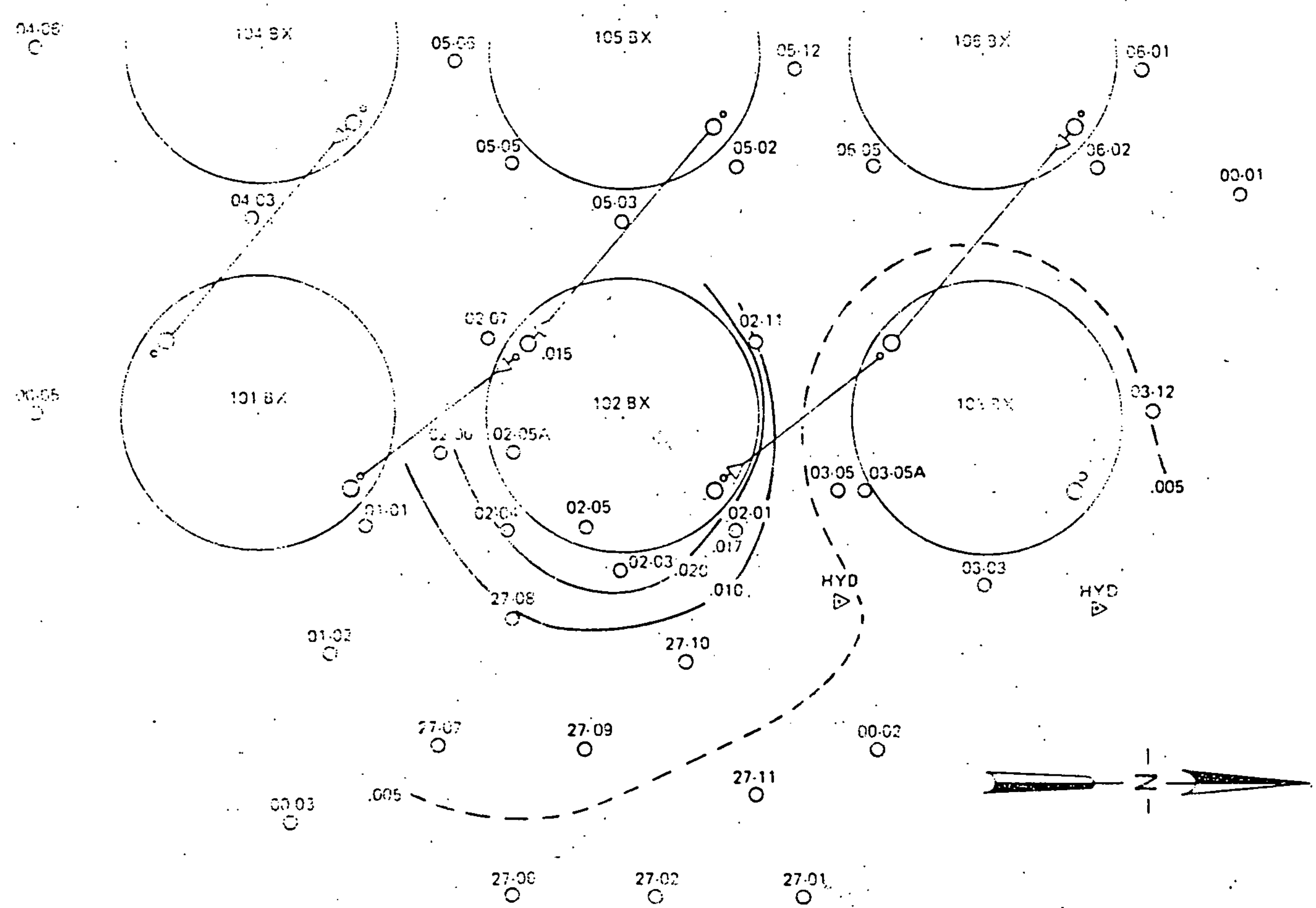


FIGURE 23

TANK 103-BX INCREMENTAL FIELD PLOT 8/26 TO 9/3/74
30 GAL $NaNO_3$ ADDED TO WELL 03-05A ON 8/23/74

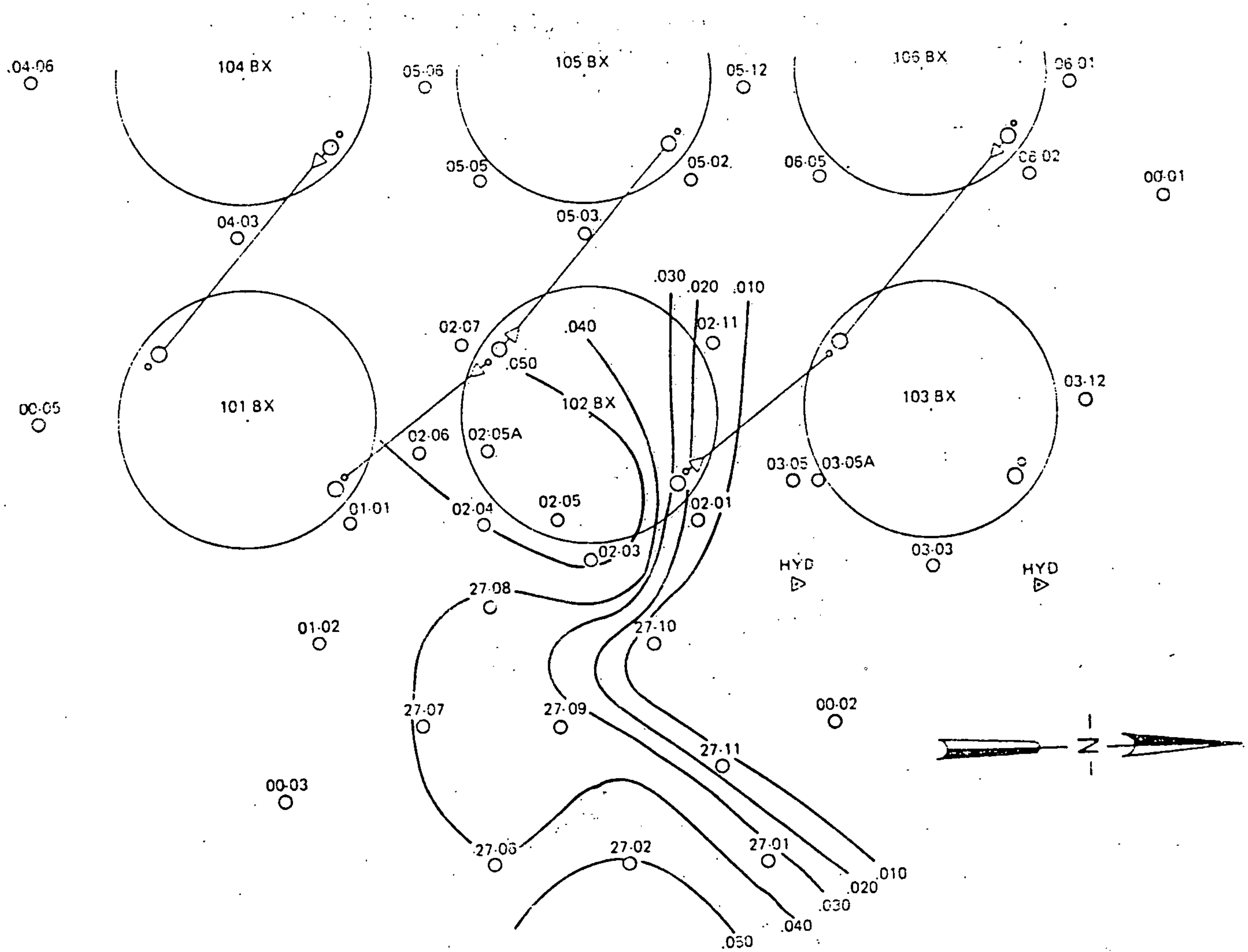


FIGURE 24

TANK 103-BX INCREMENTAL FIELD PLOT 10:10 a.m. TO 2:25 p.m., 9/10/74
200 GAL H_2O ADDED TO WELL 03-05A

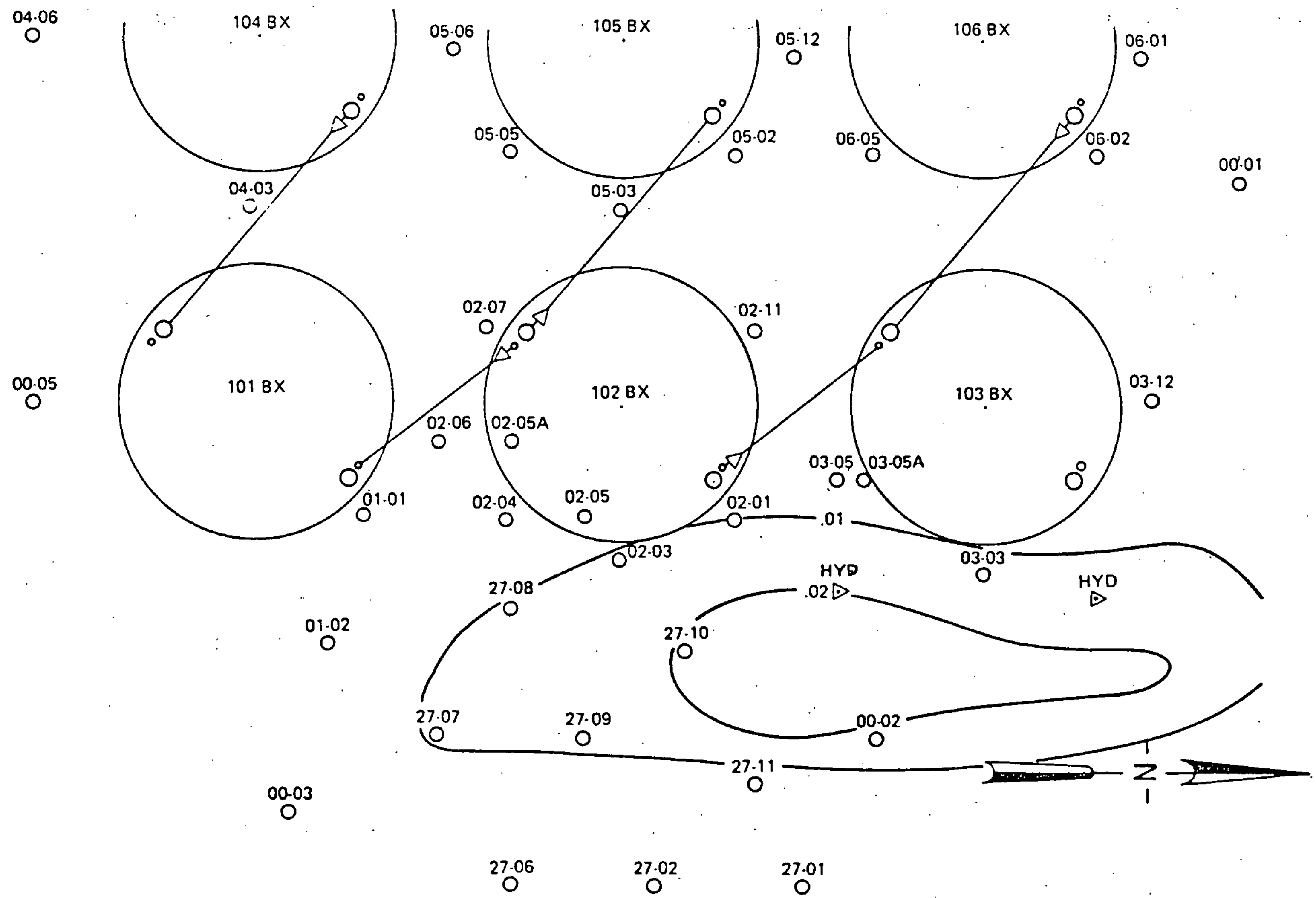


FIGURE 25

TANK 103-BX INCREMENTAL FIELD PLOT 11/6 TO 11/7/74

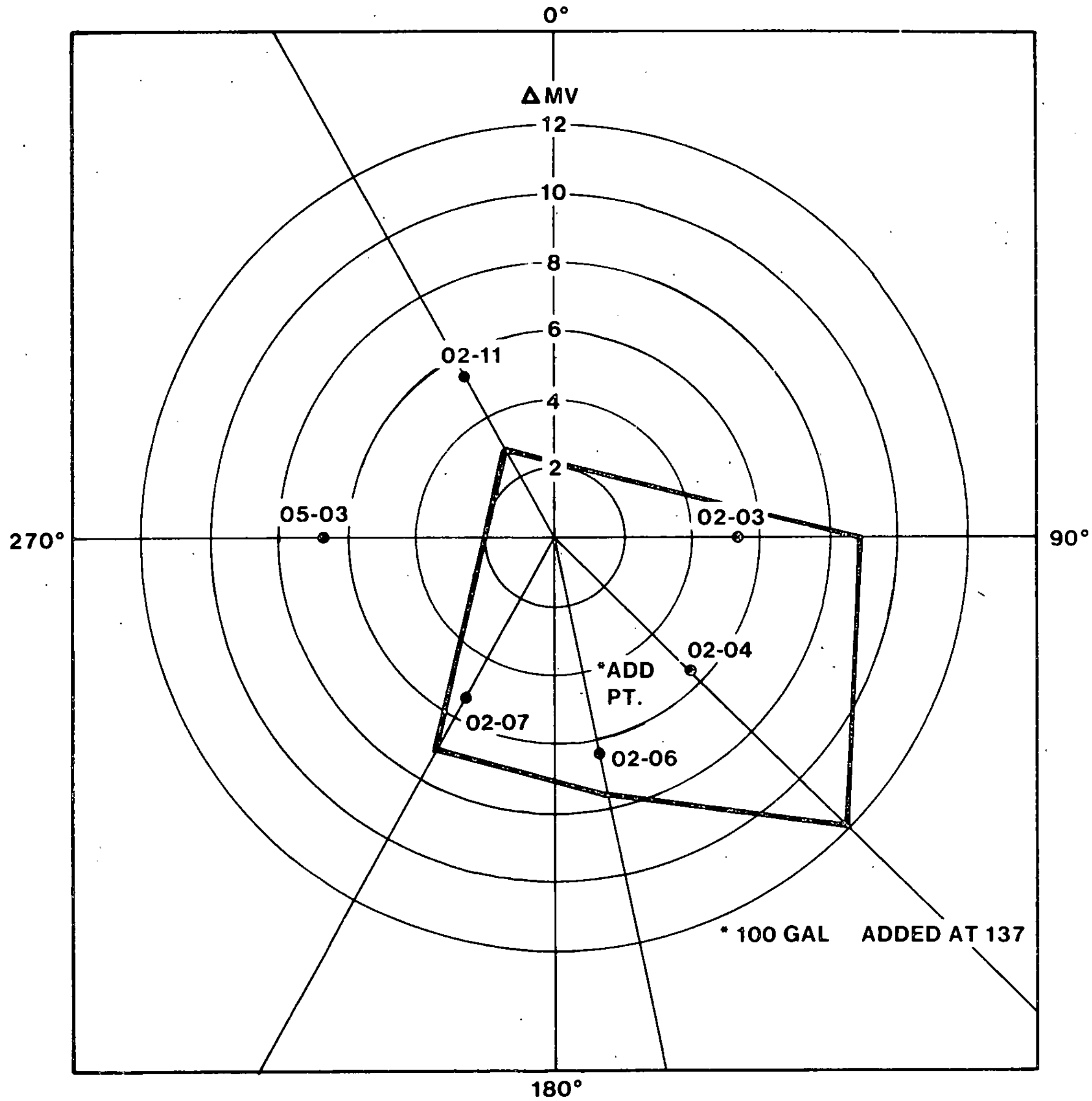


FIGURE 26

CHANGE OF VOLTAGE 11/6, 11/7/74 (From Table I)
(102-BX - BNW)

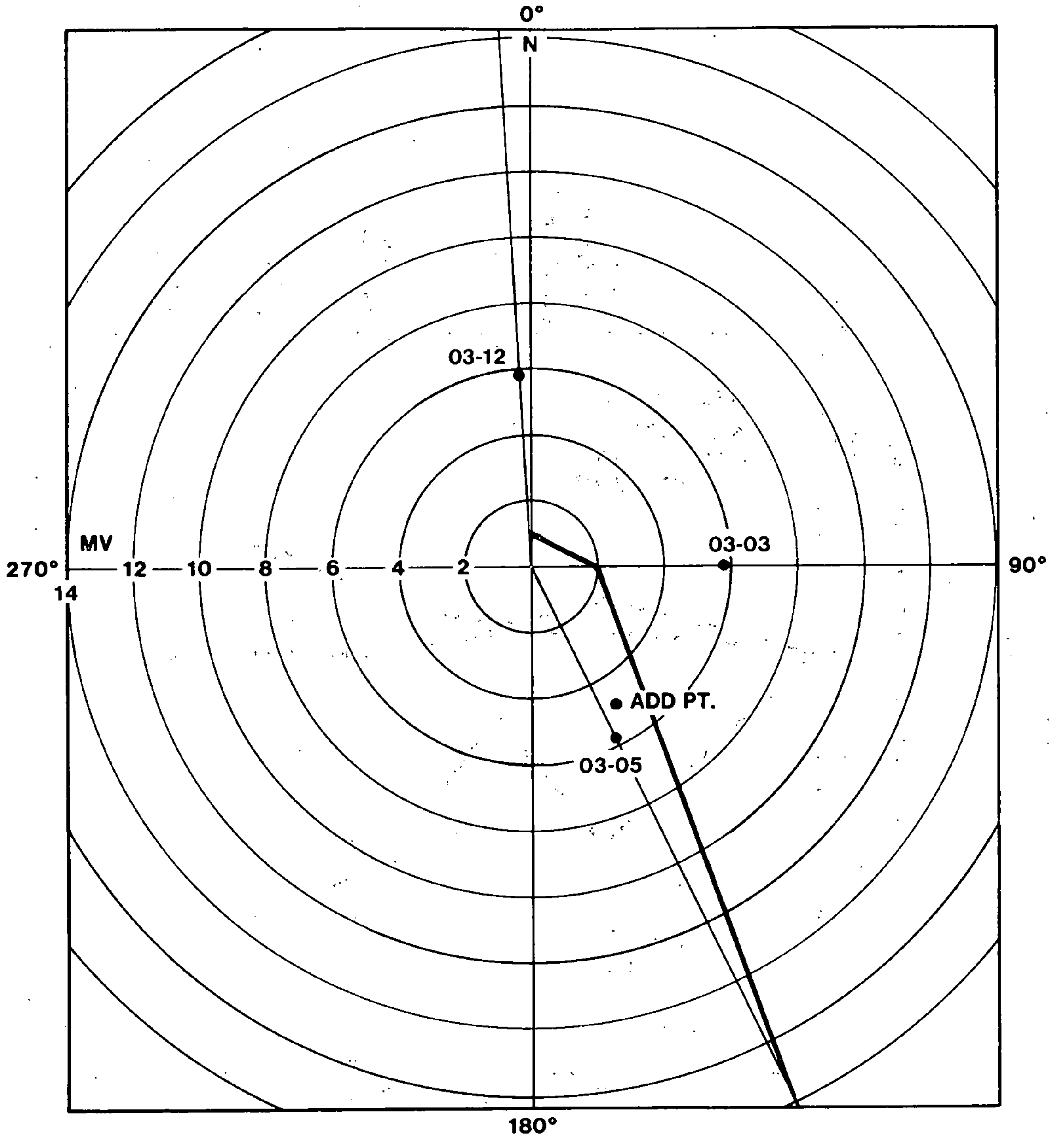


FIGURE 27

VOLTAGE CHANGE DISTRIBUTION ON THE POLAR COORDINATE
(103-BX - BNW)

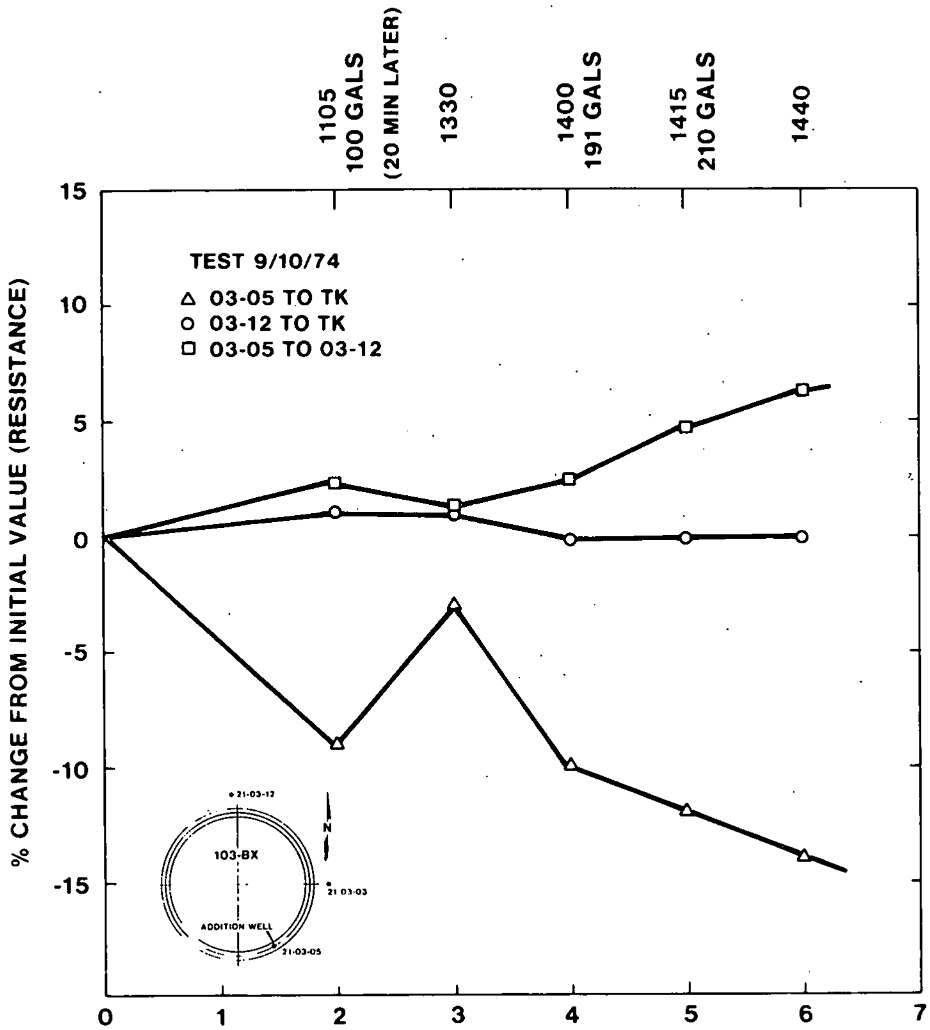


FIGURE 28

RESISTANCE CHANGE AFTER ADDITION OF WATER

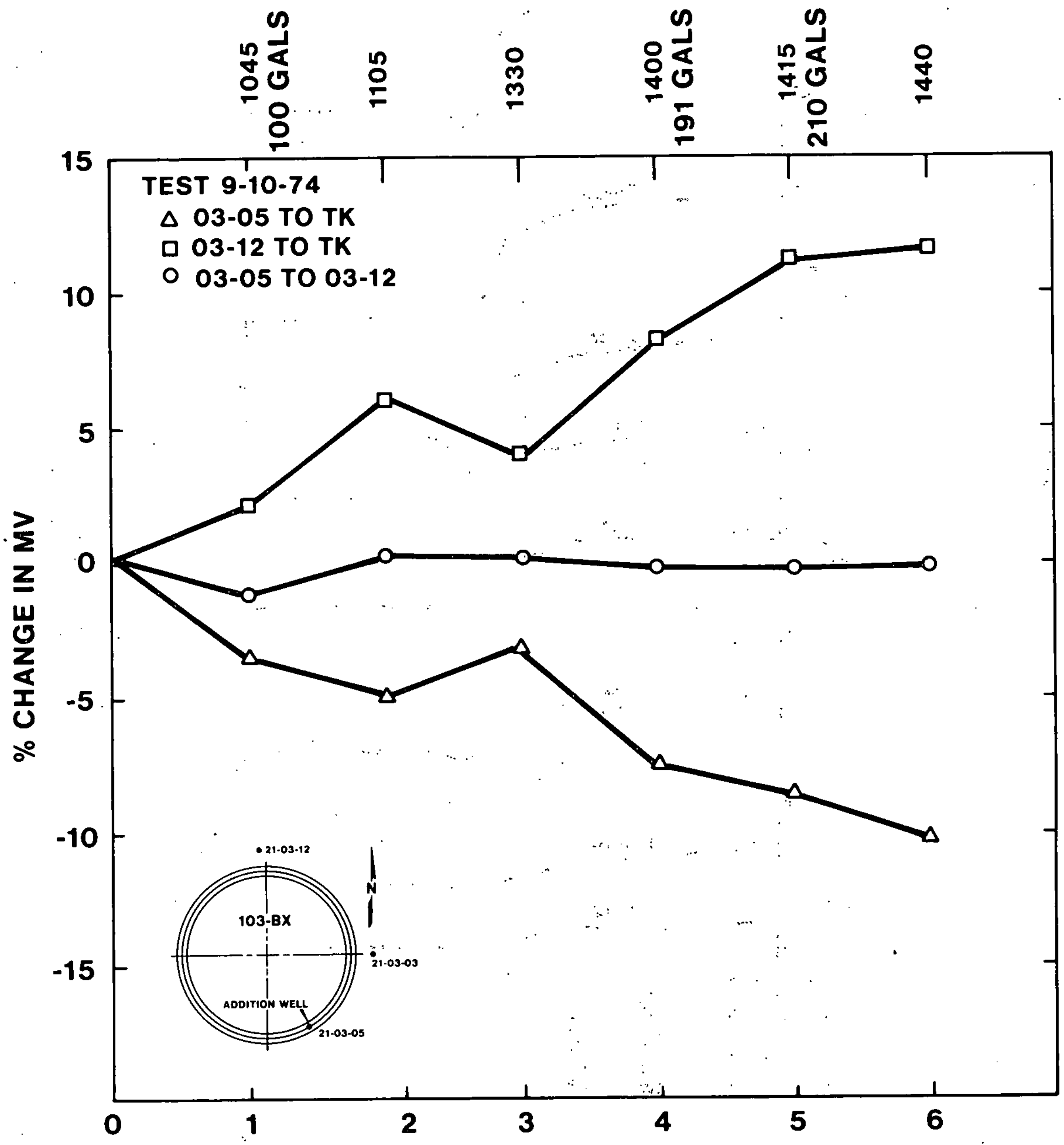


FIGURE 29

VOLTAGE CHANGE AFTER ADDITION OF WATER

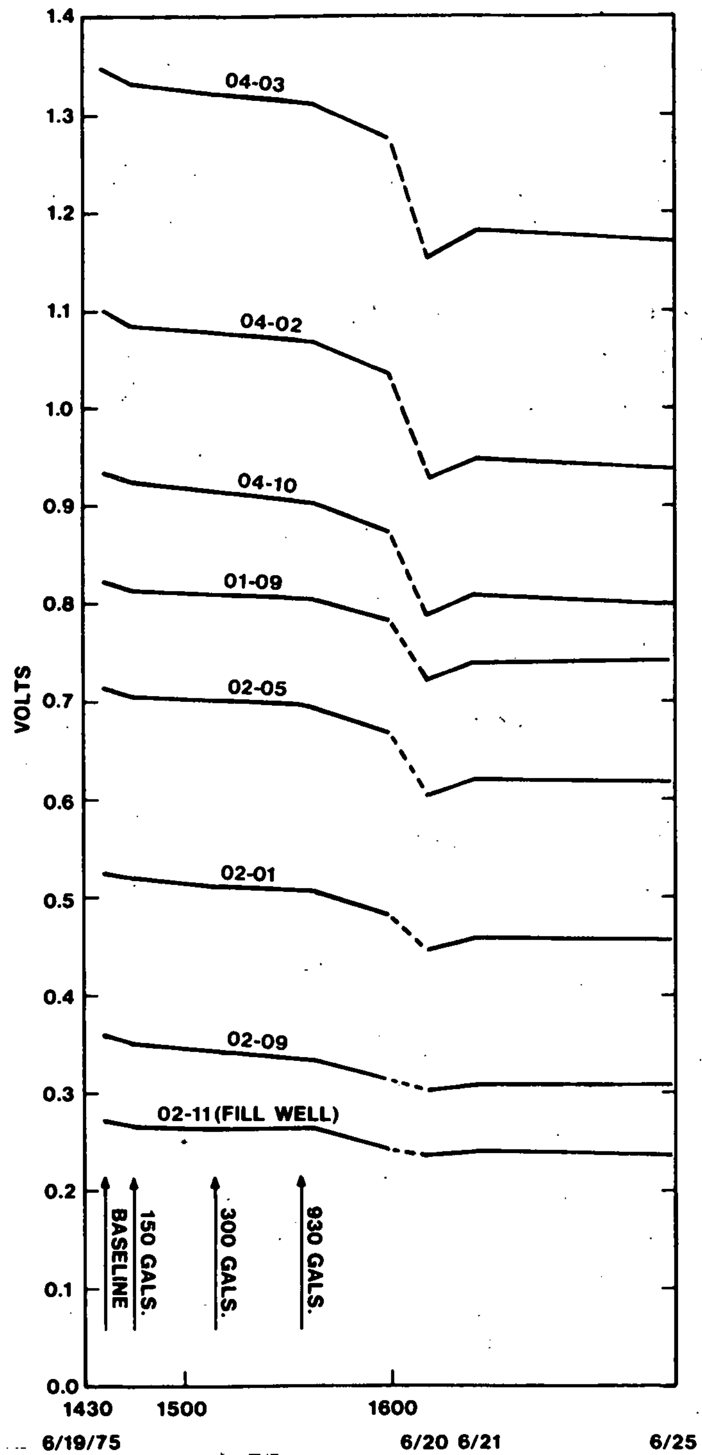


FIGURE 30

POTENTIAL VARIATION VERSUS TIME (102-TY - BOEING)

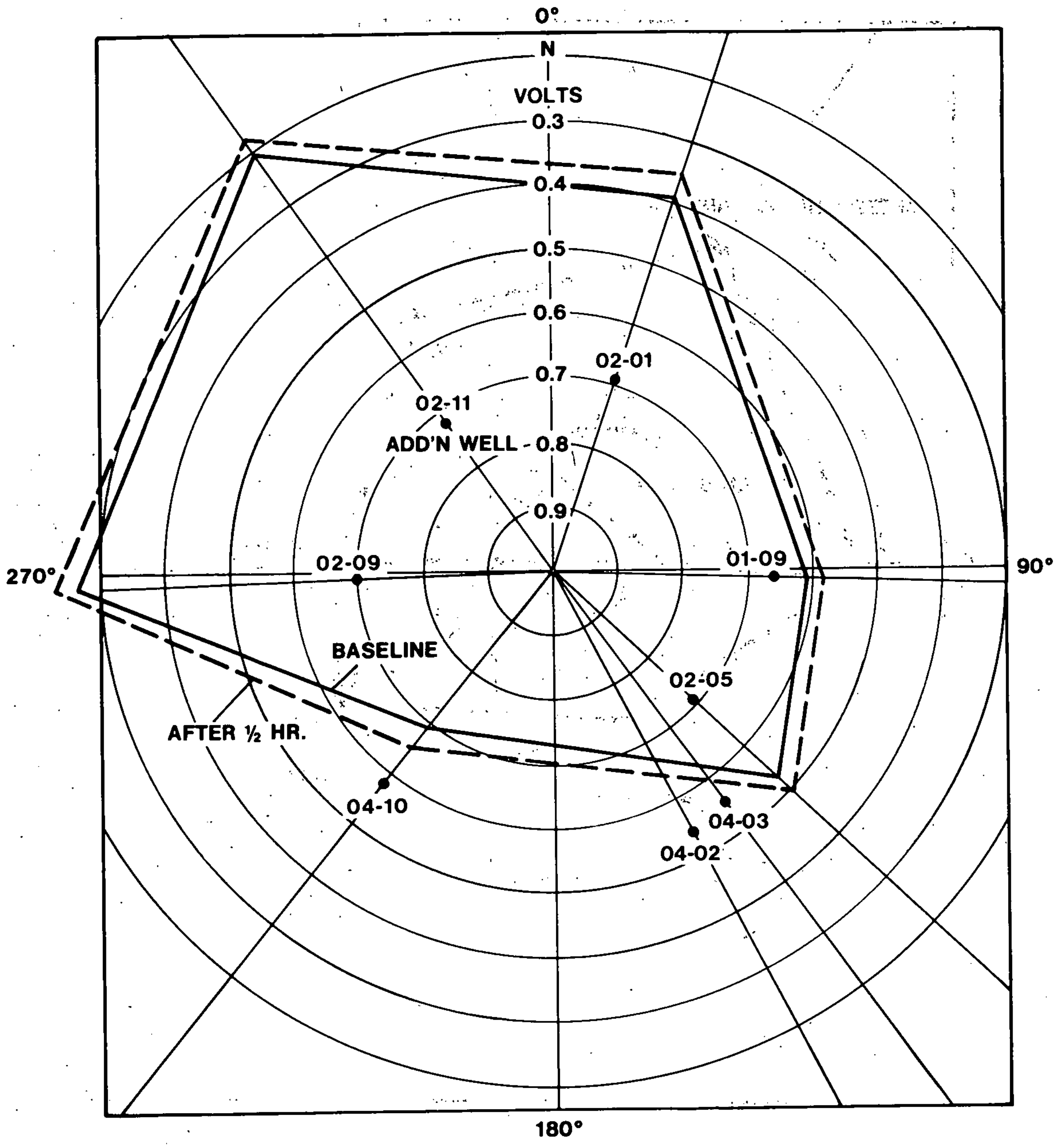


FIGURE 31

POTENTIAL DISTRIBUTION (102-TY - BOEING)

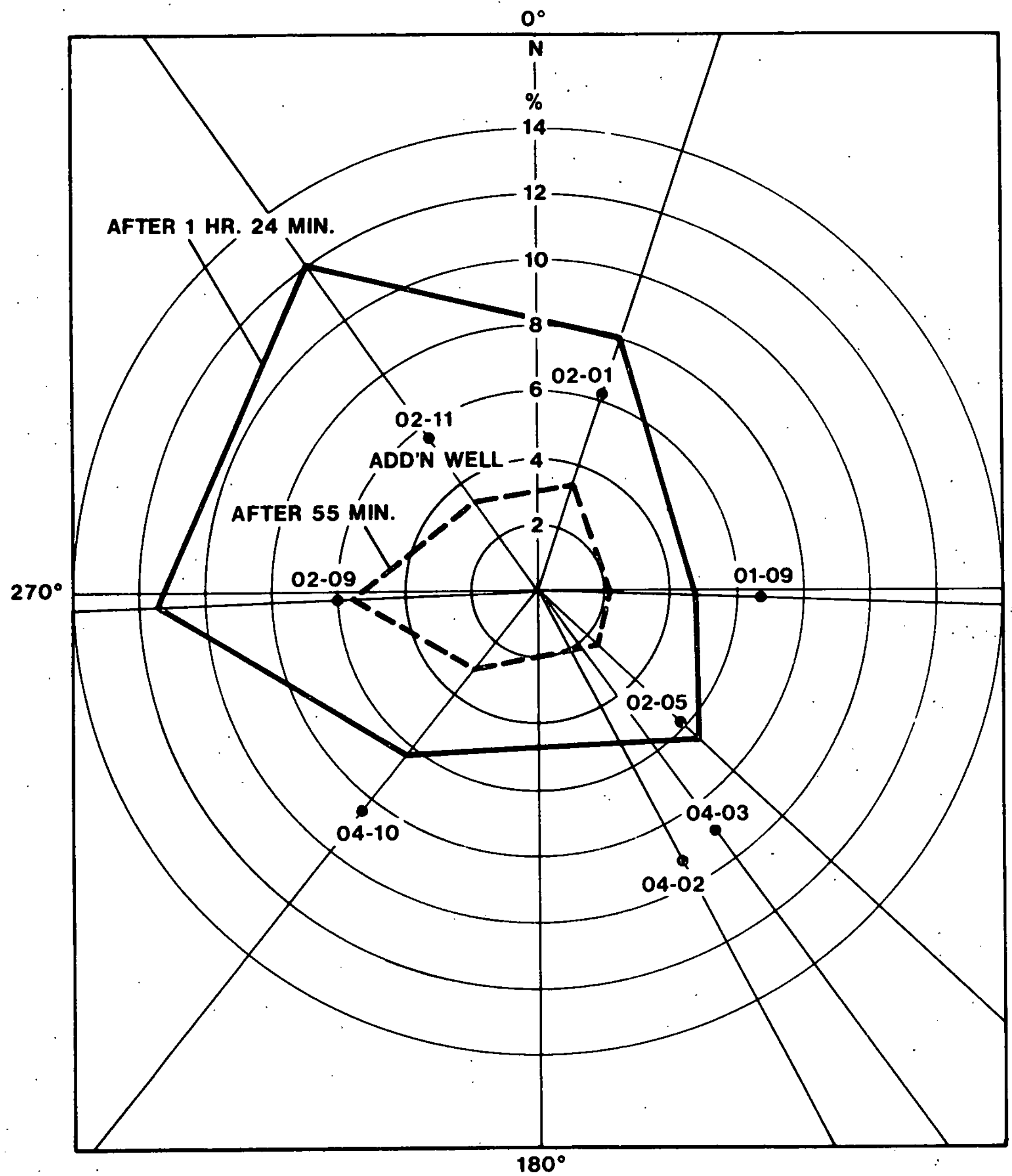


FIGURE 32

PERCENTAGE OF POTENTIAL DROP (102-TY - BOEING)

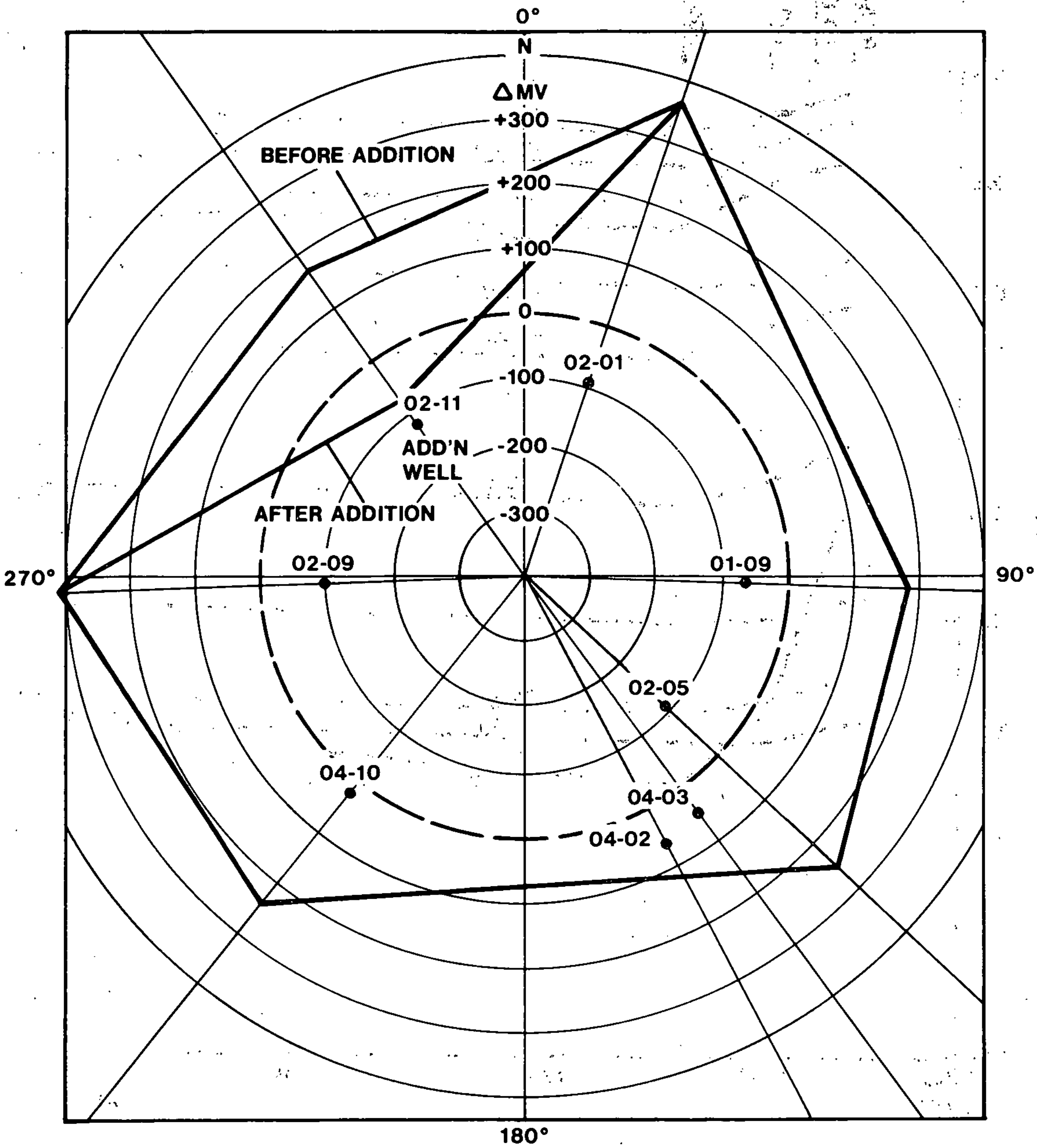


FIGURE 33
POTENTIAL DISTRIBUTION (102-TY - BNW)

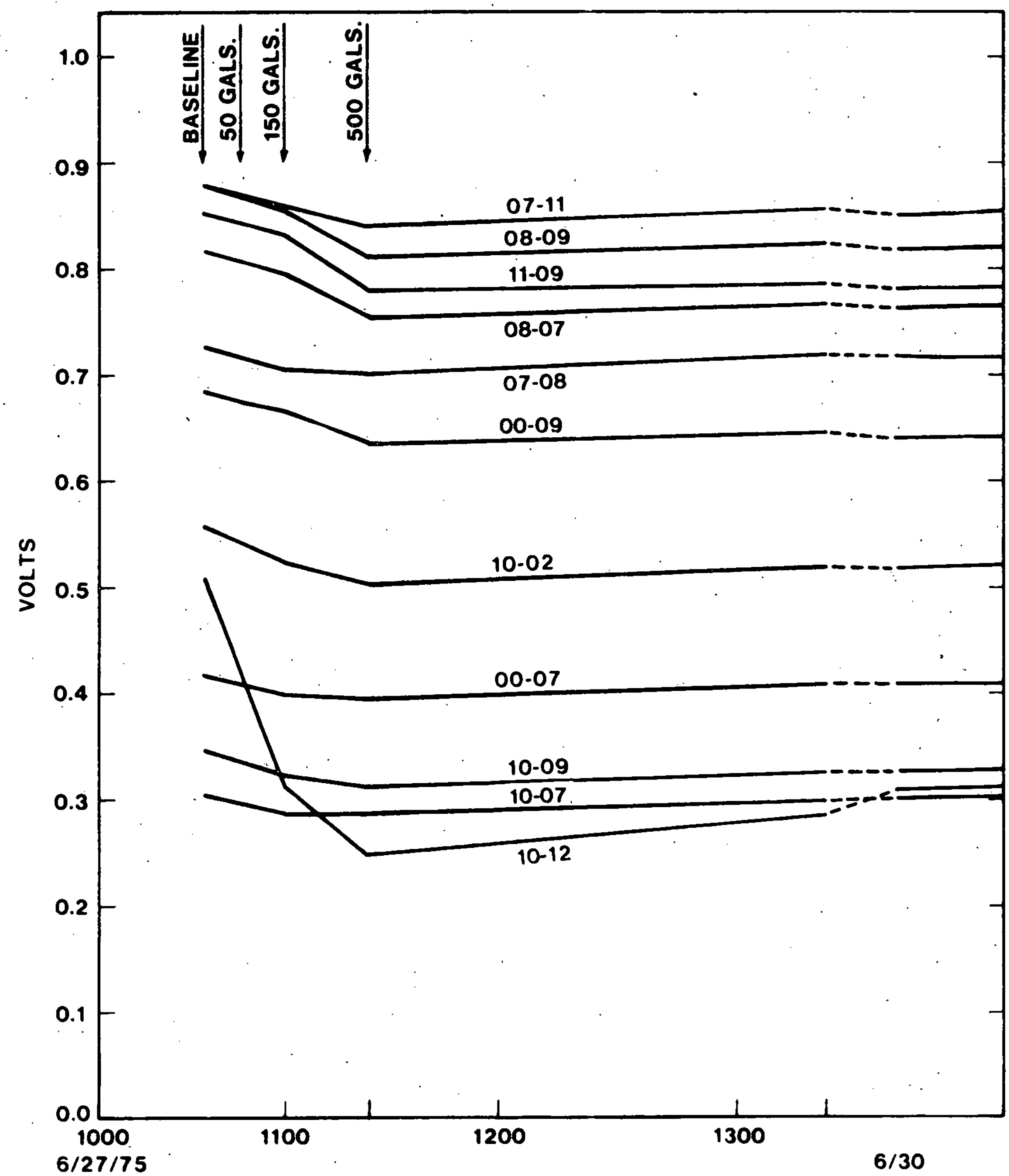


FIGURE 34

110-B TANK TEST
BOEING SYSTEM

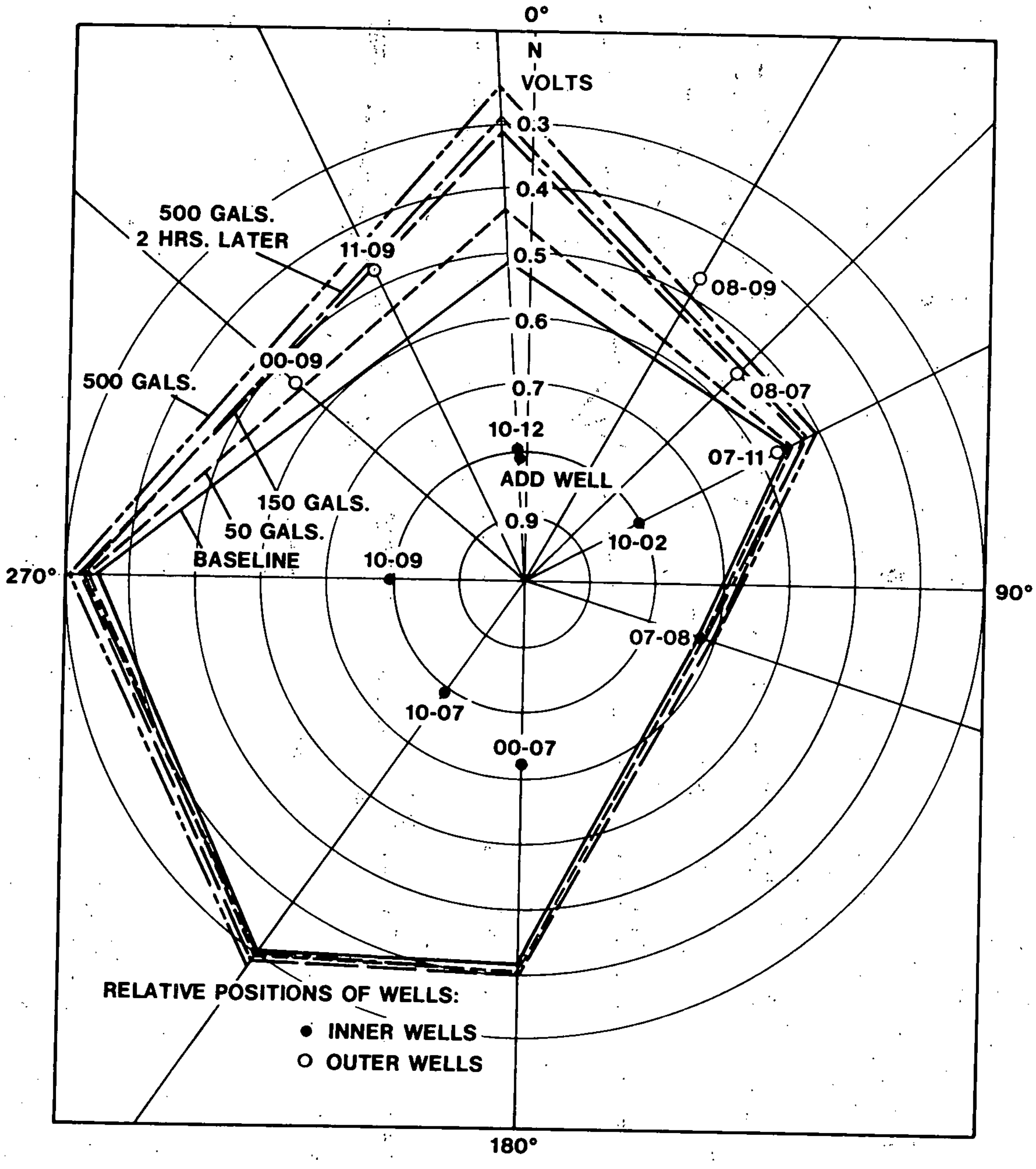


FIGURE 35

POTENTIAL DISTRIBUTION
110-B - BOEING

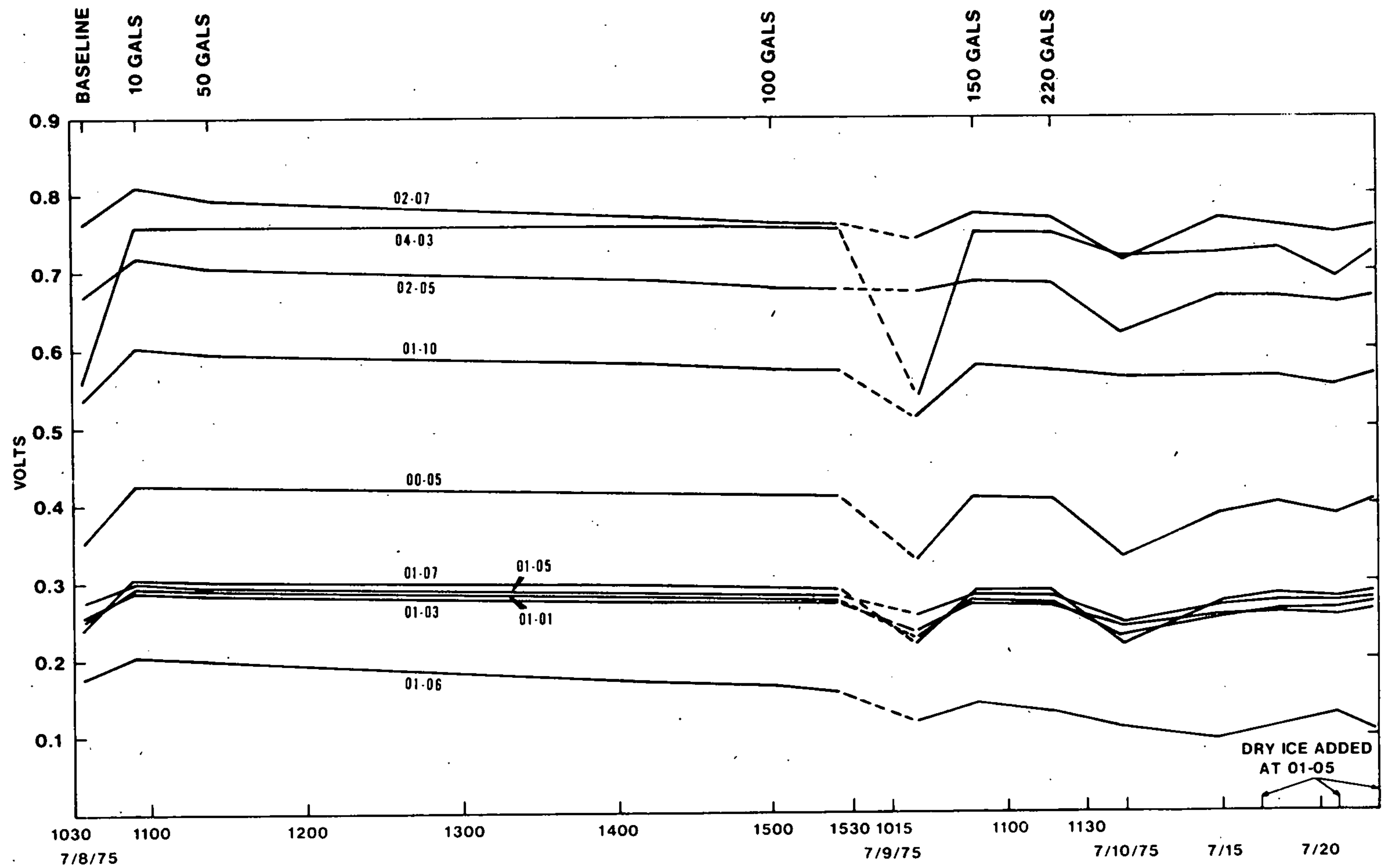


FIGURE 36

DRIBBLING TEST (101-B - BOEING)

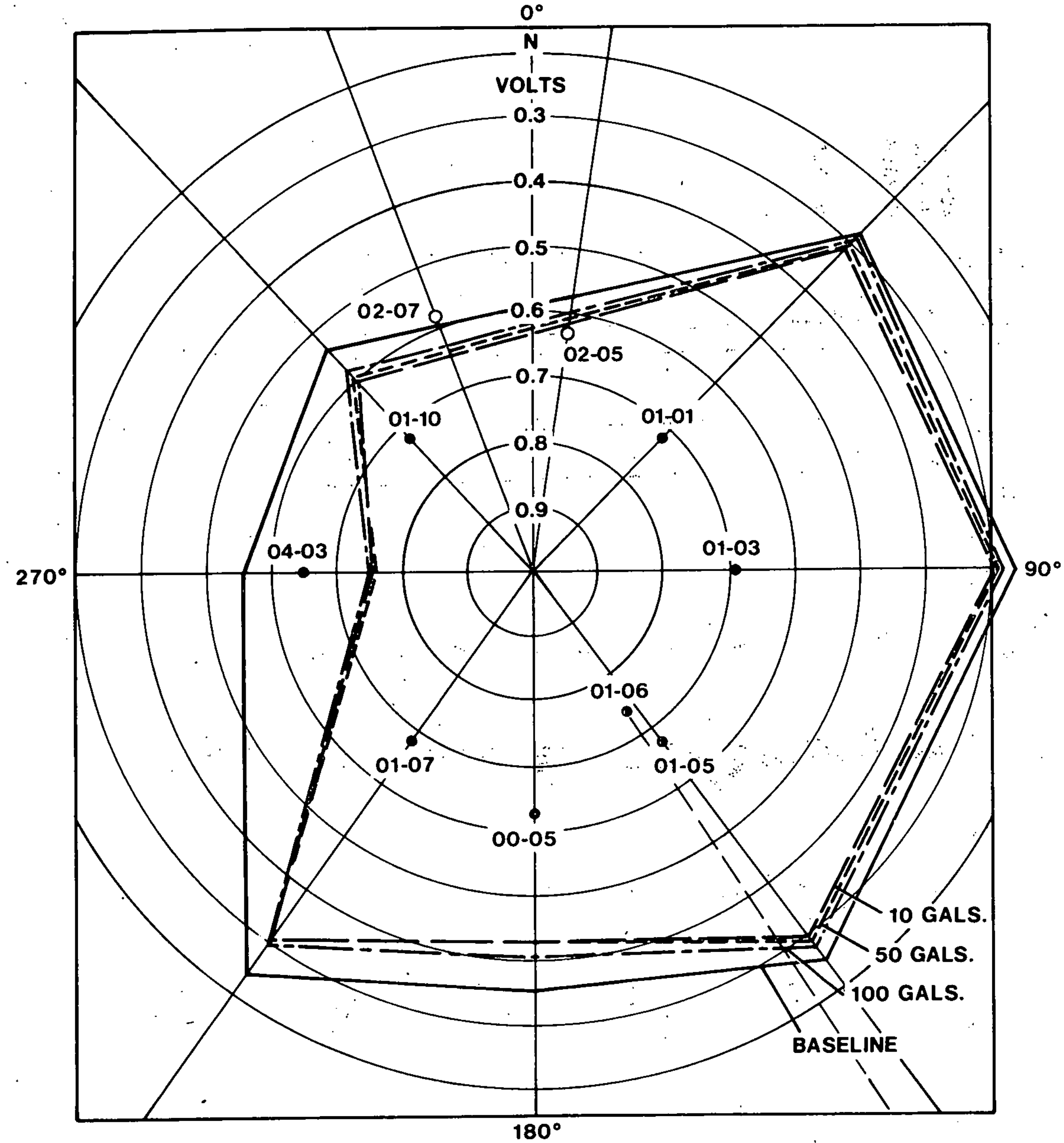


FIGURE 37

DRIBBLING TEST (POLAR PLOT)
(101-B - BOEING)

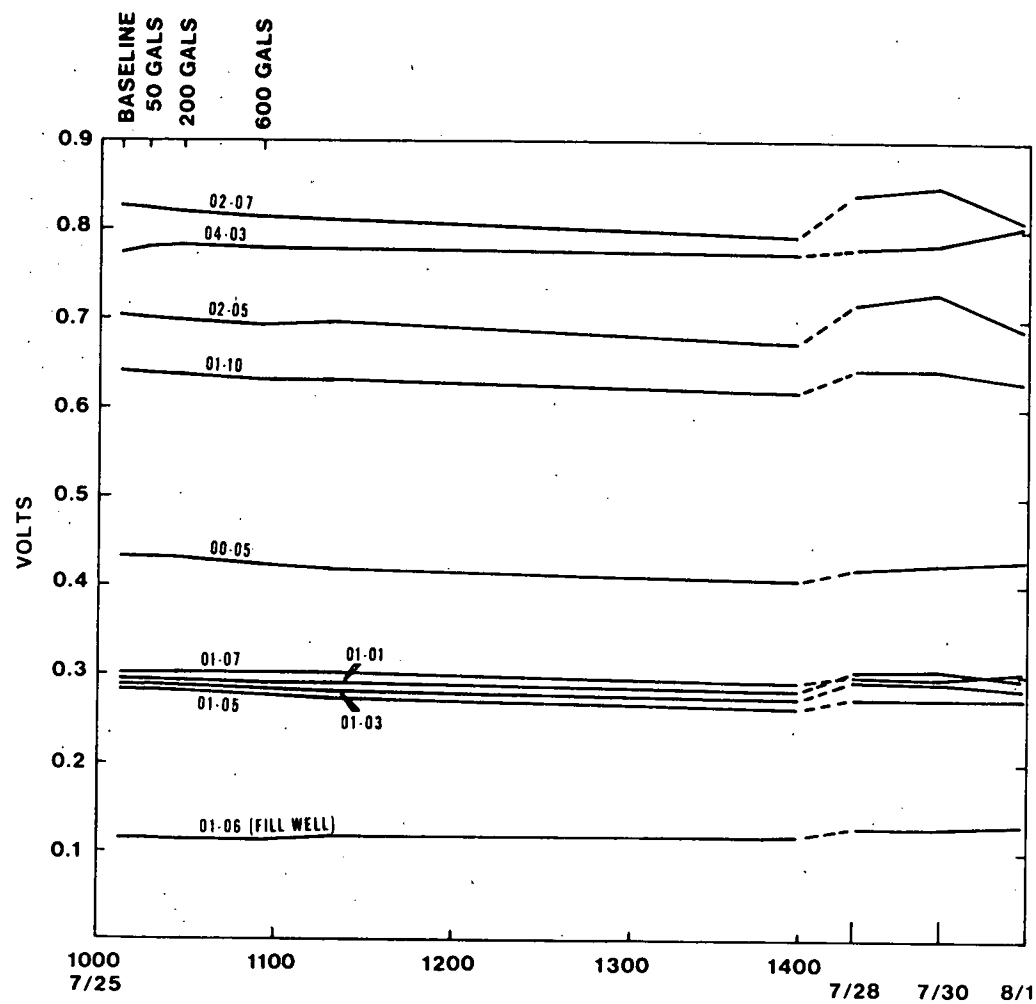


FIGURE 38

TANK FOOTING LEAK TEST
(101-B - BOEING)

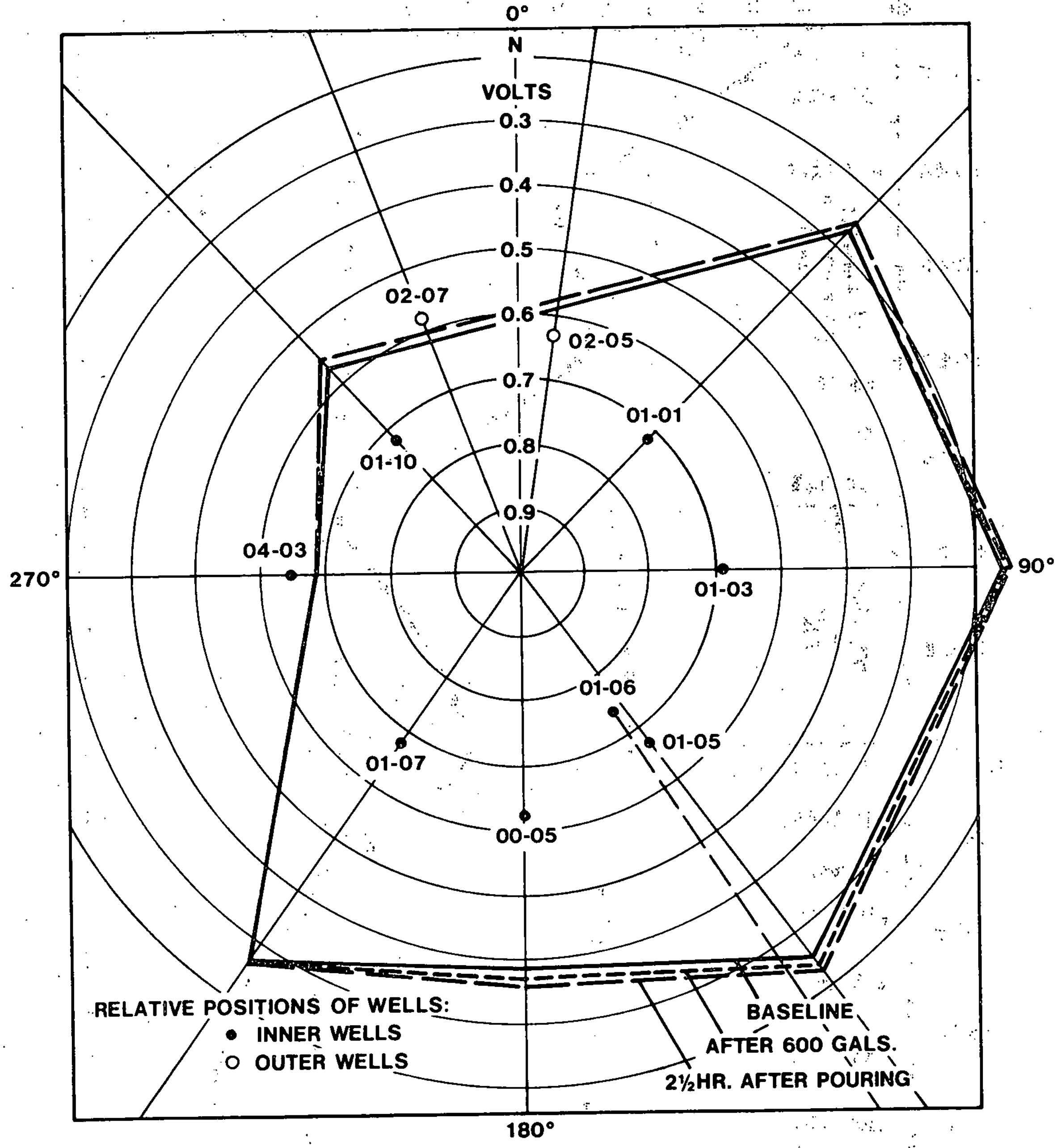


FIGURE 39

TANK FOOTING LEAK TEST (POLAR PLOT)
(101-B - BOEING)

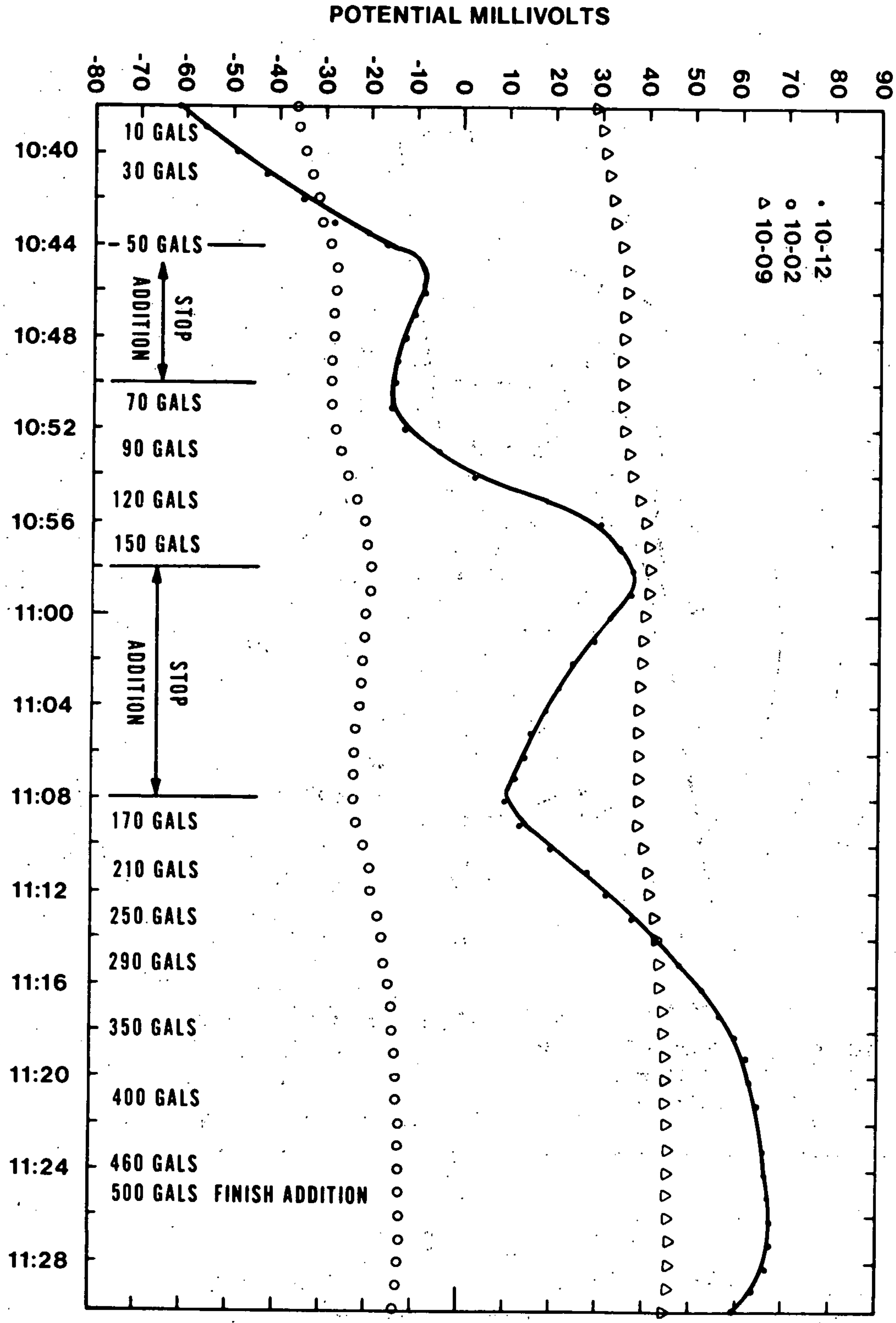


FIGURE 40

PLOT OF SELECTED TANK TO WELL POTENTIALS (TANK 110-B - BNW)

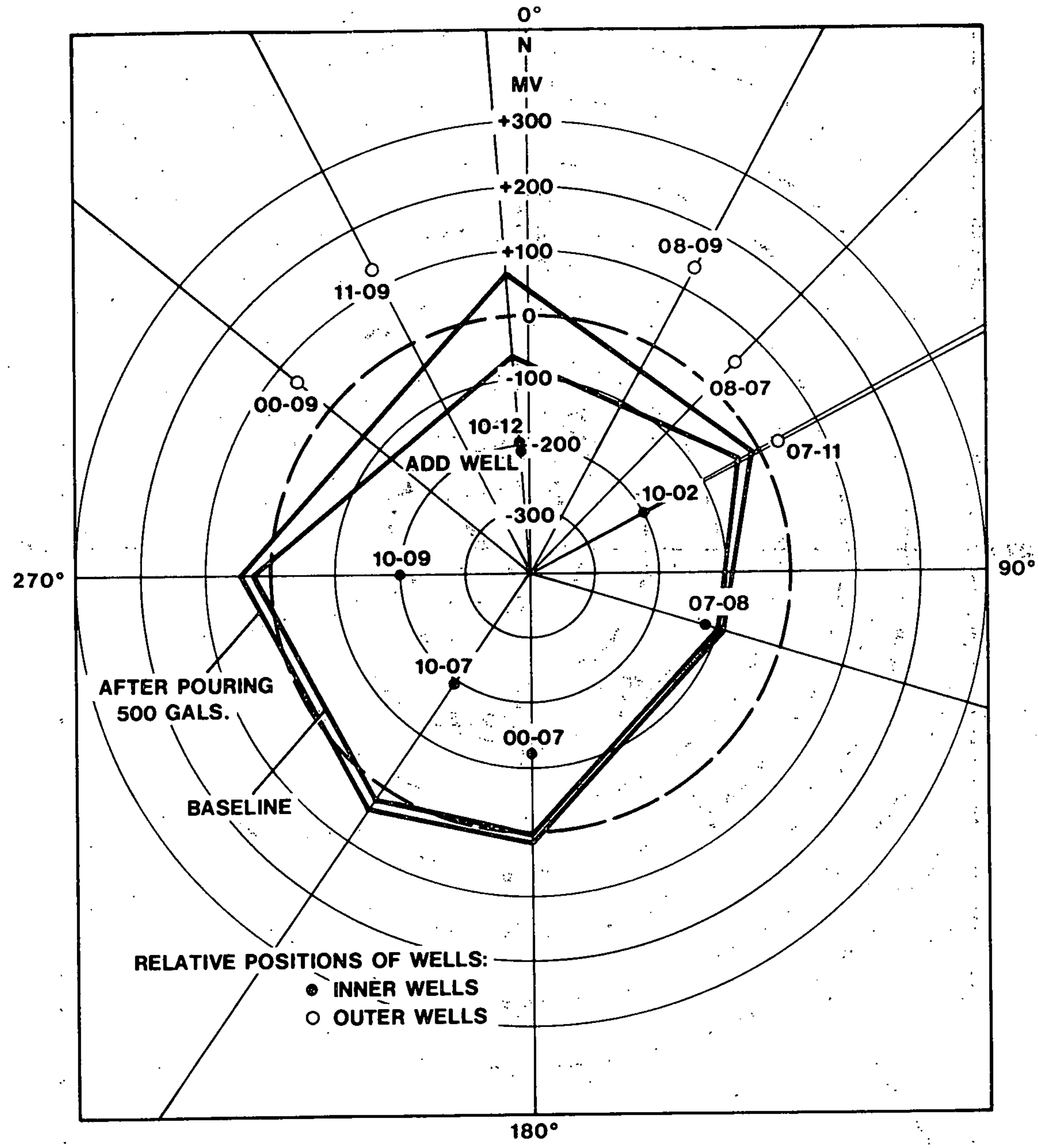


FIGURE 41

TANK LEAK TEST (110-B - BNW)

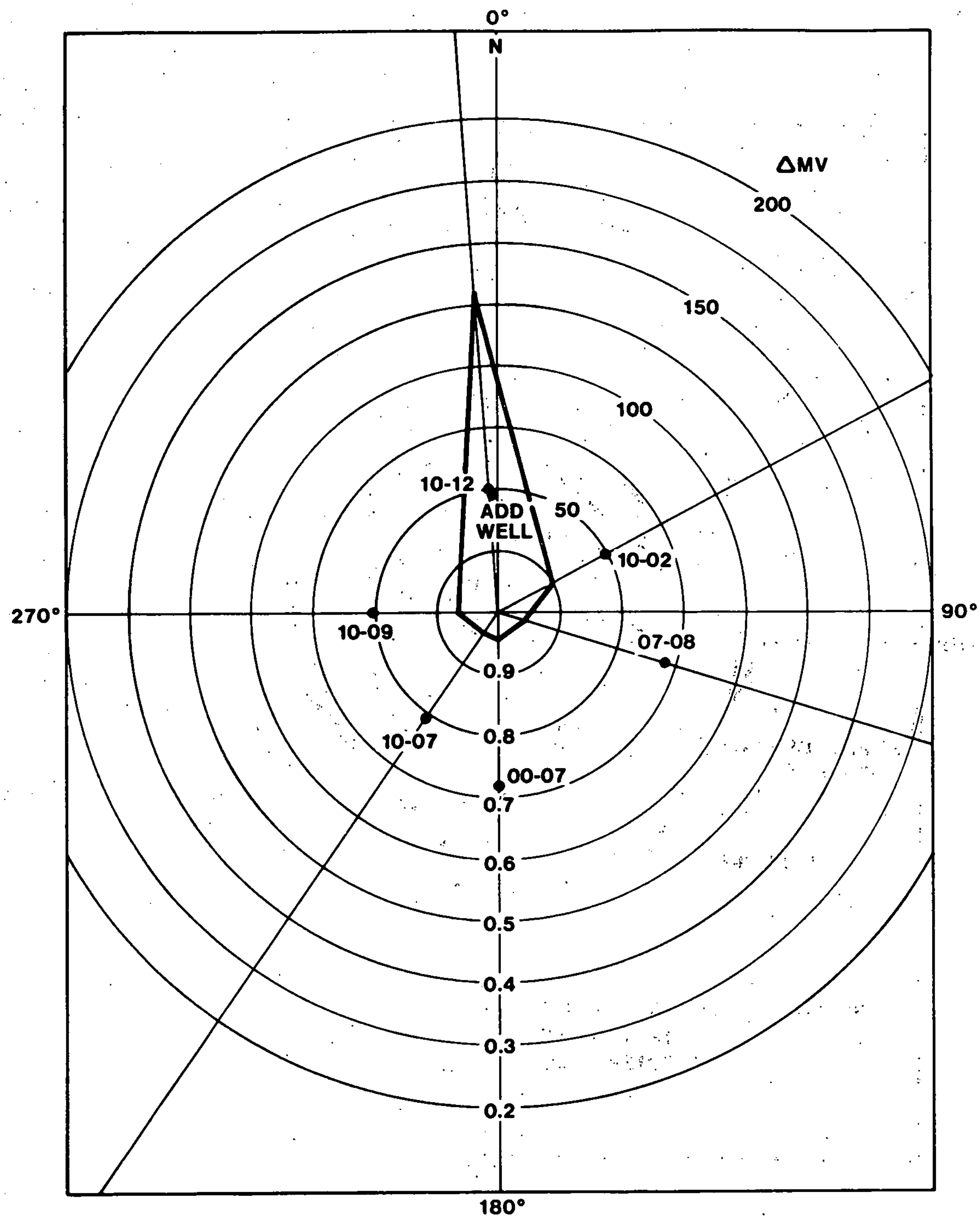


FIGURE 42

DISTRIBUTION OF POTENTIAL DIFFERENCE
AFTER 500 GAL ADDITION (110-B - BNW)

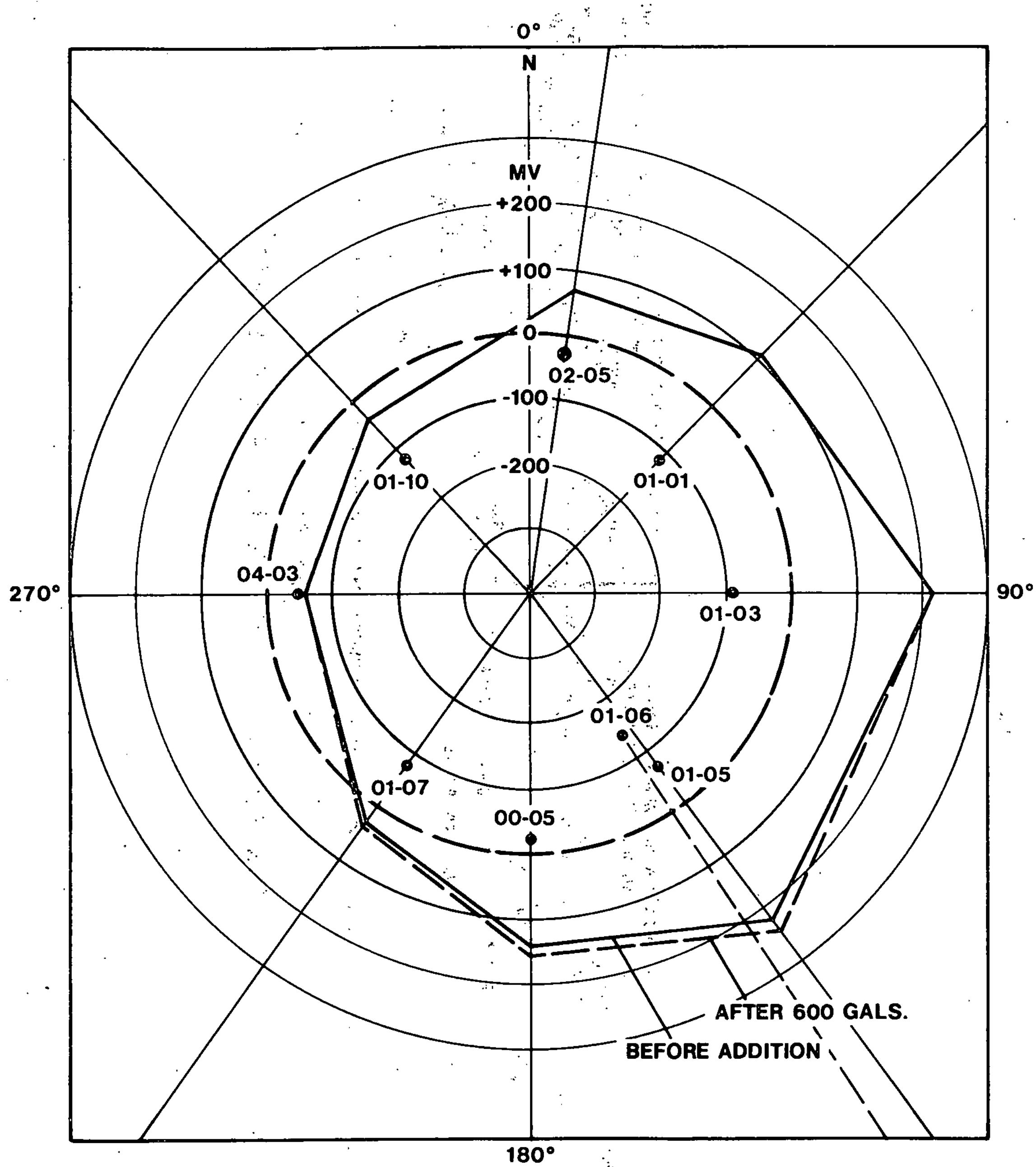


FIGURE 43
DISTRIBUTION OF POTENTIAL (101-B - BNW)

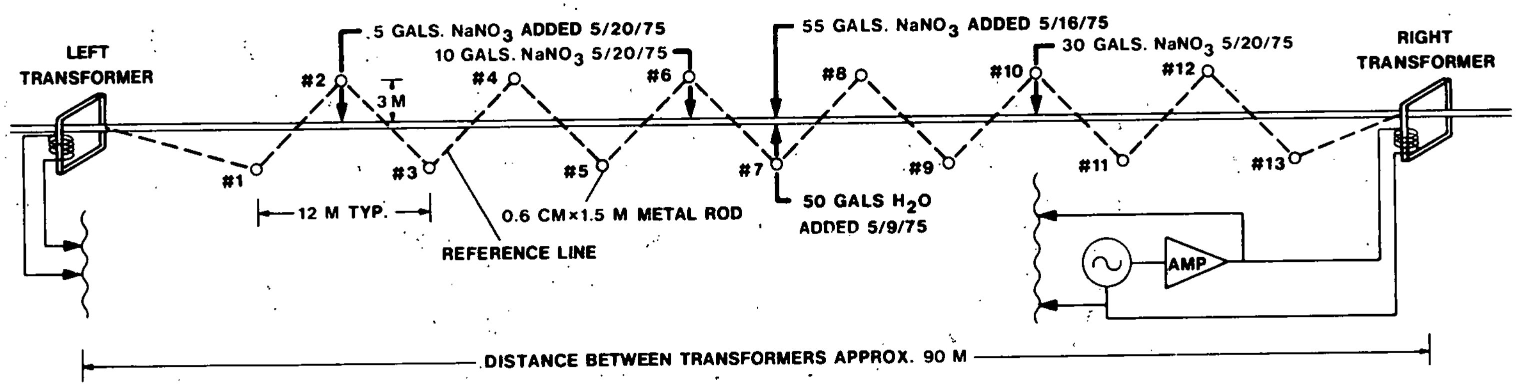


FIGURE 44

CONFIGURATION FOR PIPELINE LEAKAGE SIMULATIONS

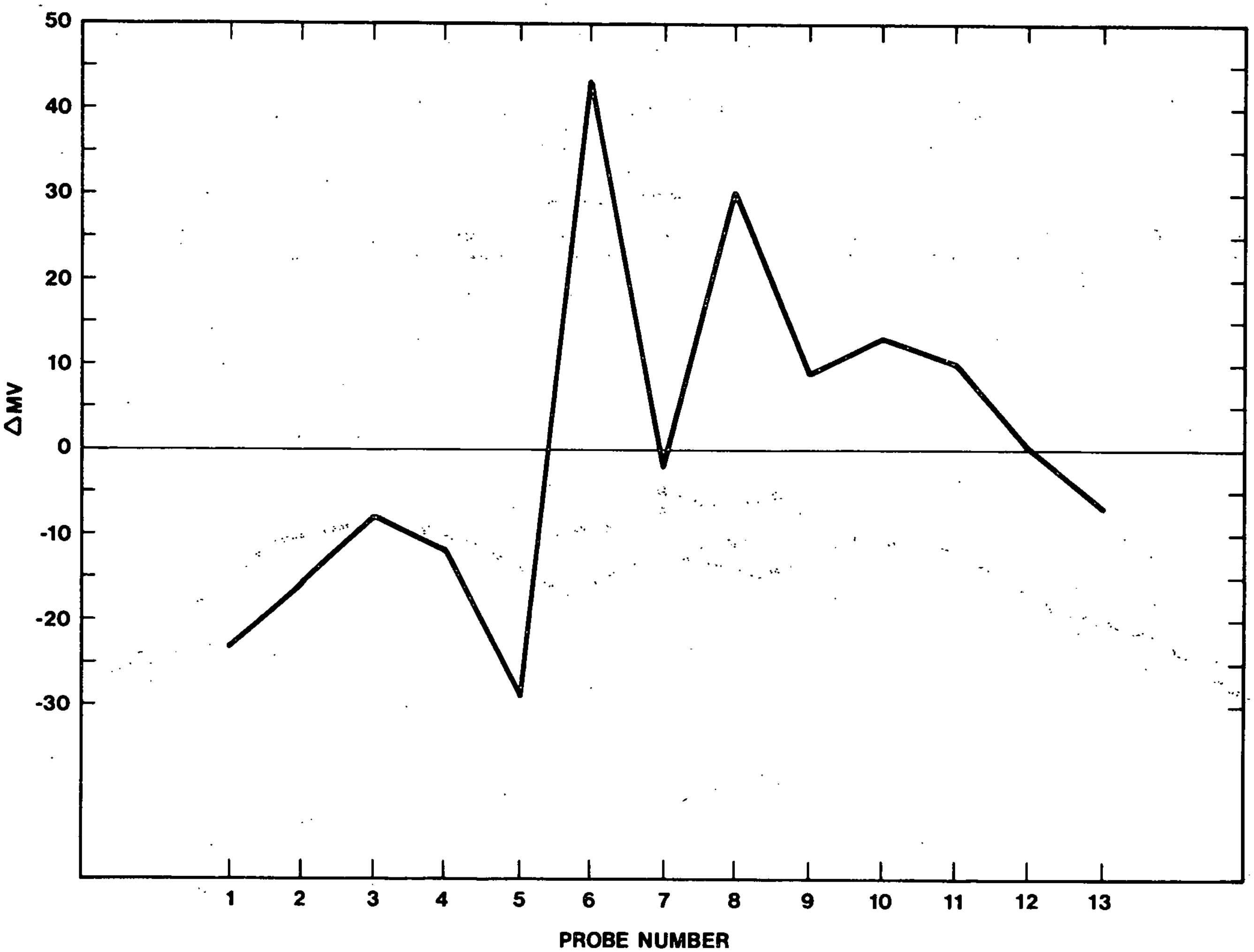


FIGURE 45

WATERLINE LEAKAGE POTENTIAL DIFFERENCE (55 GAL ADDITION - BNW)

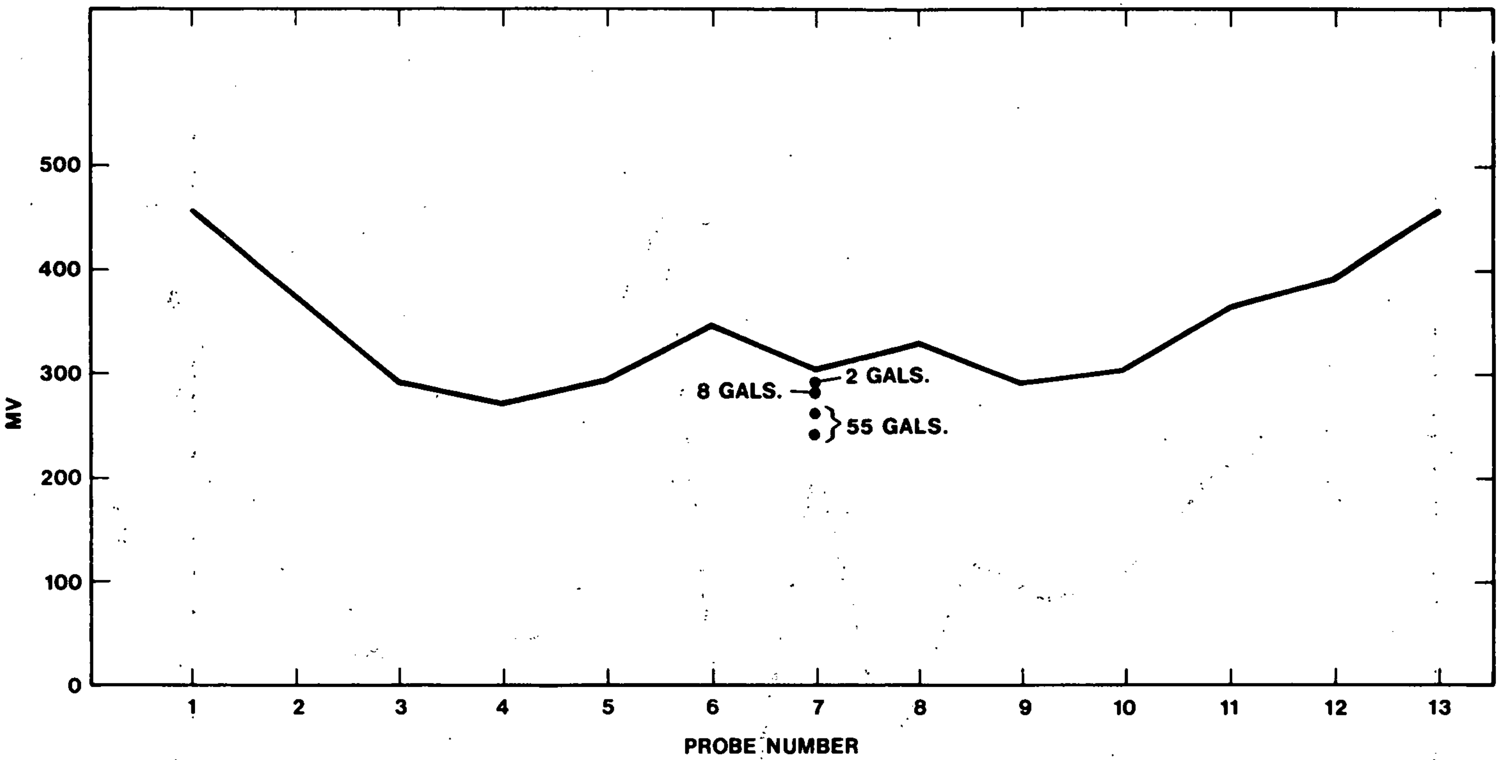


FIGURE 46

POTENTIAL DISTRIBUTION ALONG PIPELINE (55 GAL AT #7 - BOEING)

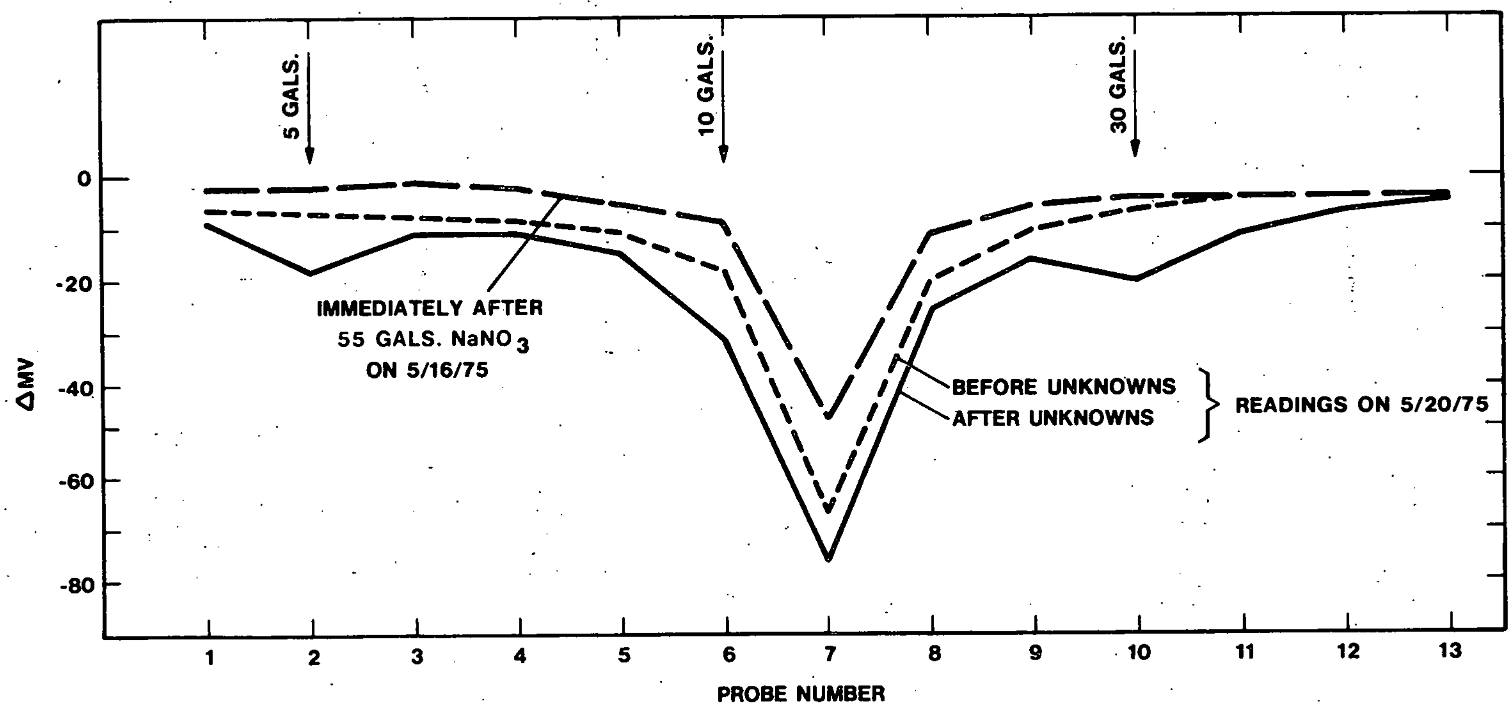


FIGURE 47

DISTRIBUTION OF POTENTIAL DIFFERENCE ALONG PIPELINE (BOEING)

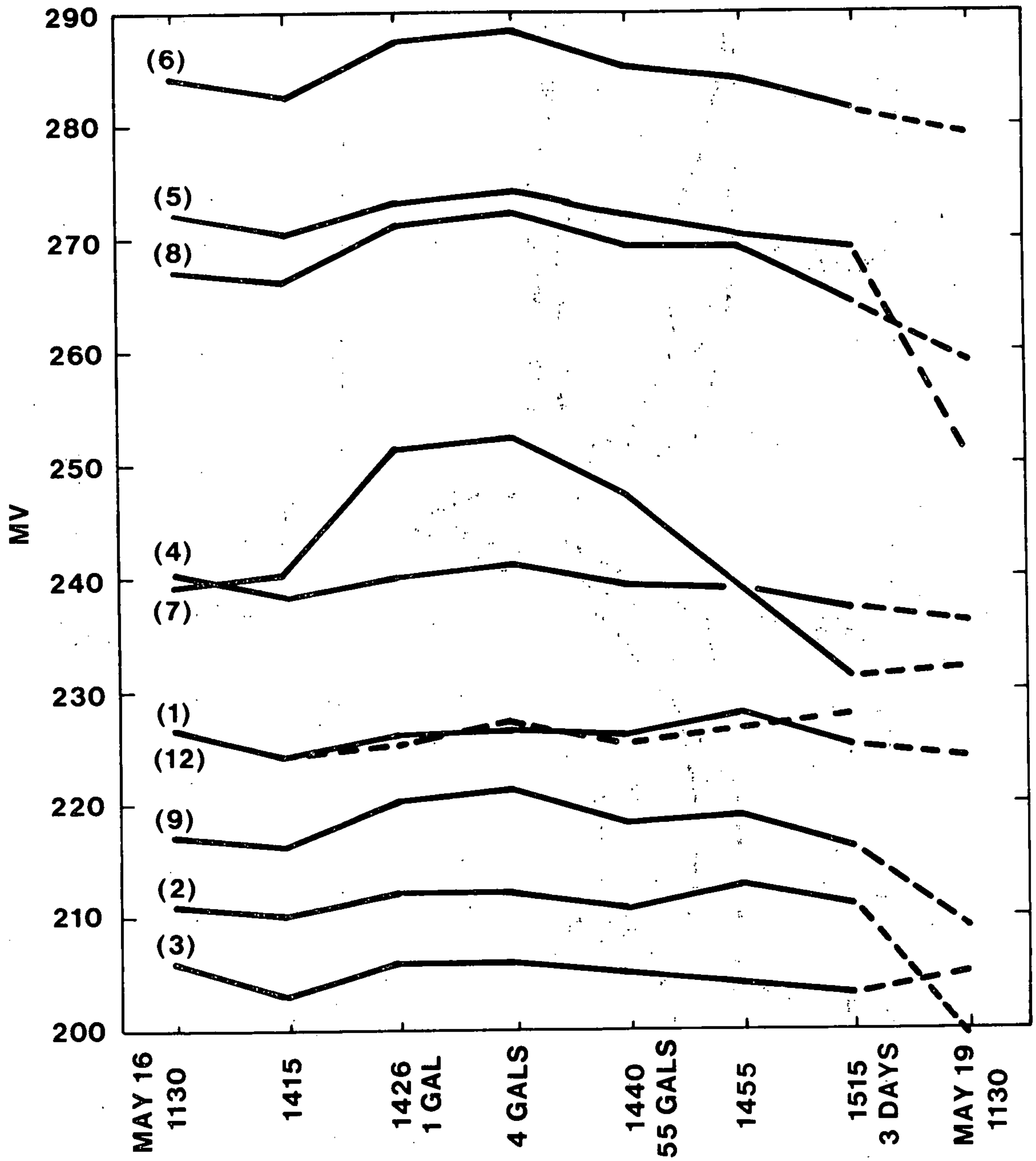


FIGURE 48

POTENTIAL-TIME VARIATION
(55 GAL $NaNO_3$ ADDITION AT #7 - BNW)

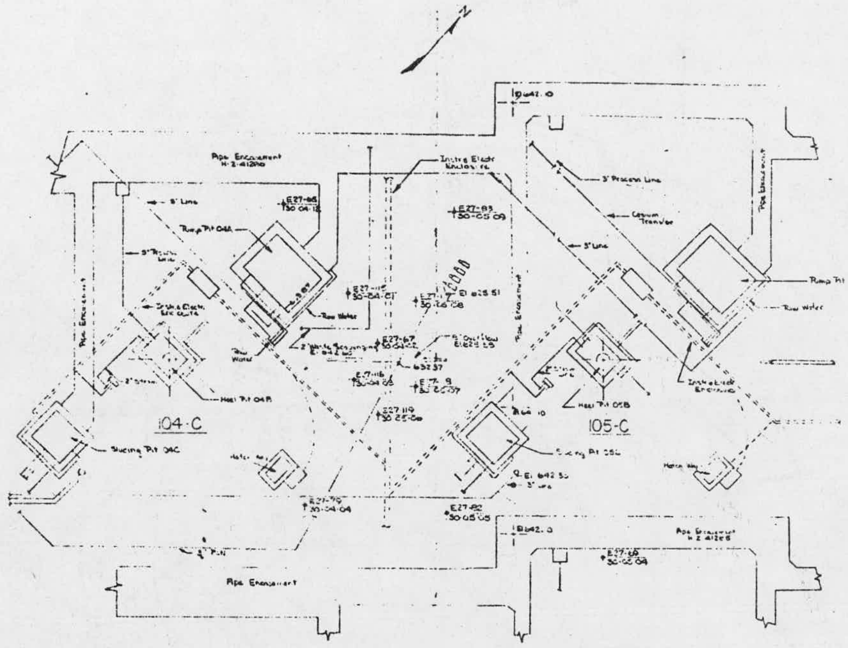


FIGURE 49

241-C TANK FARM SHOWING TANKS 104-C and 105-C

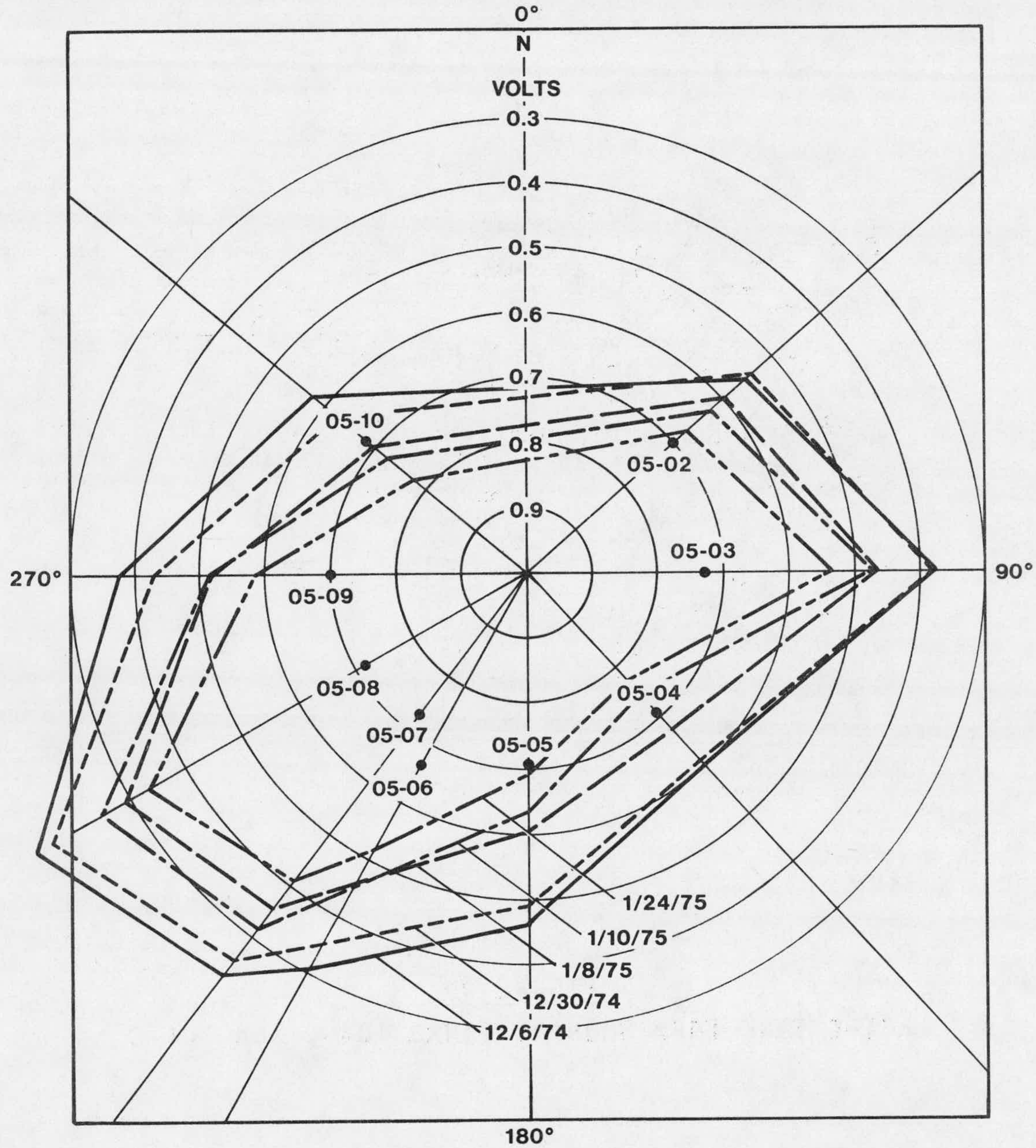


FIGURE 50

POTENTIAL DISTRIBUTION (105-C - BOEING)

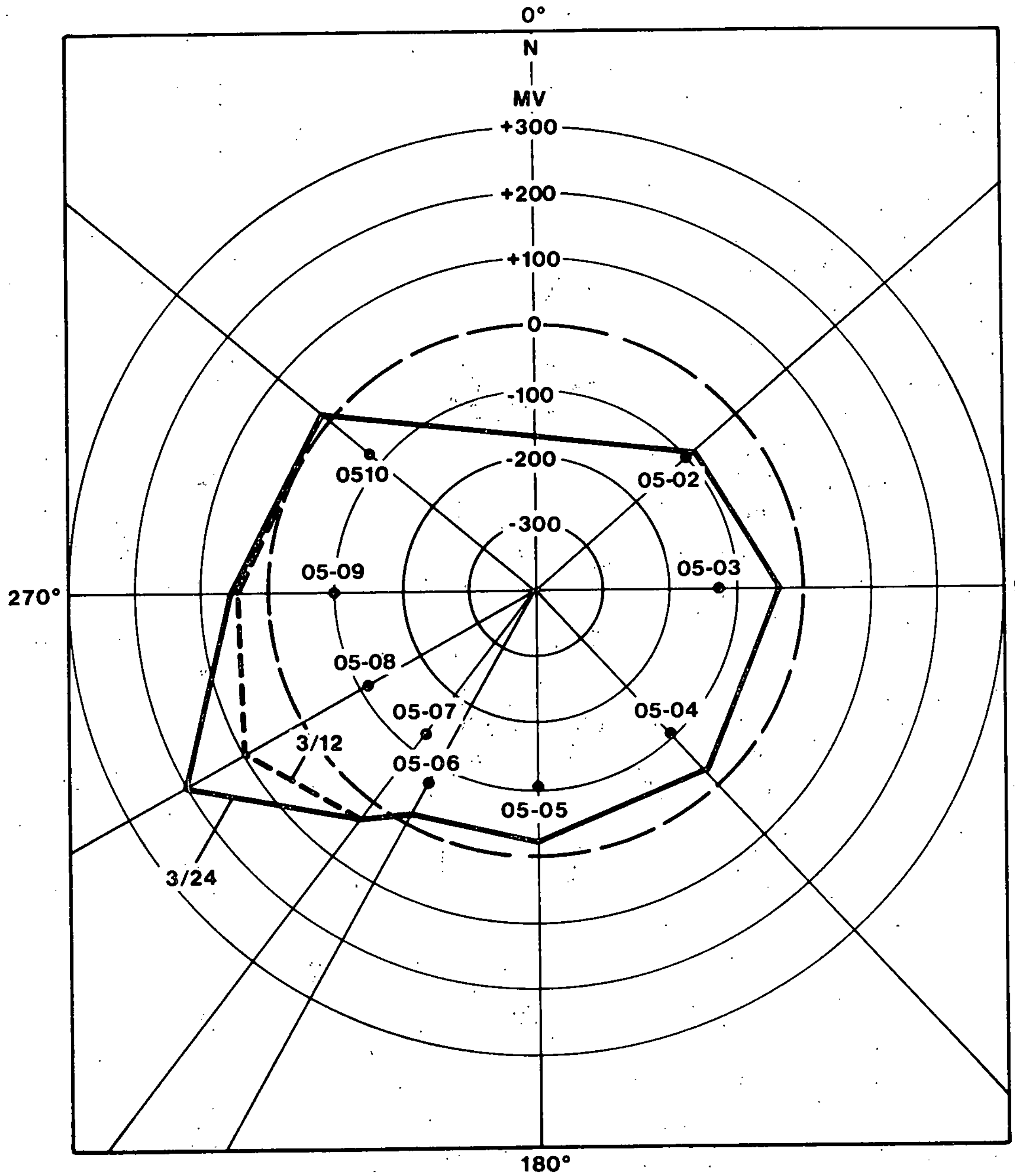


FIGURE 51

POTENTIAL DISTRIBUTION (105-C - BNW)

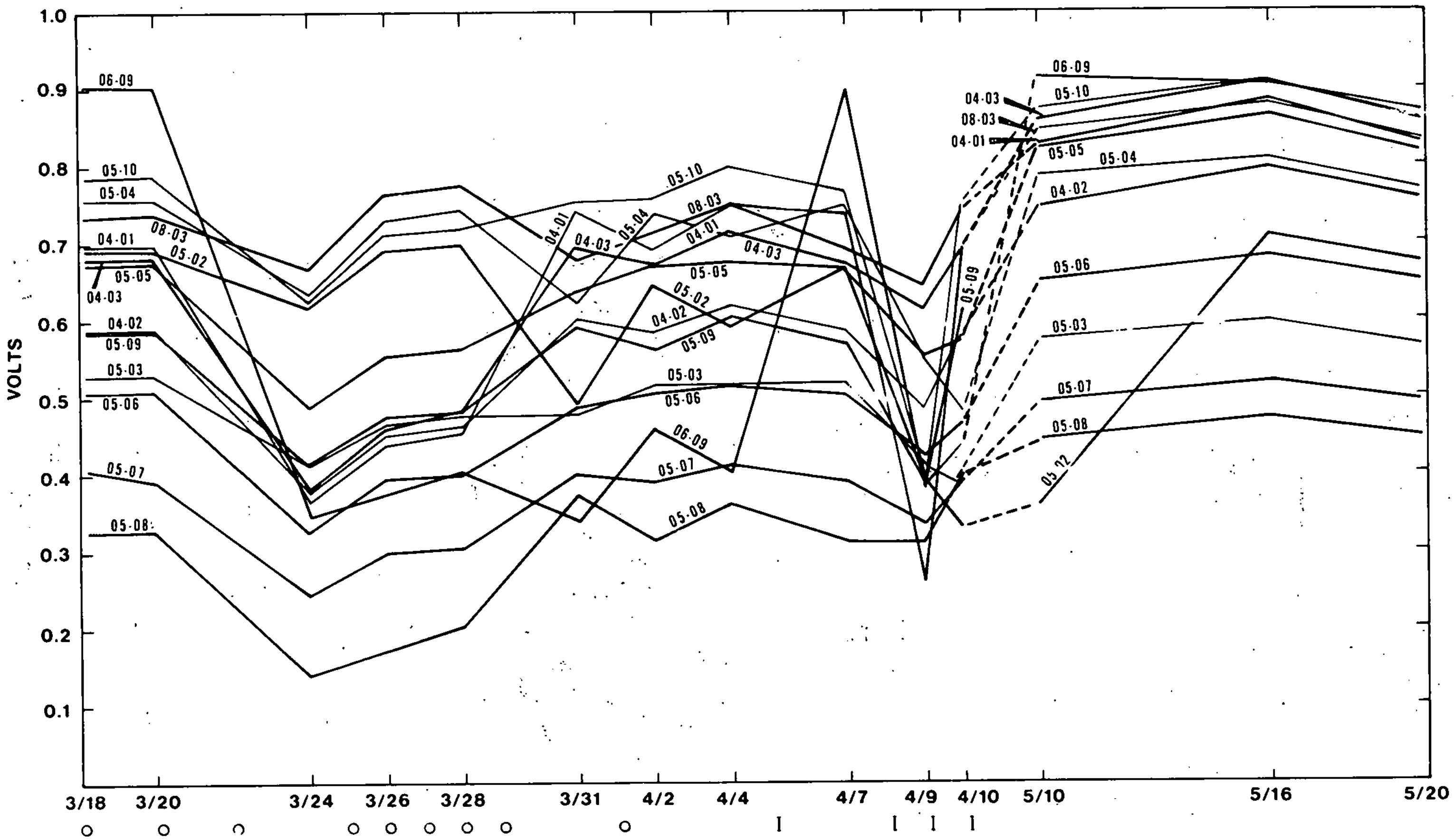


FIGURE 52

POTENTIAL-TIME VARIATION (105-C - BOEING)

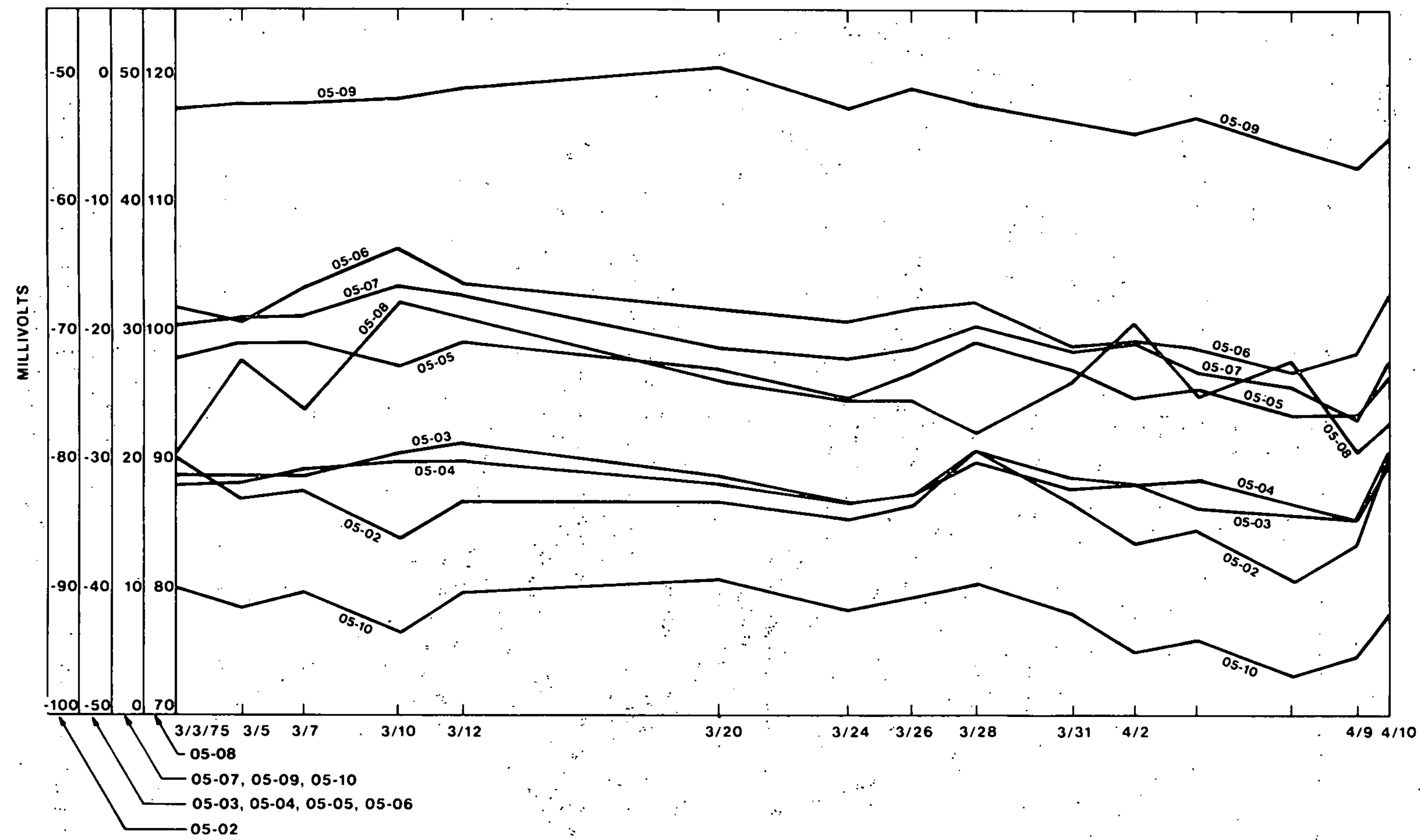


FIGURE 53

POTENTIAL-TIME VARIATION (105-C - BNW)

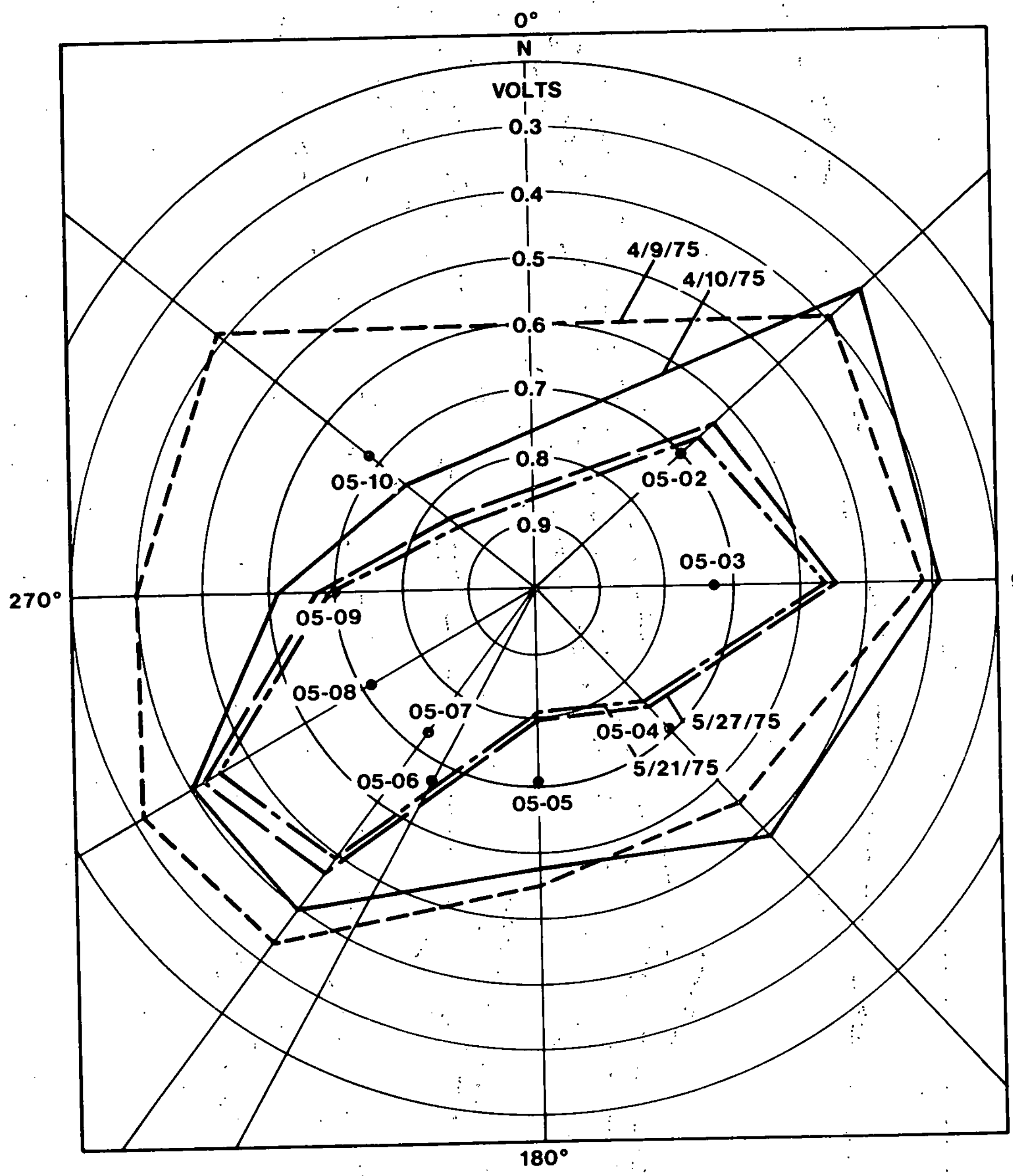


FIGURE 54

CHANGE IN POTENTIAL DISTRIBUTION (4/75-5/75)
(105-C - BOEING)

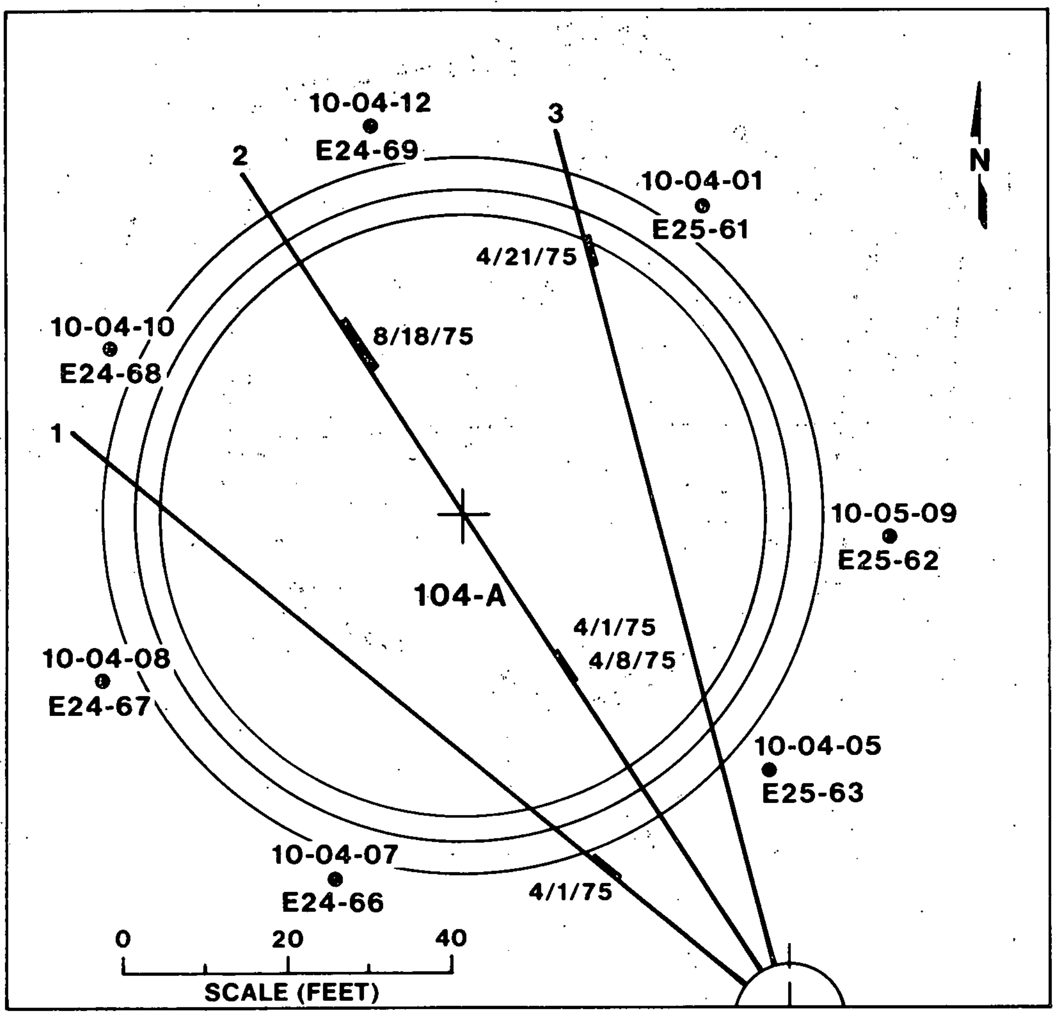


FIGURE 55

241-A-104 LEAK INVESTIGATION

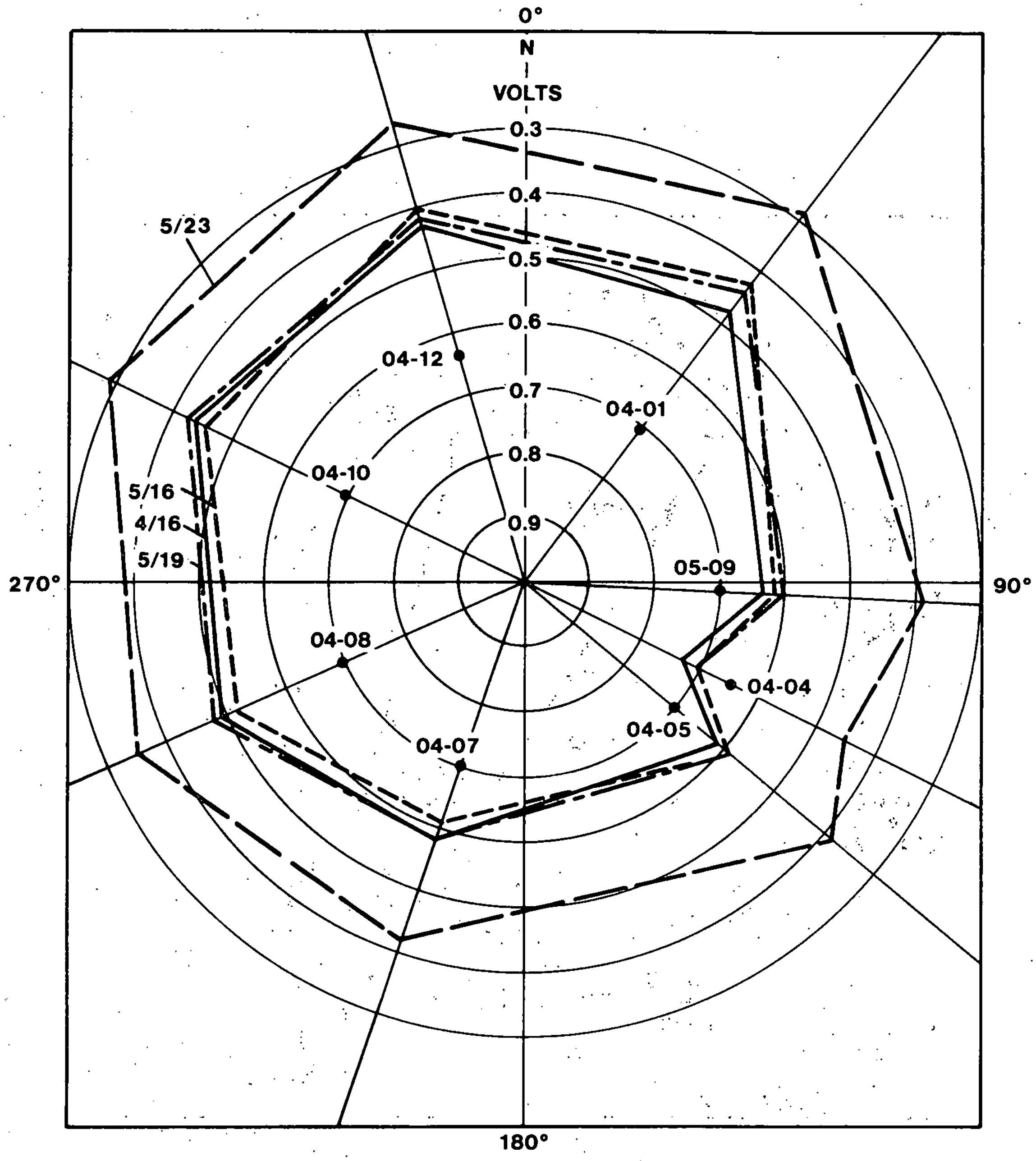


FIGURE 56

POTENTIAL DISTRIBUTION (4/75-5/75)
(104-A - BOEING)

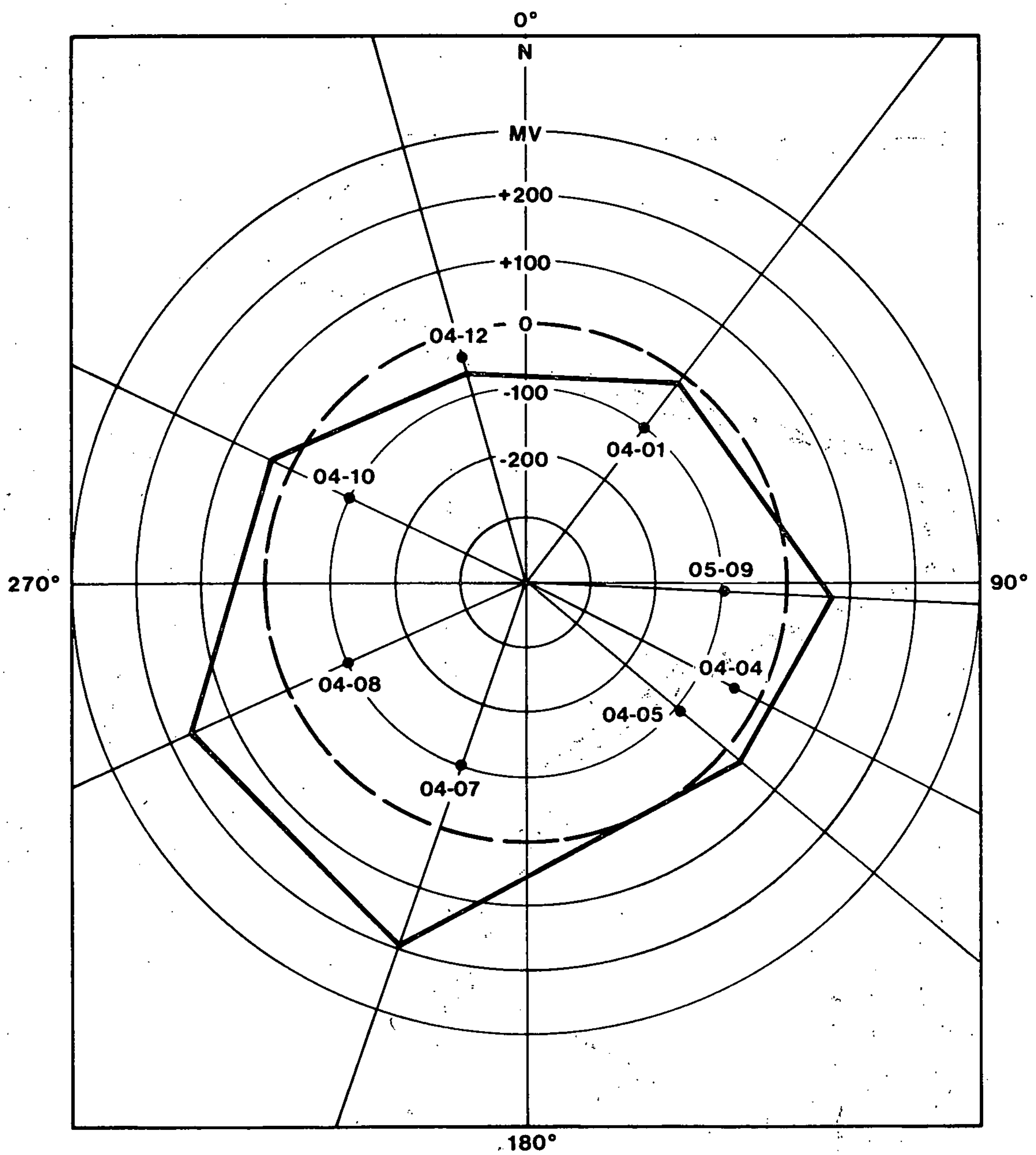


FIGURE 57

POTENTIAL DISTRIBUTION
(104-A, 4/11/75 - BNW)

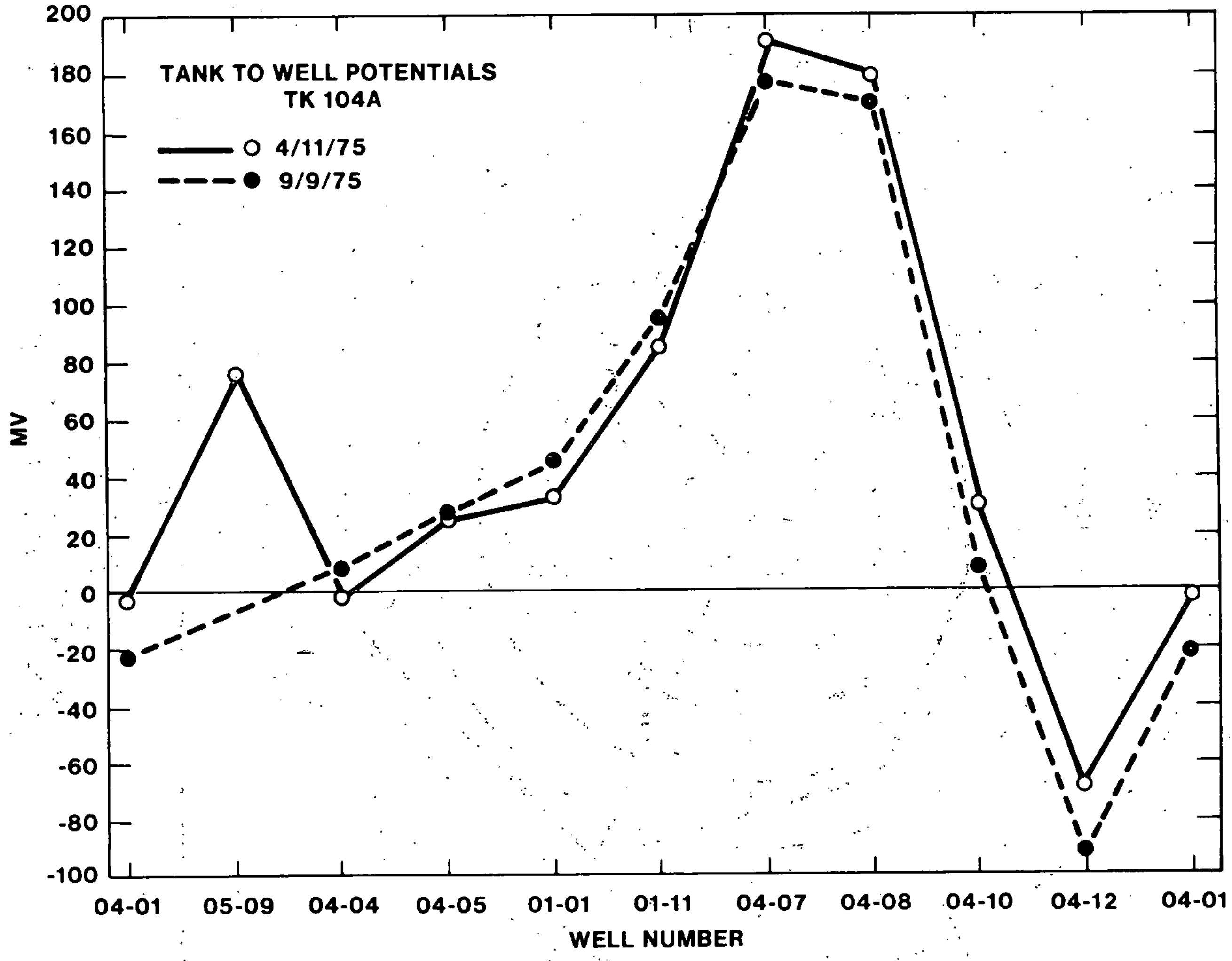


FIGURE 58

CHANGE IN POTENTIAL (4/75-9/75)(104-A - BNW)

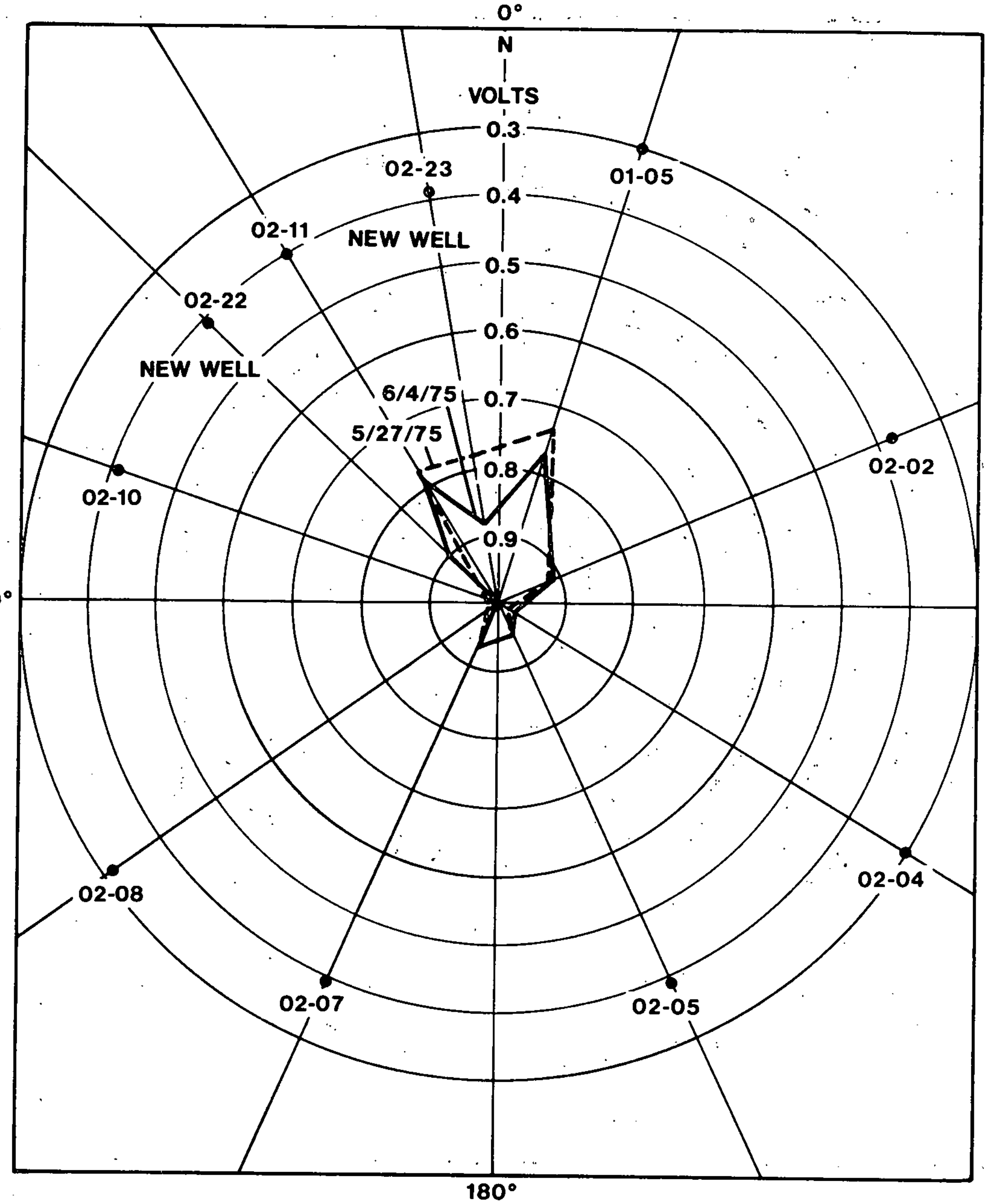


FIGURE 59

POTENTIAL DISTRIBUTION (5/75-6/75)
102-AX - BOEING)

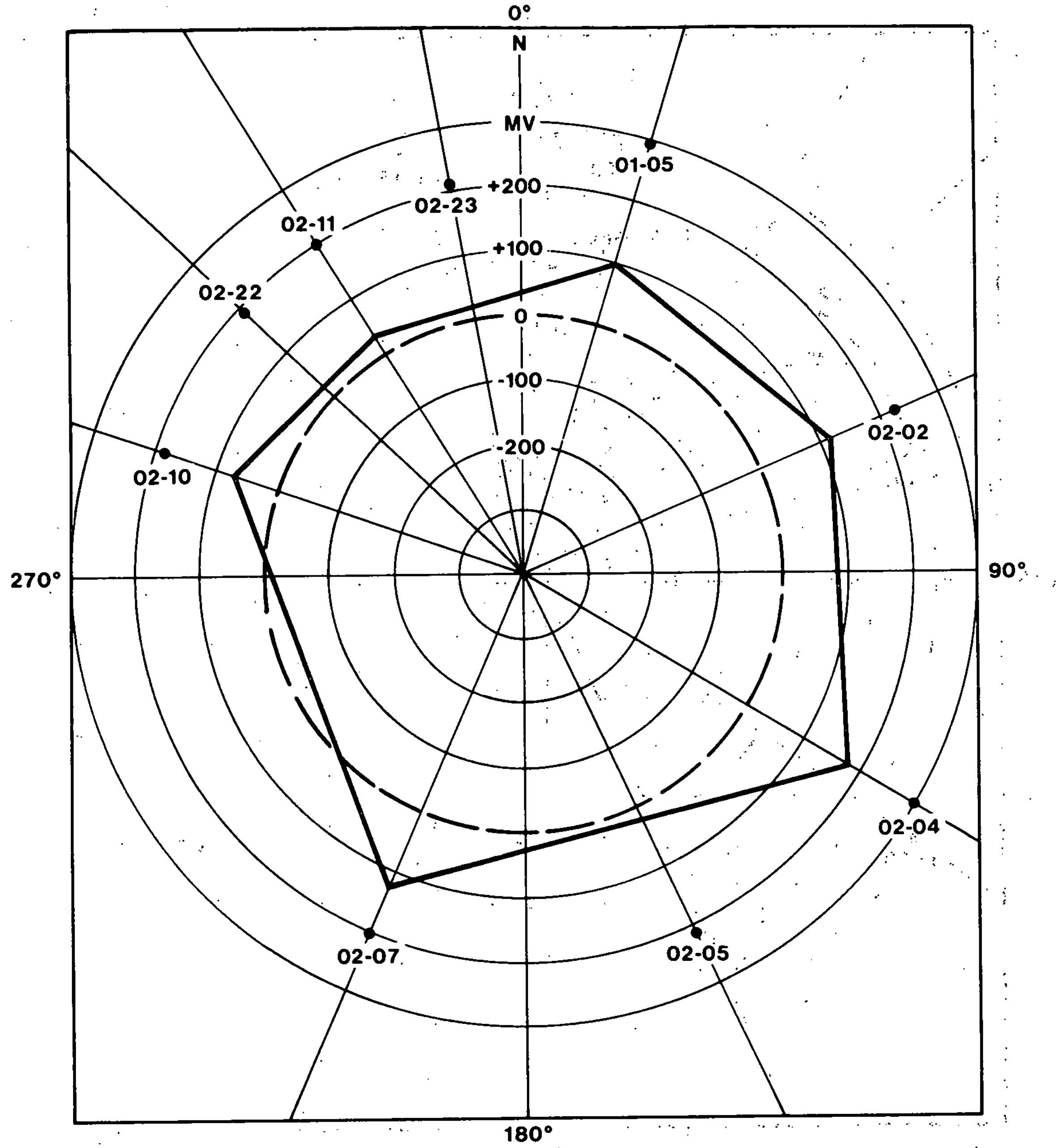


FIGURE 60

POTENTIAL DISTRIBUTION
(102-AX, 5/27/75 - BNW - AVERAGE OF HOURLY DATA)

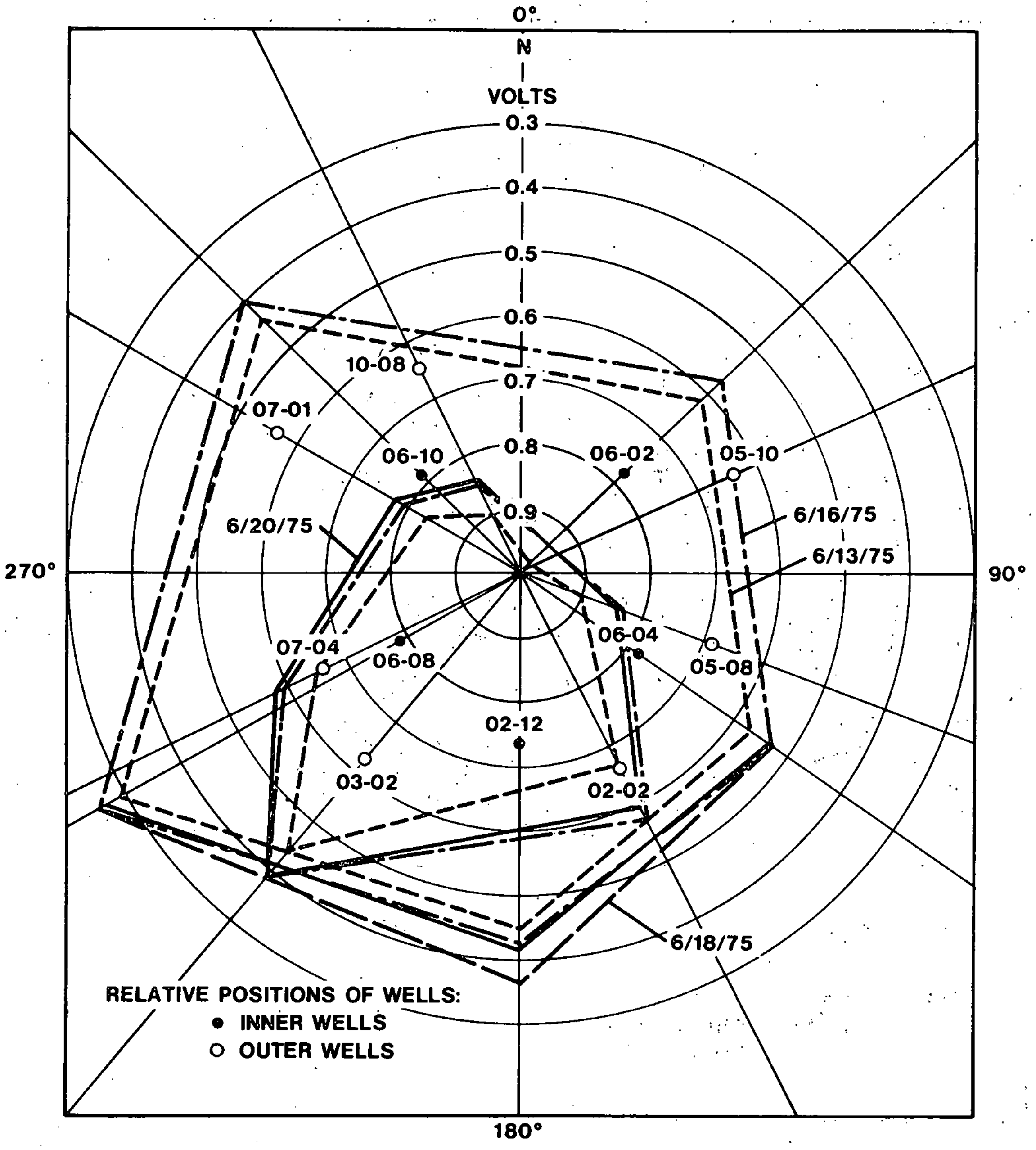


FIGURE 61

POTENTIAL DISTRIBUTION
(106-TX - BOEING)

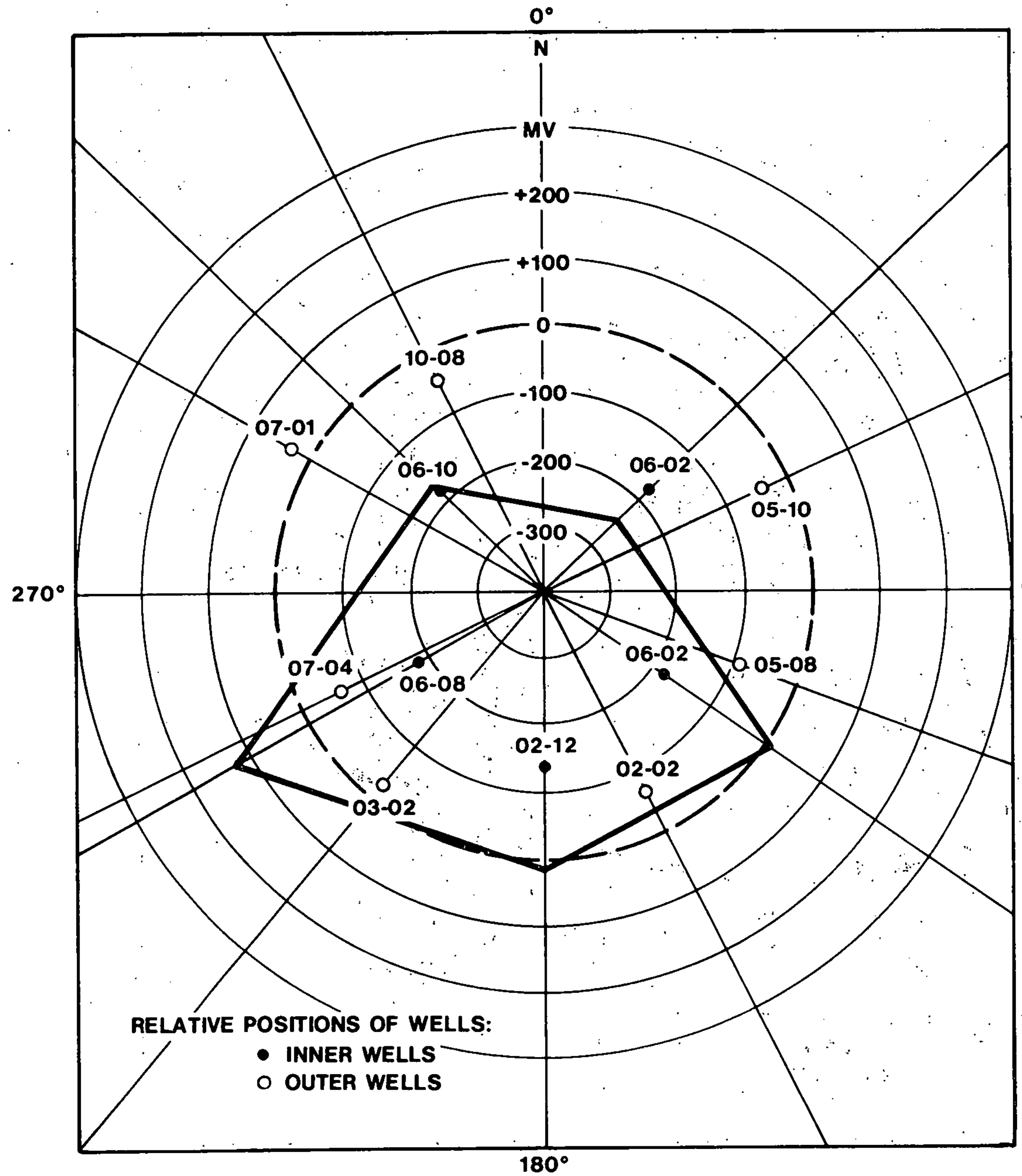


FIGURE 62

POTENTIAL DISTRIBUTION
(106-TX - BNW)

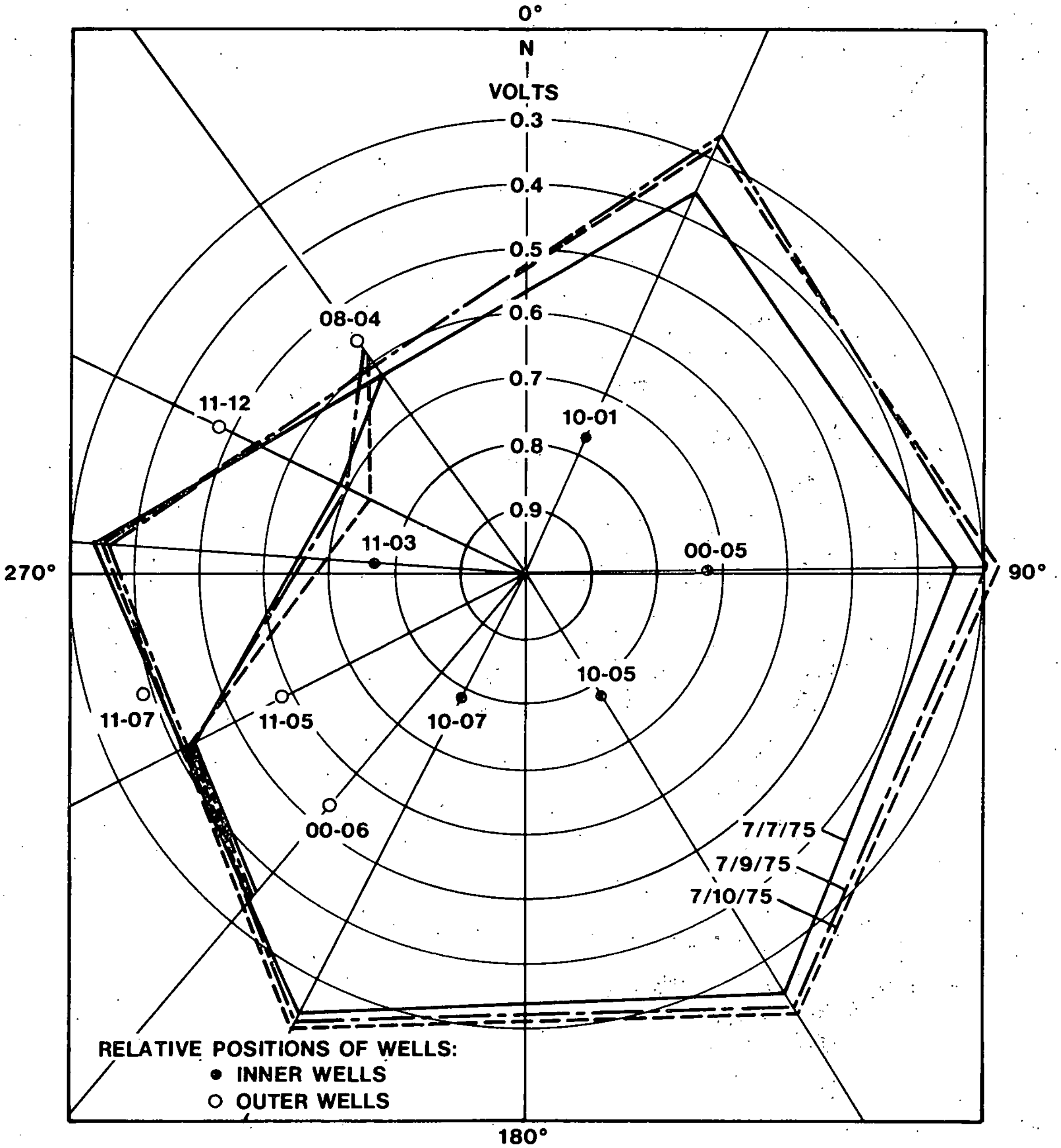


FIGURE 63

POTENTIAL DISTRIBUTION
(101-U - BOEING)

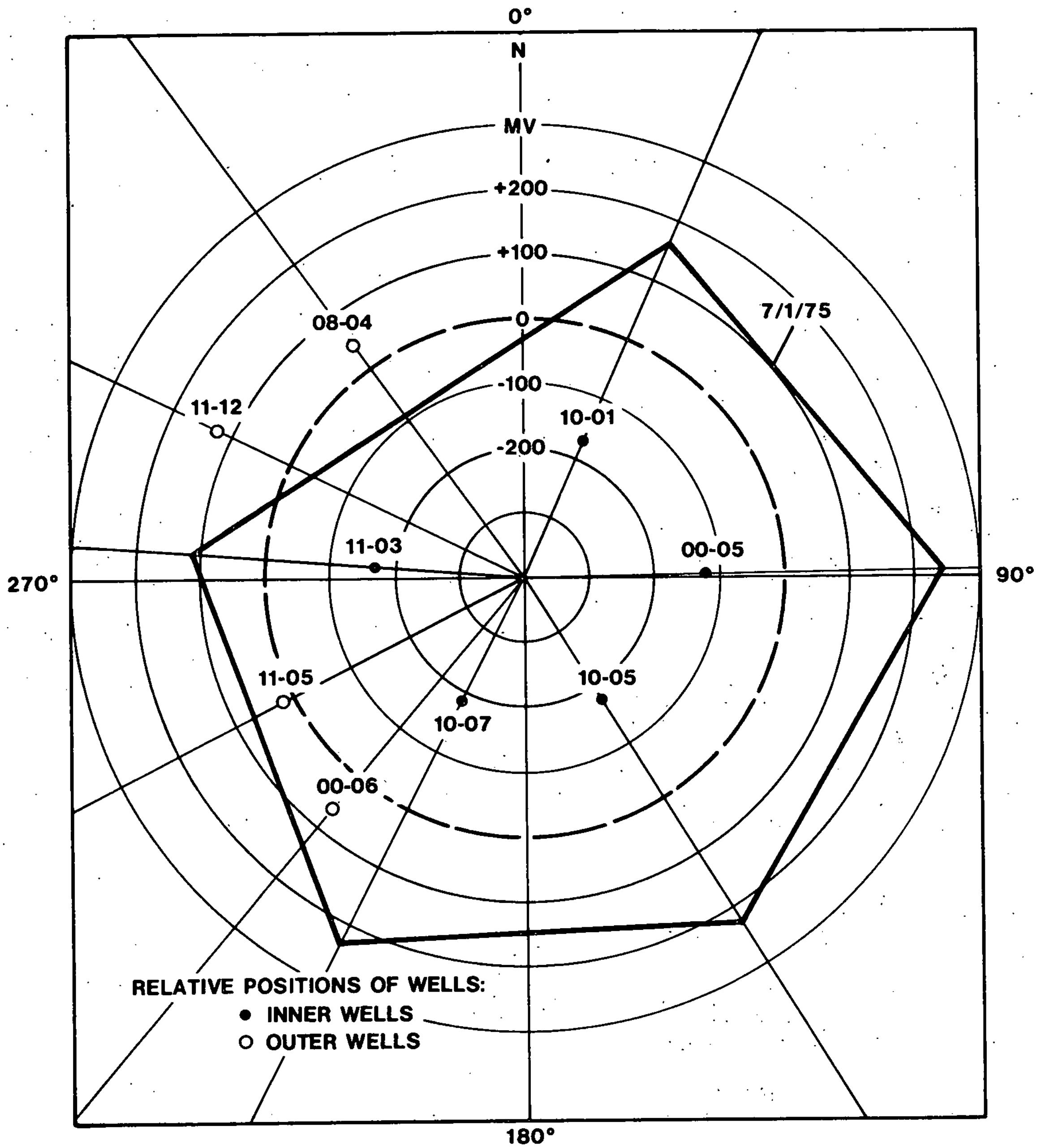


FIGURE 64

POTENTIAL DISTRIBUTION
(110-U, 5/1/75 - BNW - AVERAGE OF HOURLY DATA)

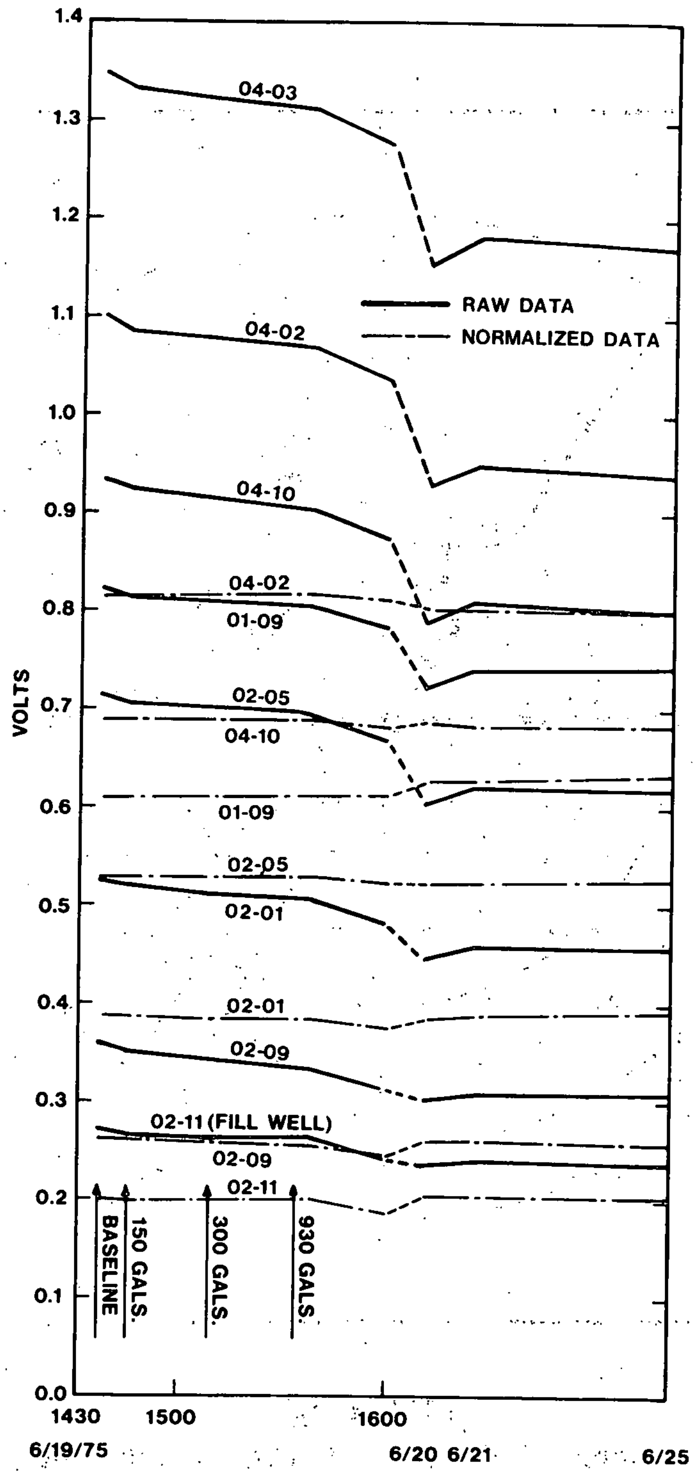


FIGURE 65

COMPARISON BETWEEN NORMALIZED AND RAW DATA
(102-TY - BOEING)

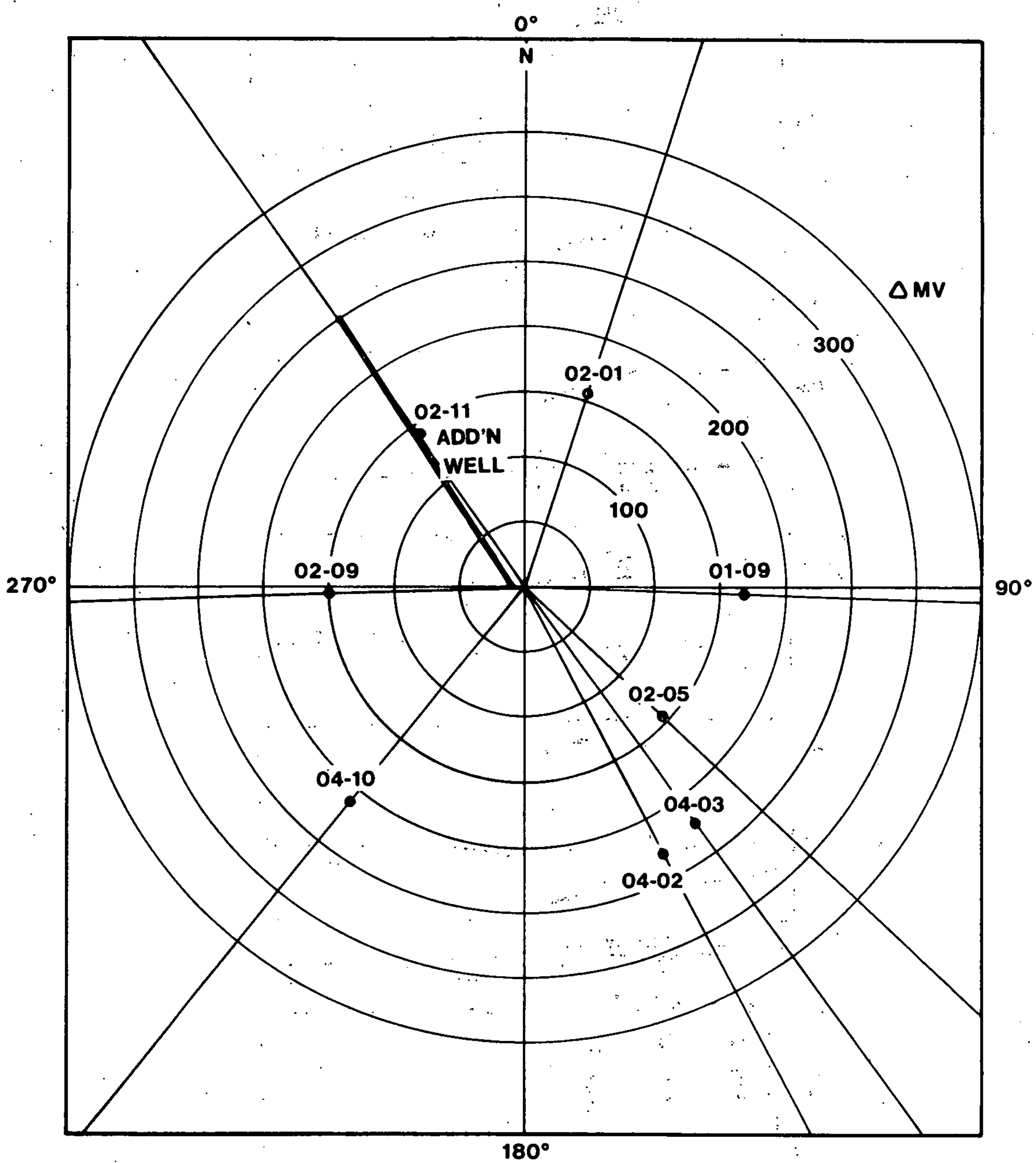


FIGURE 66

POTENTIAL CHANGE AFTER ADDITION OF SALT SOLUTION
(102-TY, 6/19/75 - BNW)

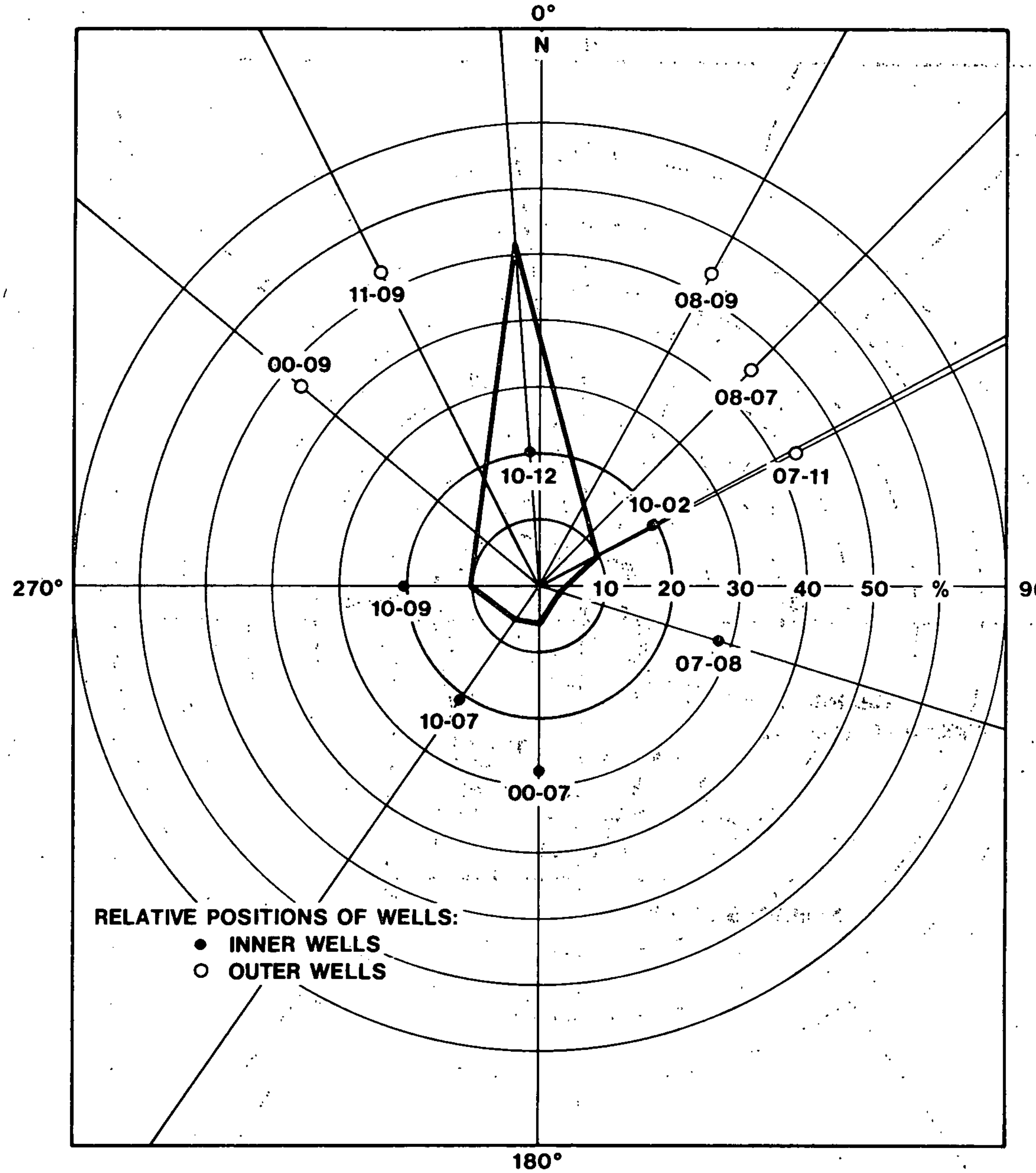


FIGURE 67

PERCENT CHANGE OF POTENTIALS AFTER 500 GAL ADDITION OF SALT SOLUTION (101-B, 6/27/75 - BOEING)

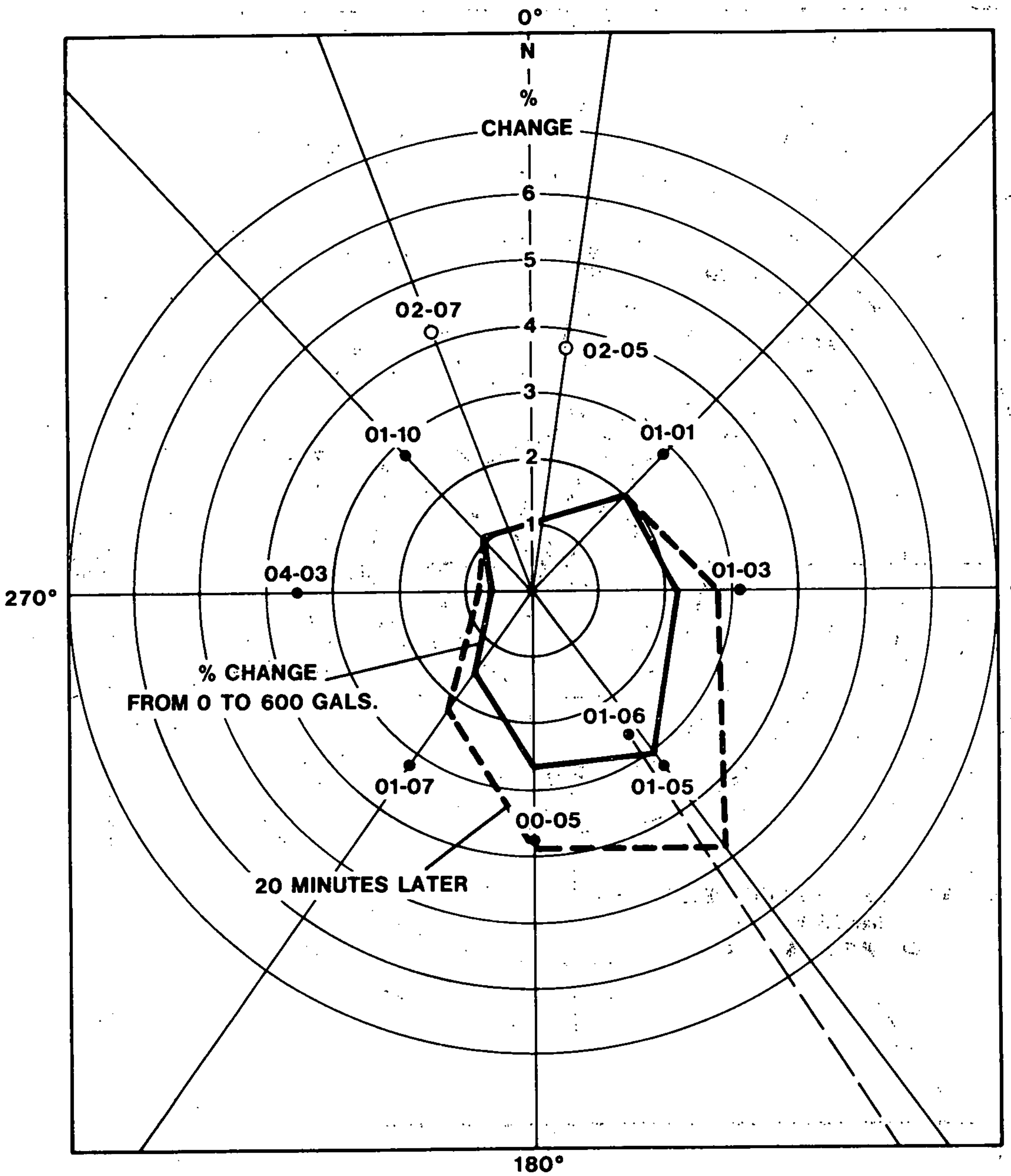


FIGURE 68

PERCENT CHANGE OF POTENTIALS
(101-B, 7/25/75 - BOEING)

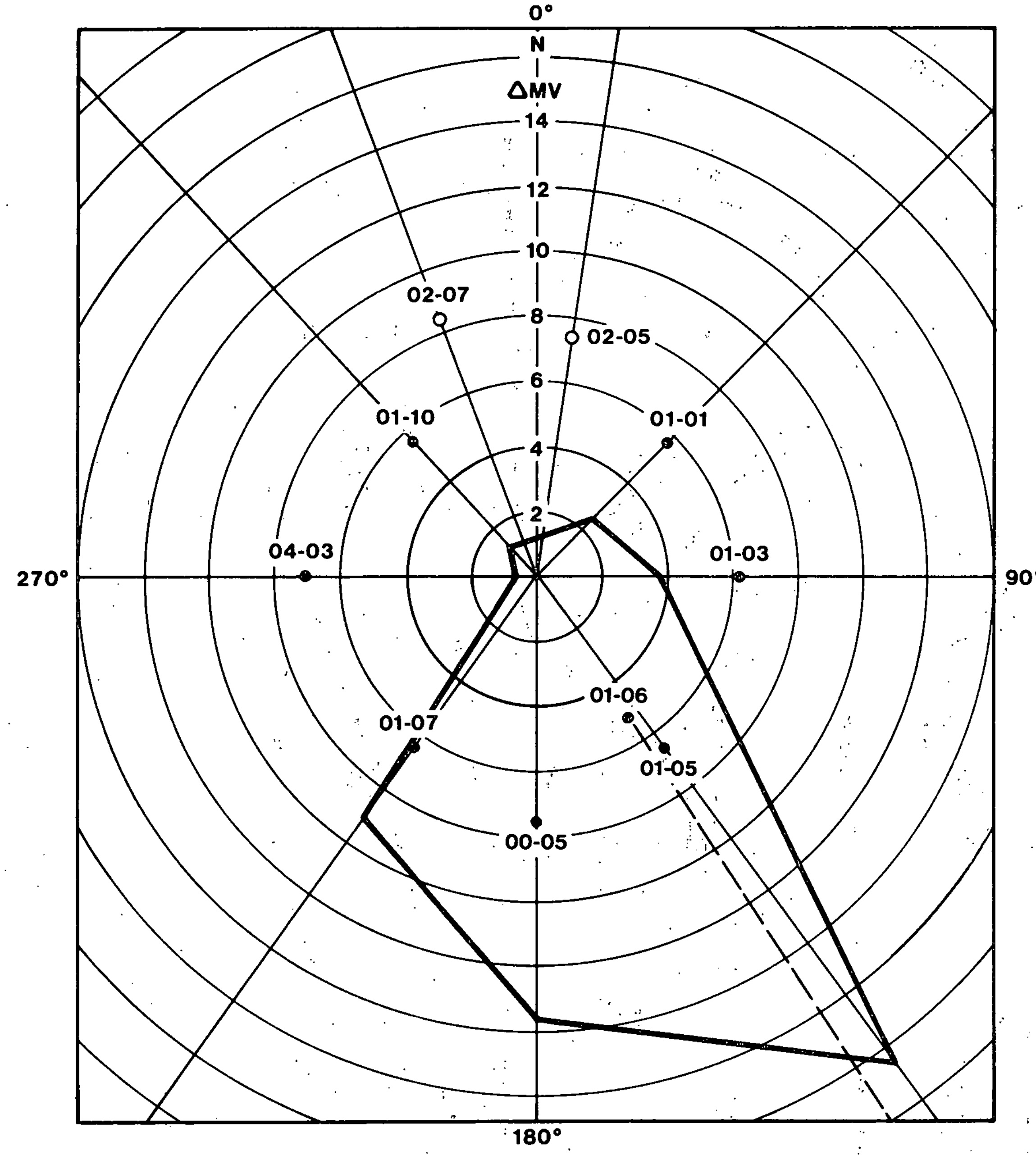


FIGURE 69

POTENTIAL CHANGE BETWEEN 0 AND 600 GAL
(101-B, 7/31/75 - BNW)

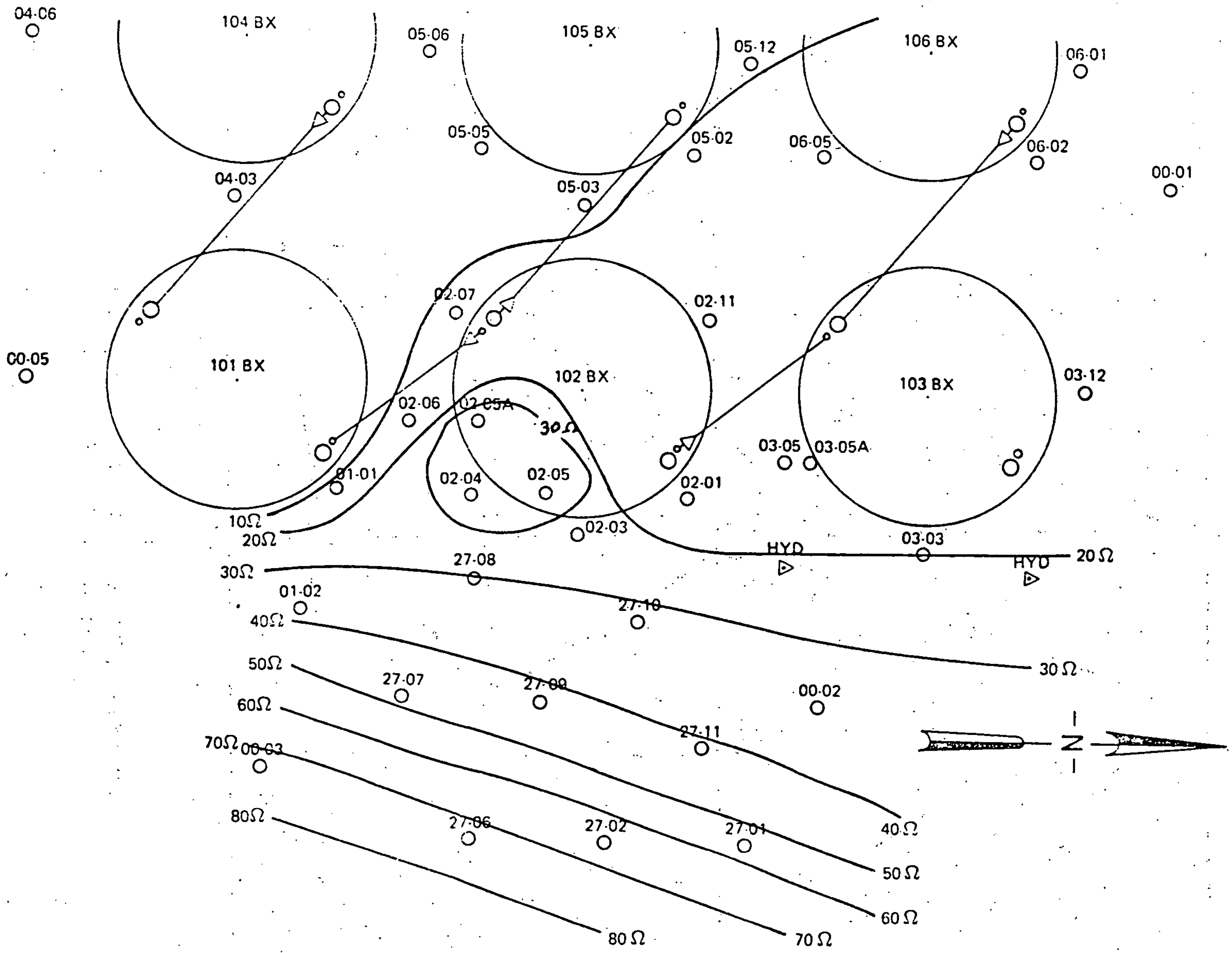


FIGURE 70

BX FARM DRY WELL RESISTANCE PLOT

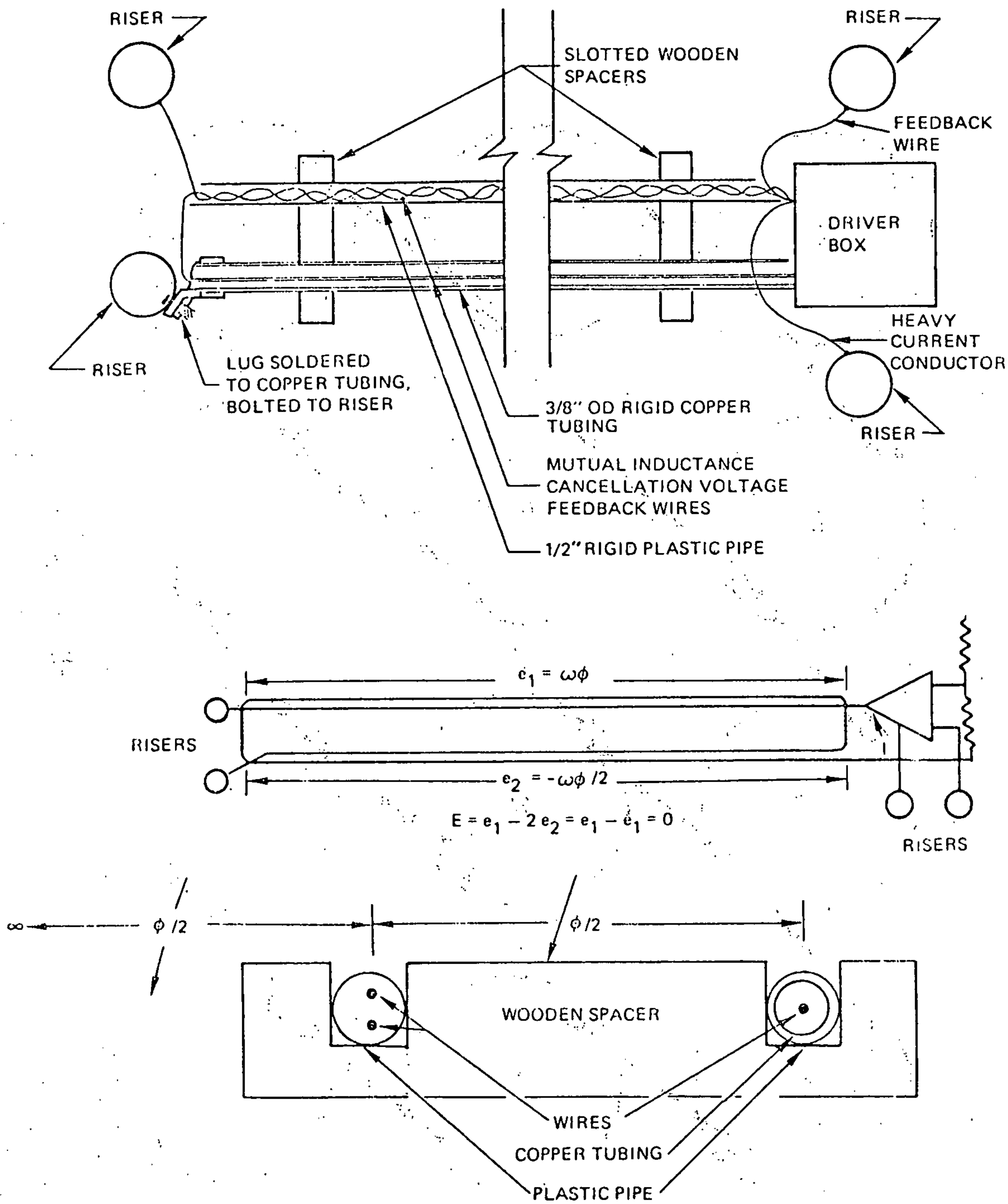


FIGURE 71

MUTUAL INDUCTANCE CANCELLATION

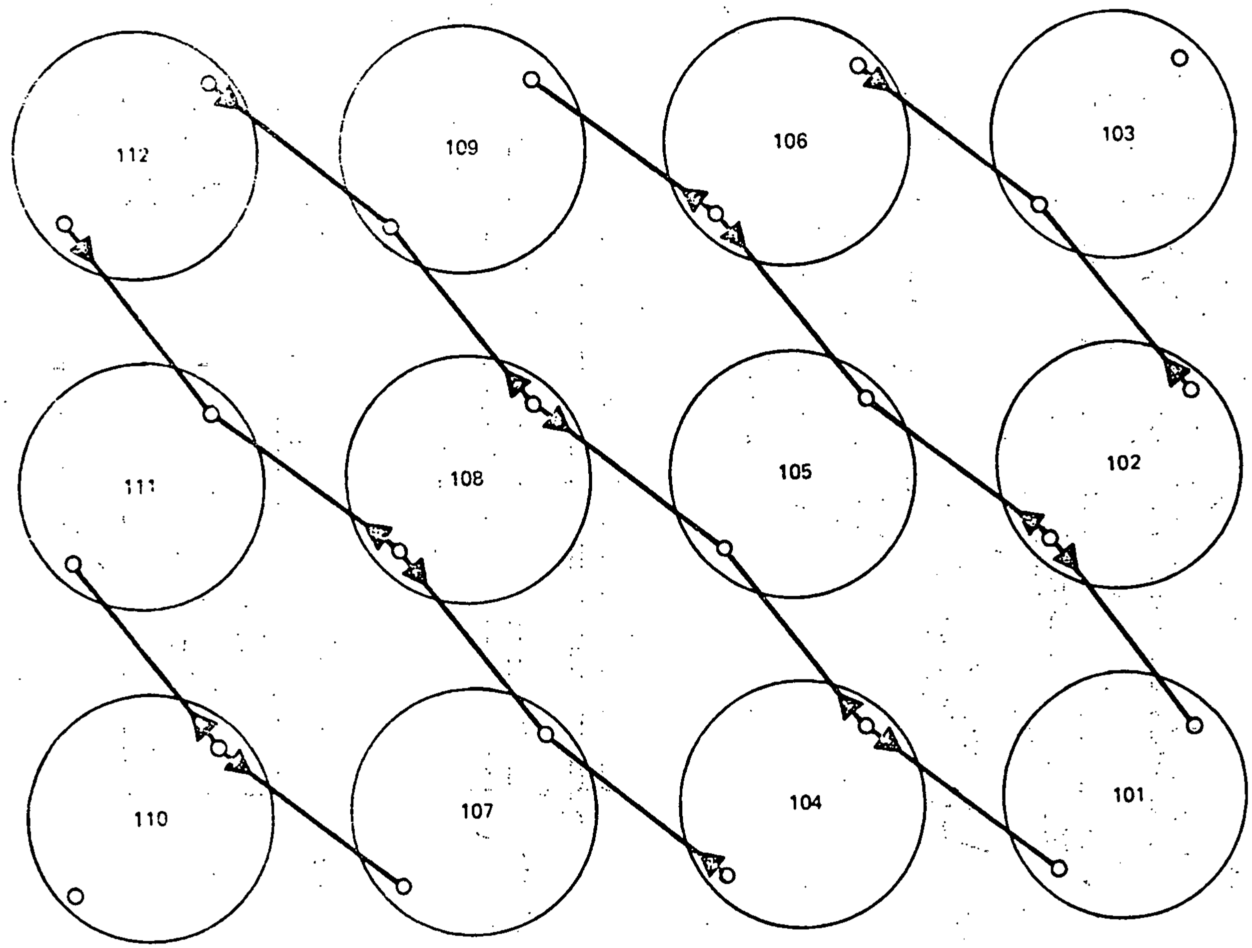


FIGURE 72

TANK FARM DRIVER PATTERN LAYOUT

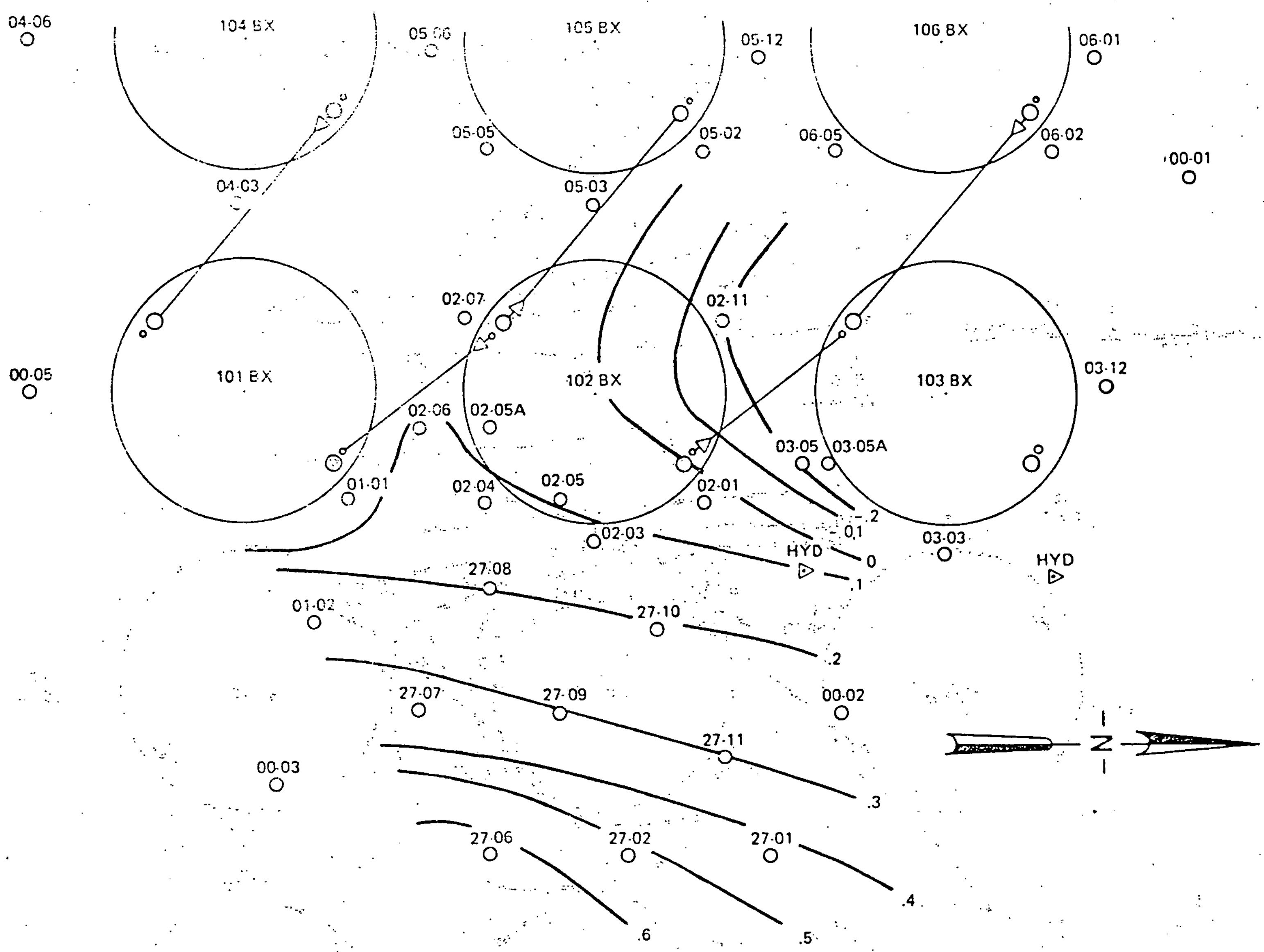


FIGURE 73

TANK 102-BX CATHODIC PROTECTION SYSTEM d.c. POTENTIAL FIELD

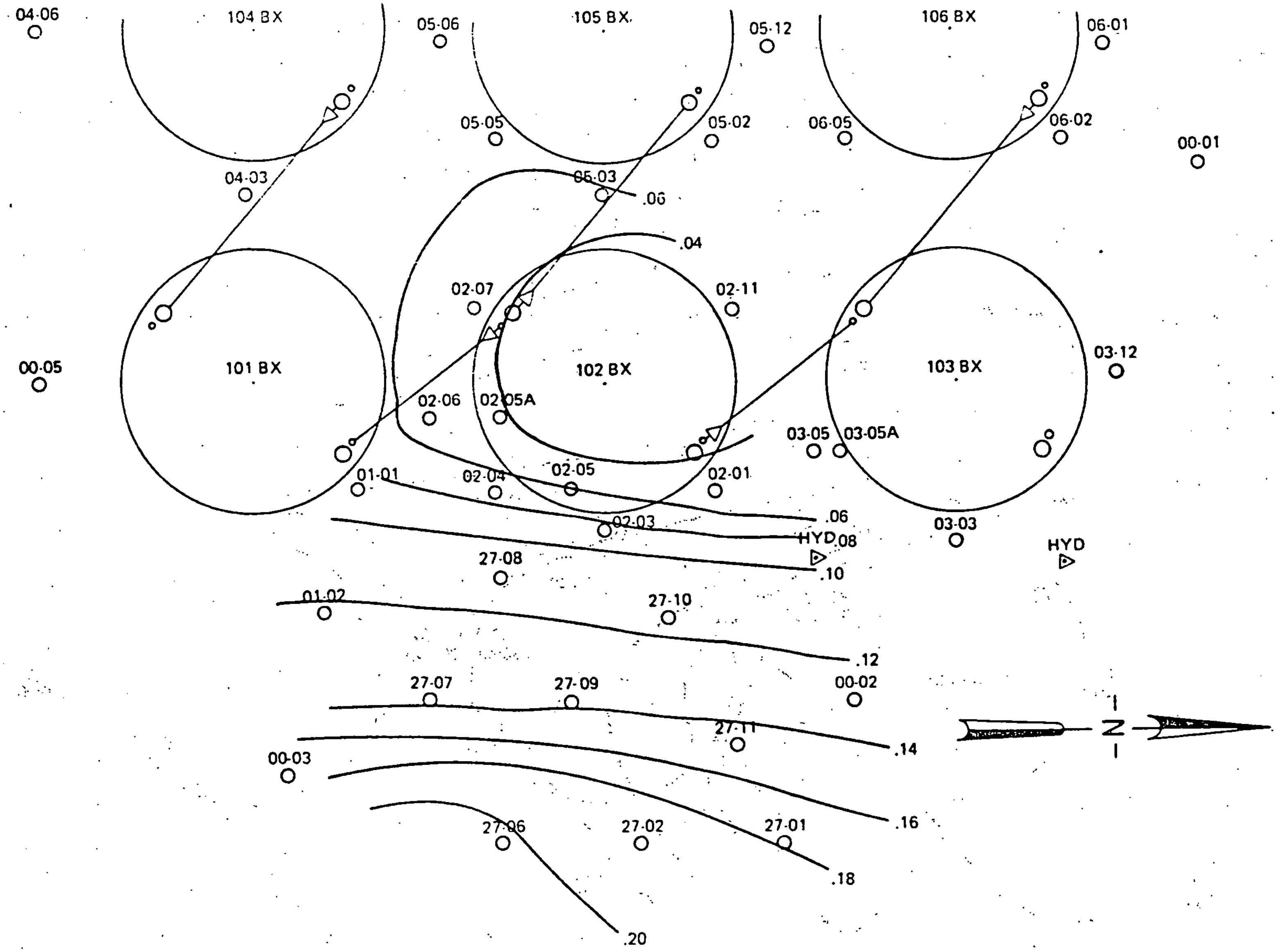


FIGURE 74

TANK 102-BX CATHODIC PROTECTION SYSTEM a.c. POTENTIAL FIELD (60 Hz)

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