[redacted]

C 2 F

BNWL-B-308

1—

REVIEW OF ARHCO WASTE TANK LEAK AND LEVEL MONITORING SYSTEMS AND MATERIAL BALANCE TECHNIQUES

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

BNWL-B-308

DISTRIBUTION RESTRICTED TO U.S. ONLY

Prepared for the U.S. Atomic Energy
Commission under Contract AT(45-1):1830

BNWL-B-308

REVIEW OF ARHCO WASTE TANK LEAK AND LEVEL MONITORING SYSTEMS AND MATERIAL BALANCE TECHNIQUES

G. Jansen
D. P. Granquist
R. D. Dierks
J. N. Hartley
O. H. Koski
J. A. Merrill
C. A. Ratcliff

(Compiled by J. L. McElroy)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

A review of selected portions of the ARHCO waste tank farm monitoring methods and systems was made. Only preliminary evaluations were made as the study was carried out over a period of only ten days. The study was requested by the Operations Support Engineering Department of ARHCO and the objectives as developed were divided into four tasks. Briefly, these were:

Task 1. Evaluation of the waste tank dry well monitoring and data processing systems.

Task 2. Evaluation of the accuracy (and precision) of material balance calculations for transfers from one tank to another tank.

Task 3. Evaluation of the capabilities of material balance techniques for the detection of leaks in evaporator bottoms loop systems.

Task 4. Evaluation of the general operability of liquid level instrument systems currently in use and alternatives to these systems.

The objectives of these tasks are restated in more detail in each of the sections below.

An overview of the entire Hanford radioactive waste program including a limited description of the physical equipment involved can be found in PWM-530, Hanford Radioactive Waste Management Plans. Documentation related directly to this study would also include HW-83218, First In-Tank Waste Solidification Unit Information Manual and RL-SEP-306, 242-T Evaporator Facility Information Manual.

Additional efforts have been initiated to establish an overall R&D program to more fully evaluate these systems and other factors relative to the successful operation of the ARHCO tank farm system.

REVIEW OF ARHCO WASTE TANK DRY WELL MONITORING SYSTEM (Task 1)

G. Jansen and J. N. Hartley

Task 1 of this study is concerned with the review of the waste tank dry well monitoring system. The objectives of this task were:

(1) To review the present dry well monitoring systems

(2) To determine the ultimate leak detection capabilities of an idealized dry well monitoring system such as the size of leak that can be detected, the number of dry wells needed and the monitoring frequency required

(3) To review the flow of dry well logging data and the data analysis system

(4) To develop alternatives to the present system.

SUMMARY

It is clear that in the absence of leak spreading inhomogeneities in the soil, very large leaks could occur before they could be detected by dry wells. They would certainly be detected by an effective liquid level monitor within the tank long before they reached this size.* In the absence of a reliable liquid level monitor, the installation of laterals beneath the tank could reduce the undetected leak size.

---

* The two liquid level measuring devices now in use are the tape and the FIC system. Technical discussions of these instrument systems are presented under the fourth task in this study.

The following statements summarize the general conclusions that can be reached about the use of dry well monitoring and data processing:

- The overall reliability of current dry well monitoring systems would be improved if modified to provide two independently functioning information flow paths from the point of monitoring to the decision point. One of these systems should be personnel-activated and the other automatically realized. This would provide for a more reliable system for evaluating the data obtained from dry well logging. A number of minor modifications could also be made to improve the system. These could include instrument calibration, better depth determination, operator training, writing of standard procedures, reference dry wells with known properties, neutron moisture monitors, greater probe range capabilities, and more prompt data processing.
- The placing of three or four dry wells per tank to include all the tanks in the tank farms should be completed as soon as possible. This will provide for a more complete monitoring system and provide data for characterization of the microgeology of the tank farms.
- In some circumstances, the current system of dry wells is unable to detect leaks from the center of the tank bottom until they get very large. For tanks in which liquid level monitors are not present or reliable, laterals placed beneath the tanks in addition to dry wells would provide a more effective leak detection system. Laterals are currently used only in the A and SX farms.
- The monitoring interval should be of the same magnitude as the time to stop the leak, which is about one day.

- The present system of operator-activated well logging equipment is incapable of being modified to achieve the desired monitoring frequency for all dry wells.
- A permanent total radiation level detection system would provide the desired monitoring frequency for leak detection. Appreciable instrument development work would be required to perfect such a system but we believe it is necessary. A system could be developed and put in place in each dry well and lateral, with the present system to be used only when a change is detected by the permanent system. The permanent system could contain local alarms as well as a computer-controlled data logging system.
- Permeability measurements in selected samples from the monitoring wells drilled for soil characterizations are needed so that they can be used in hydrological models.
- Sufficient hydrological model development should be done and enough hypothetical base cases should be run to give a rough idea of the peculiarities of leak-soil interactions in each tank farm.
- A data display system for tank farm data similar to the one for the groundwater table of the Hanford project would provide for quick background reference by technical personnel, management, decision-makers in ARHCO, and AEC monitors. This would be particularly valuable in educating a wide range of people to the implications of a leak event.
- A capability for "quick and dirty" engineering analysis by the Operation Support Engineering Department based on the geological and hydrological knowledge of the ARHCO R&D Department and BNW Land and Water Resources Department would contribute to the early evaluation of a leak so that its size might be reduced.

SYSTEM DESCRIPTION

Logging of dry wells adjacent to the waste tanks is used to detect the presence of radionuclides in the soil around and beneath the tanks. This system, in conjunction with liquid level measurements, provides a means of initially detecting leaks and allows the monitoring of the movement of a tank leak.

The logging system is manually operated and consists basically of a scintillation probe, a hoisting winch, a count rate meter and a paper punch or recorder. This equipment is mounted in a carryall truck. This truck is driven into position at a dry well site, the probe is lowered down the dry well (usually about 100 feet deep) and then automatically raised at a constant predetermined rate. The data is logged by a tape punch in the 200-East tank farms and by a recorder in the 200-West tank farms. At the end of each day after logging about 20 wells the operator sends the punch tape to the UNIVAC 1108 in the Federal Building for processing or delivers the recorder strip chart to the data analysis personnel.

The overall system consists of logging the dry wells, sending the punch tape to CSC or delivering strip charts to data analysis personnel, and then data compilation and filing. The computer is used in the present system to print out a list of changes that have occurred in readings and to plot graphs of depth versus counts per minute for the wells that have changed. Often 3 or 4 days of turnaround time elapses before the data is seen by the data analysis personnel.

The frequency of dry well monitoring presently is at one-month or one-week intervals, depending on the contents of the tank being monitored. The number of dry wells around each tank varies from 0 to about 9 but most have about 4.

LEAK DETECTION CAPABILITIES OF AN IDEALIZED DRY WELL SYSTEM

The degree of soil saturation with moisture by a leak varies continuously from 100 percent near the point of the leak origin down to less than 10 percent in the far distant soil. The permeability of the soil to water flow is a function of the soil particle size distribution, particle shape cementation, and indeterminate factors, and it decreases logarithmically as the saturation is decreased, with the water nearly immobile at 25 percent saturation. The leak movement is driven by the pressure head within the tank, the force of gravity on the leak volume itself, and capillary forces. In a homogeneous medium the shape of the leak, the percent saturation, and the rate of leakage are a function of these forces, with the leak shape varying from hemispherical for capillary action only, or spherical (for sissile drop-like) with capillary action and gravity predominating, to conical with the tank pressure head and gravity predominating. In heterogeneous media like the Hanford soil, differences in permeability from layer to layer can cause the leak to spread out preferentially at layer boundaries. (This is called feathering.) In an extreme case a relatively impermeable caliche layer (crust of calcium carbonate) can inhibit downward penetration. The complex behavior in leaks can then only be understood with rather detailed computer modeling based on painstaking characterization of the microgeological parameters and taking hours of computer time to follow the progress of a single hypothetical leak.

With the above factors in mind, the present study was undertaken to estimate the maximum volume of leaks that could escape being detected by dry wells under various conditions. The following assumptions were made:

1. The leak has a sharp boundary and spreads out as a cone with the point of leakage as its apex and a horizontal base.
2. The angle the surface of the cone makes with the vertical axis is 30°, 45°, or 60°.

3. The degree of saturation within the leak (based on 33 percent void volume in the soil at 100% saturation) is 25%, 50%, or 100%.
4. The leak is detected when the edge of the base of the cone reaches a dry well, or when the base reaches a horizontal impermeable layer which spreads it out, or when the base intersects a lateral beneath a tank.
5. The ring of dry wells is placed 8 feet from the tank wall.
6. The leak rate is 1.6 gallons per minute. (This is characteristic of the calculated average 106T leak rate.)
7. The void fraction in the soil is 0.33.

With additional effort and a better knowledge of the interaction of the hydrological parameters, a probablistic model of the leak detection system could be developed, resulting in a most probable size leak that could be detected and the distribution of leak sizes. The current study, however, is limited to worst case situations.

The leak rate of 1.6 gallons per minute as used here is typical of the average leak rate from the 106T tank. This corresponds to the leak rate from a circular hole with a 2.8-inch diameter, with 4 feet of water head above the hole, leaking in 100% saturated flow into coarse sand with a permeability of 100 ft/day and a hemispherical leak shape. Since most of the resistance to flow is in the sand near the hole, the leak would be at a constant rate (assuming a constant head in the tank). With the same assumptions, the leak rate from a crack would decrease with time because the resistance to flow is more evenly distributed throughout the leak volume.

Effect of Leak Location and Shape on Dry Well Leak Detection Capabilities

With allowances for the tank wall thickness, the footing extending from the bottom of the tank, and the debris at the toe of the footing, a dry well can be placed about 8 feet from the inside wall of the tank. The volume of leaks at incipient detection by a continuously monitored ring of dry wells (a very large number of dry wells are placed in this ring) is shown in Figures 1a, 1b and 1c for 25%, 50% and 100% saturation and for cone angles of 30°, 45° and 60°. (The data used in these figures are given in Appendix A.) The ordinate is the depth at which the leak is detected.

For example, for 50% saturation, if the leak is at the edge of the tank it would be detected at depths of 4 to 14 feet below the leak point when the volume had reached 380 to 1150 gallons, depending on the cone angle. If the leak is at the center of the tank it could reach a size of 68,000 to 200,000 gallons before being detected by the dry well ring at depths of 26 to 78 feet. If the leak at the center of the tank (or anywhere else) reached an impermeable layer at a depth of 15 feet, which caused it to spread out rapidly without an increase in volume, the minimum detectable leak volume would range from 1500 gallons to 12,000 gallons. The true effects of the layering of strata can only be determined by detailed models.

Effect of Number of Dry Wells on Leak Detection Capability

Since most of the leaks seem to occur at the edge of a tank, the effect of the number of evenly spaced dry wells in the ring upon the maximum size of this type of leak not detected was estimated. The results are presented in Figures 2a, 2b and 2c and in Appendix B. The maximum size undetected leak occurs halfway between a pair of dry wells and would be in the range 100,000 to 1,000,000 gallons

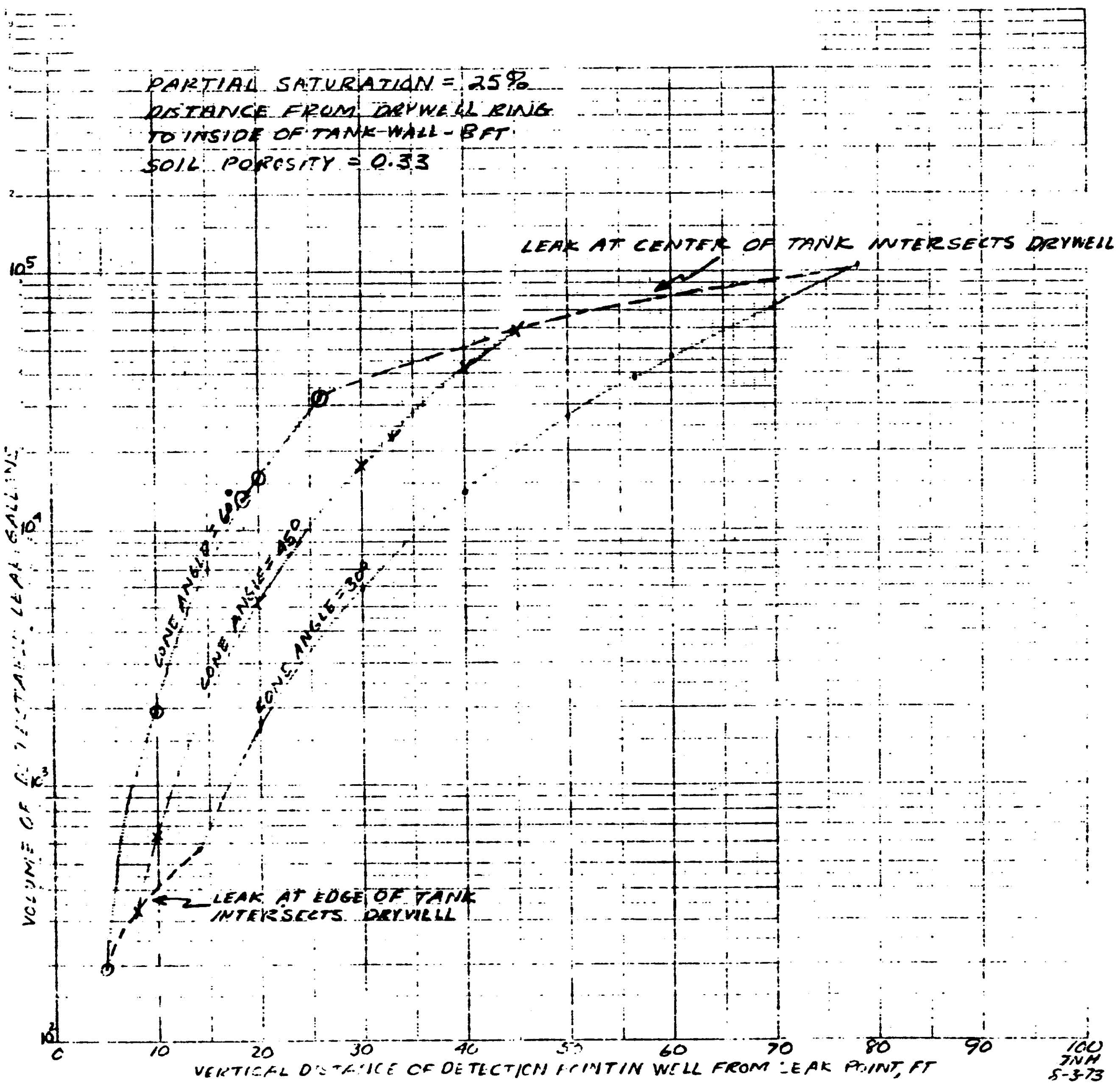
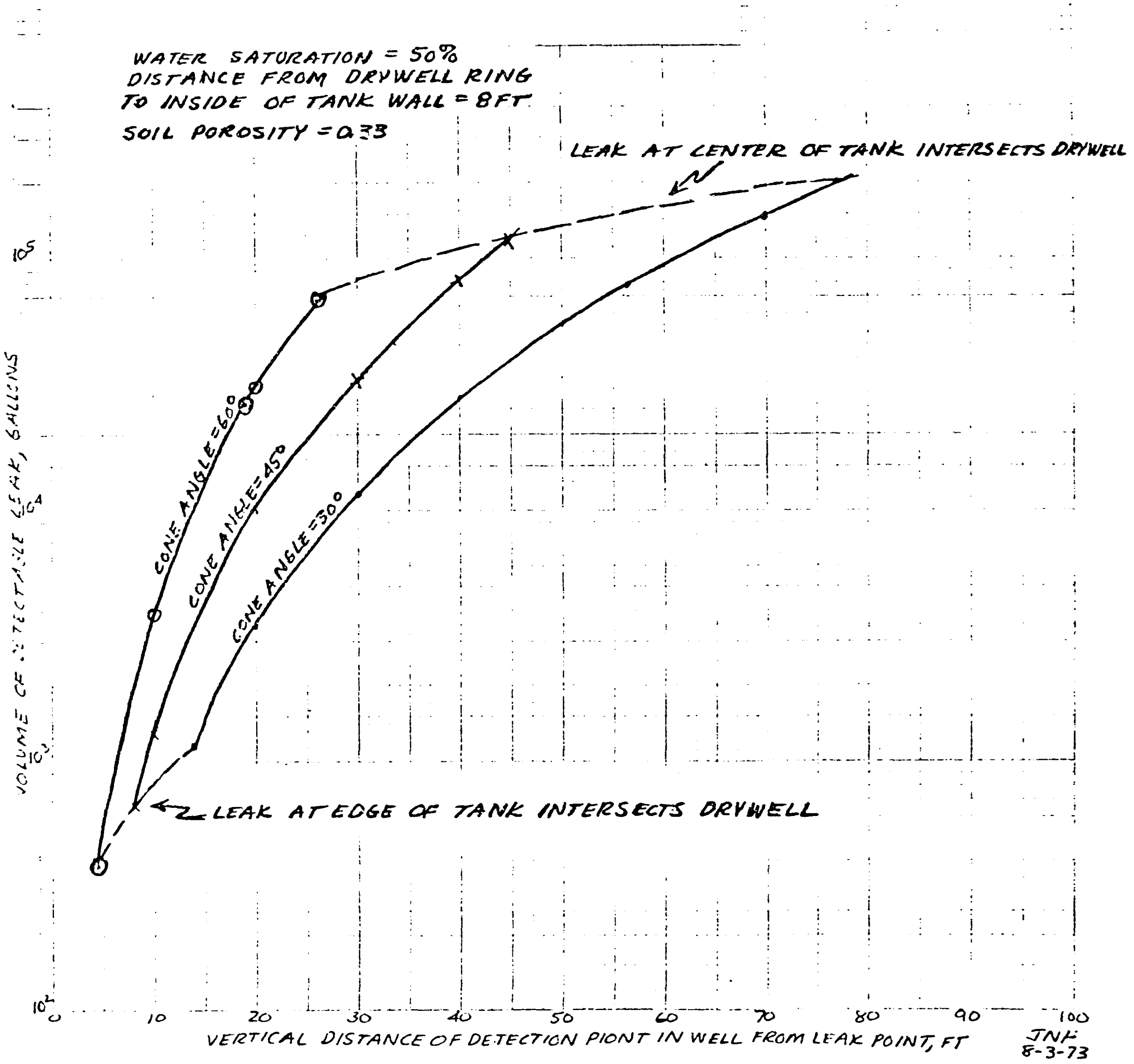


FIGURE 1a. Volume of Conical Leaks Detectable By A Ring of Closely Spaced Drywells



JNF
8-3-73

FIGURE 1b. Volume of Conical Leaks Detectable By A Ring of Closely Spaced Drywells

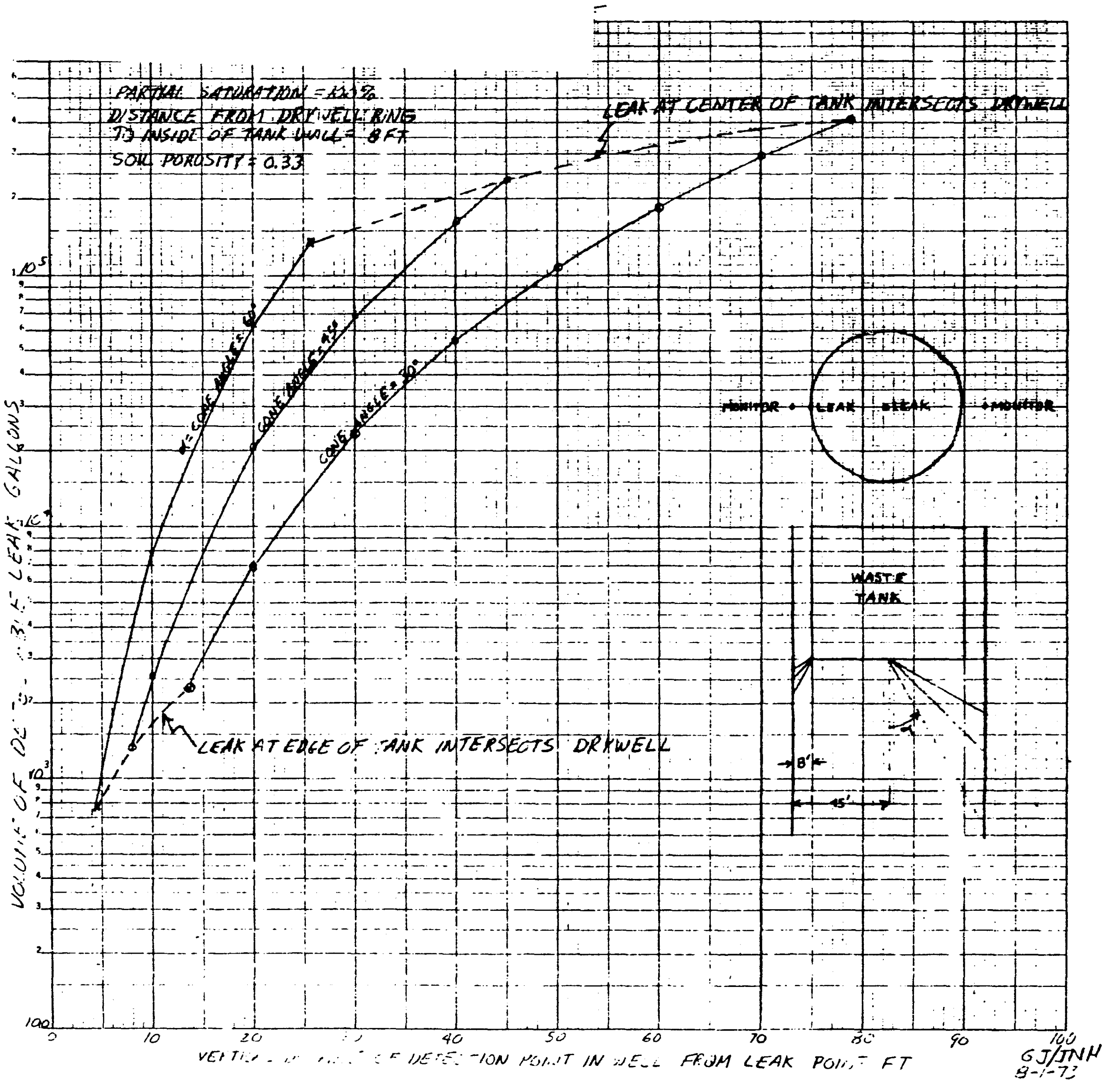
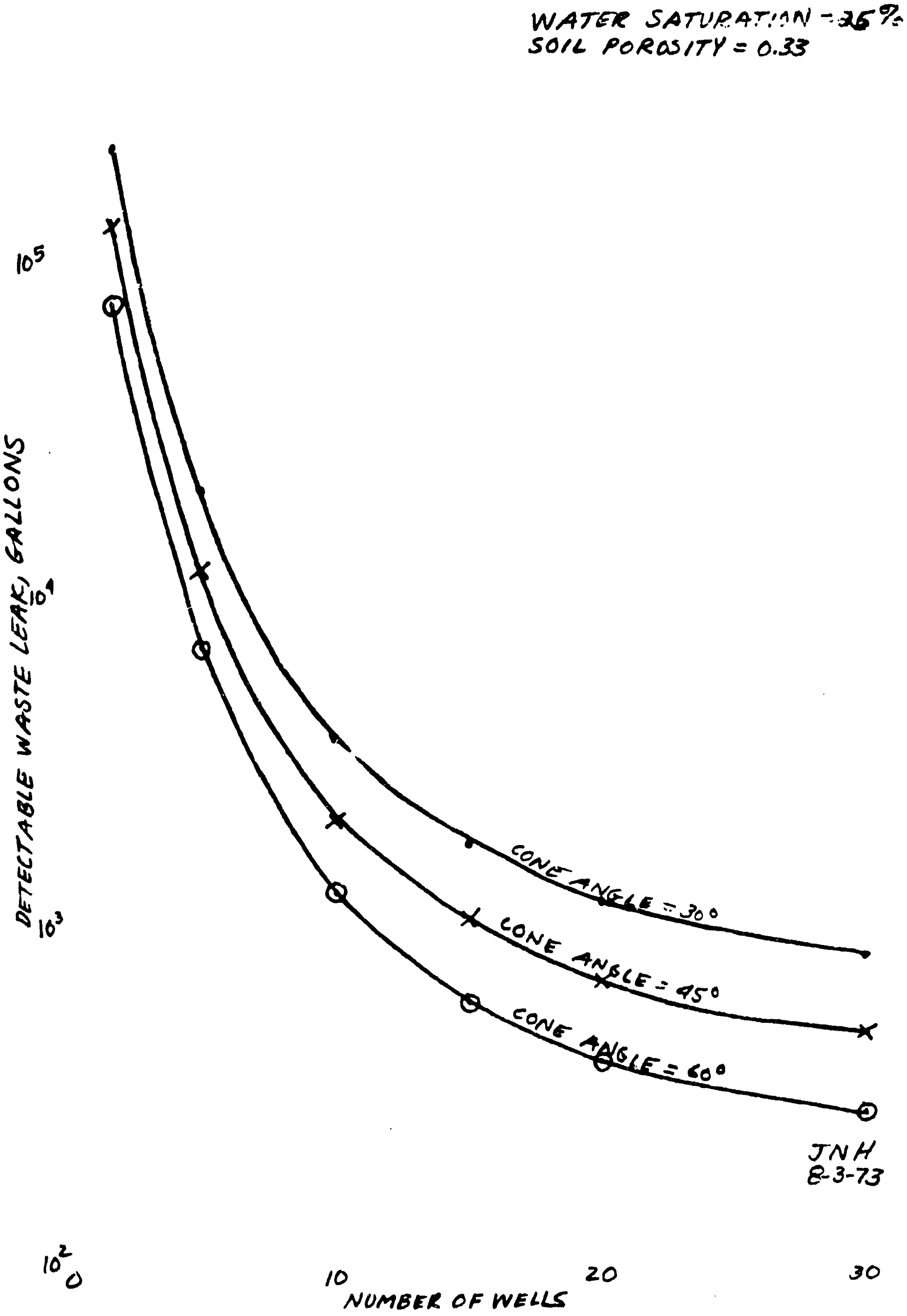


FIGURE 1c. Volume of Conical Leaks Detectable By A Ring of Closely Spaced Drywells



<u>FIGURE 2a</u>. Detectable Waste Volume By Drywell Monitors

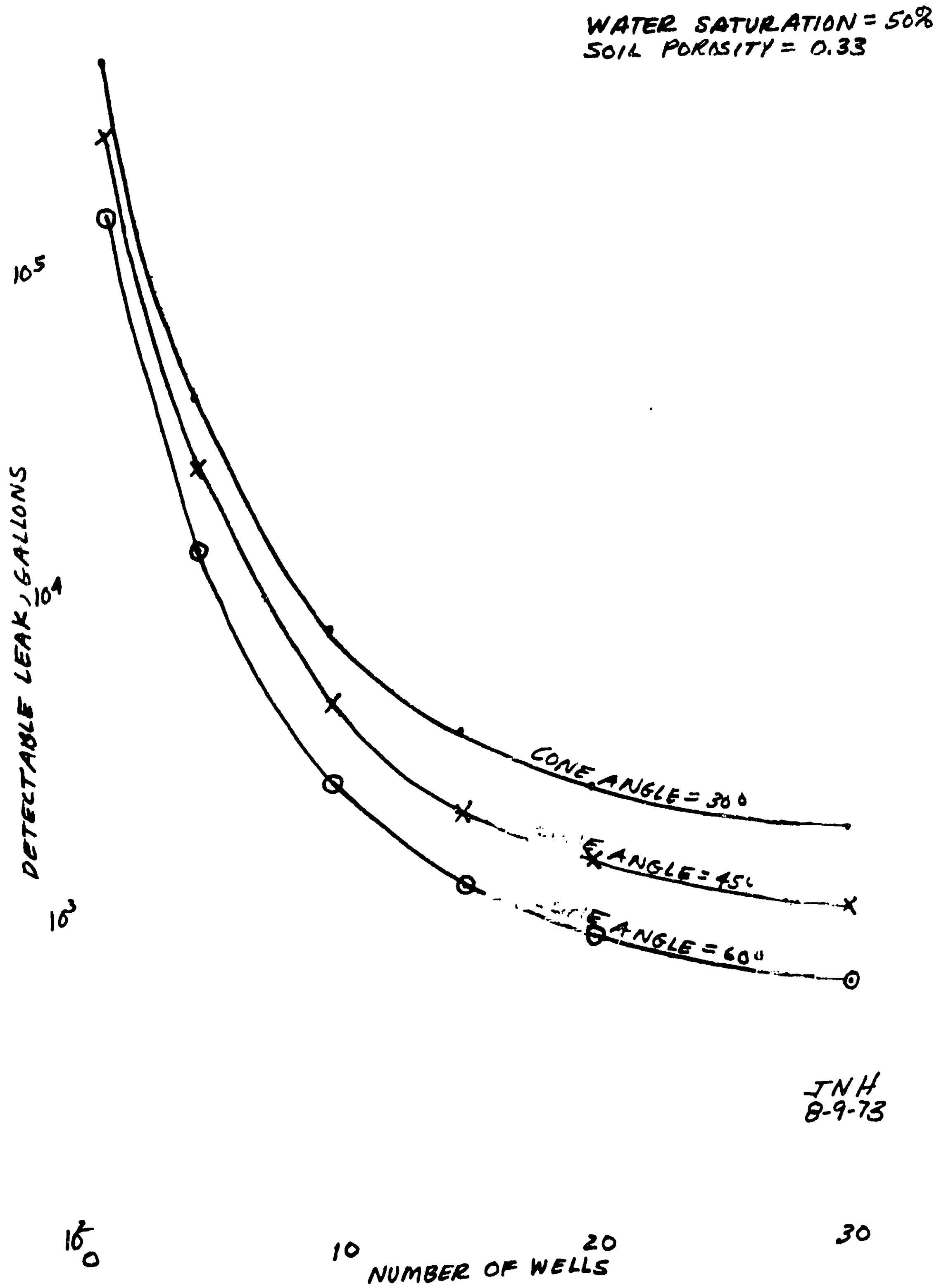


FIGURE 2b. Detectable Waste Volume By Drywell Monitors

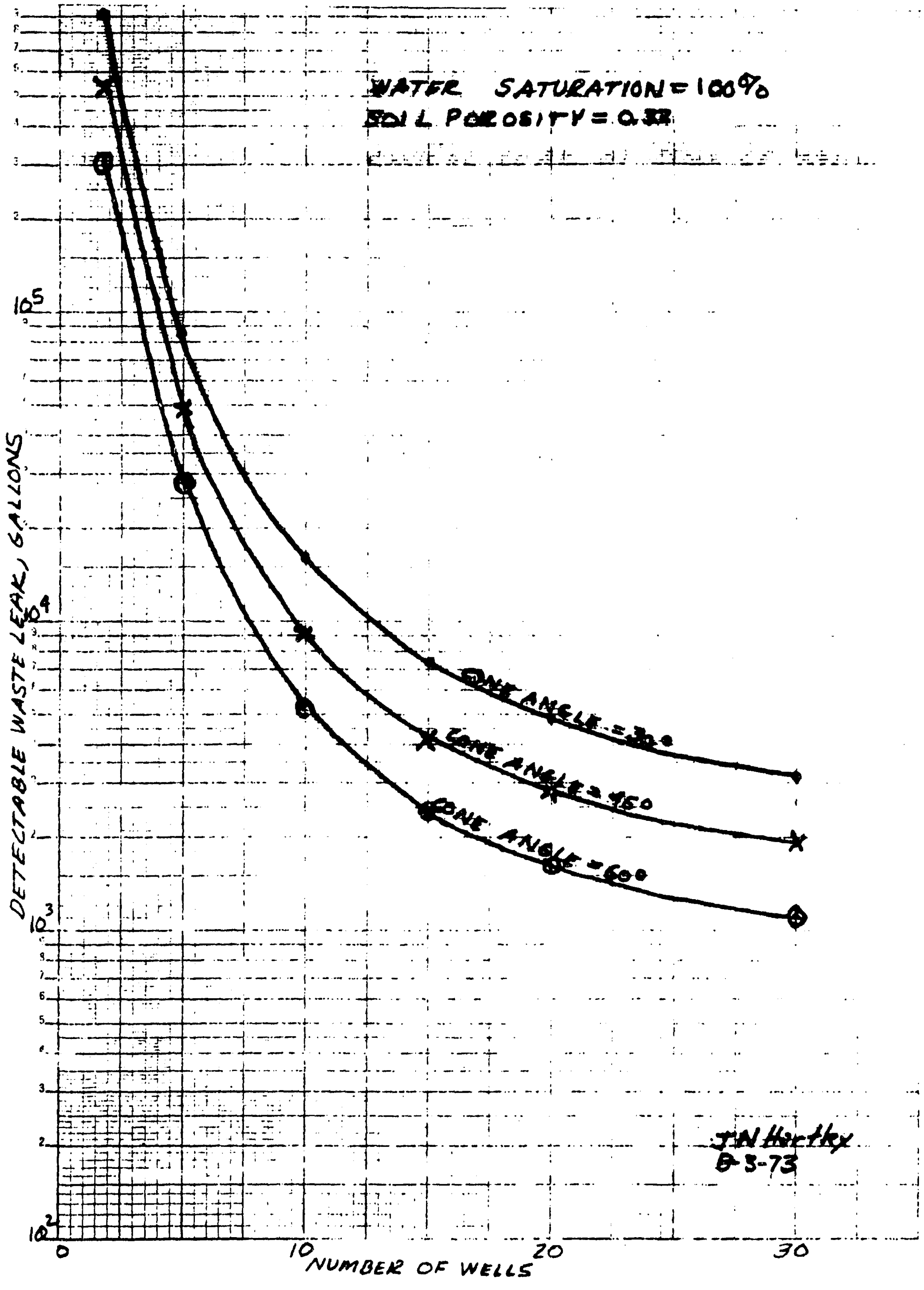


FIGURE 2c. Detectable Waste Volume By Drywell Monitors

if only two wells were present. The current tank farm dry well distribution, supplied by ARHCO, is given in Figures 3a, 3b, and 3c. The number of dry wells per tank ranges from zero for Tank 112T to nine for Tank 105A.

Increasing the number of dry wells rapidly reduces the size of the undetected leak by reducing the distance to the nearest dry well. For example, with 50% saturation the leak size with the three dry wells ranges from 56,000 to 167,000 gallons and with four dry wells it ranges from 26,000 to 78,000 gallons. Ten dry wells would detect 2600 to 7900 gallon leaks, while an infinite number of wells would detect 380 to 1150 gallon leaks. The presence of stratification in the microgeology would again reduce the maximum undetected leak size. It appears that four dry wells per tank might be a reasonable compromise between a poor detection capability and a large number of dry wells, but the cost of drilling a large number of wells and the unmanageability of a large well monitoring schedule would be important factors. The current drilling of dry wells should be accelerated to place 3 or 4 wells around each tank.

Effect of Monitoring Frequency on Leak Detection Capability

The current monitoring system logs the existing wells at a rate of generally once per month, or at most once per week. Drilling additional dry wells would put an additional load on the present system and increasing the monitoring frequency significantly would also load this system. The following analysis attempts to put the monitoring frequency into perspective.

The time for a leak to reach a dry well is given by:

$$\text{TIME FOR LEAK TO REACH WELL} = \frac{\text{VOLUME OF LEAK REACHING WELL}}{\text{LEAK RATE}}$$

The maximum time to detect a leak includes the monitoring interval:

$$\text{MAXIMUM TIME TO DETECT LEAK} = \text{MONITORING INTERVAL} + \text{TIME FOR LEAK TO REACH WELL}$$

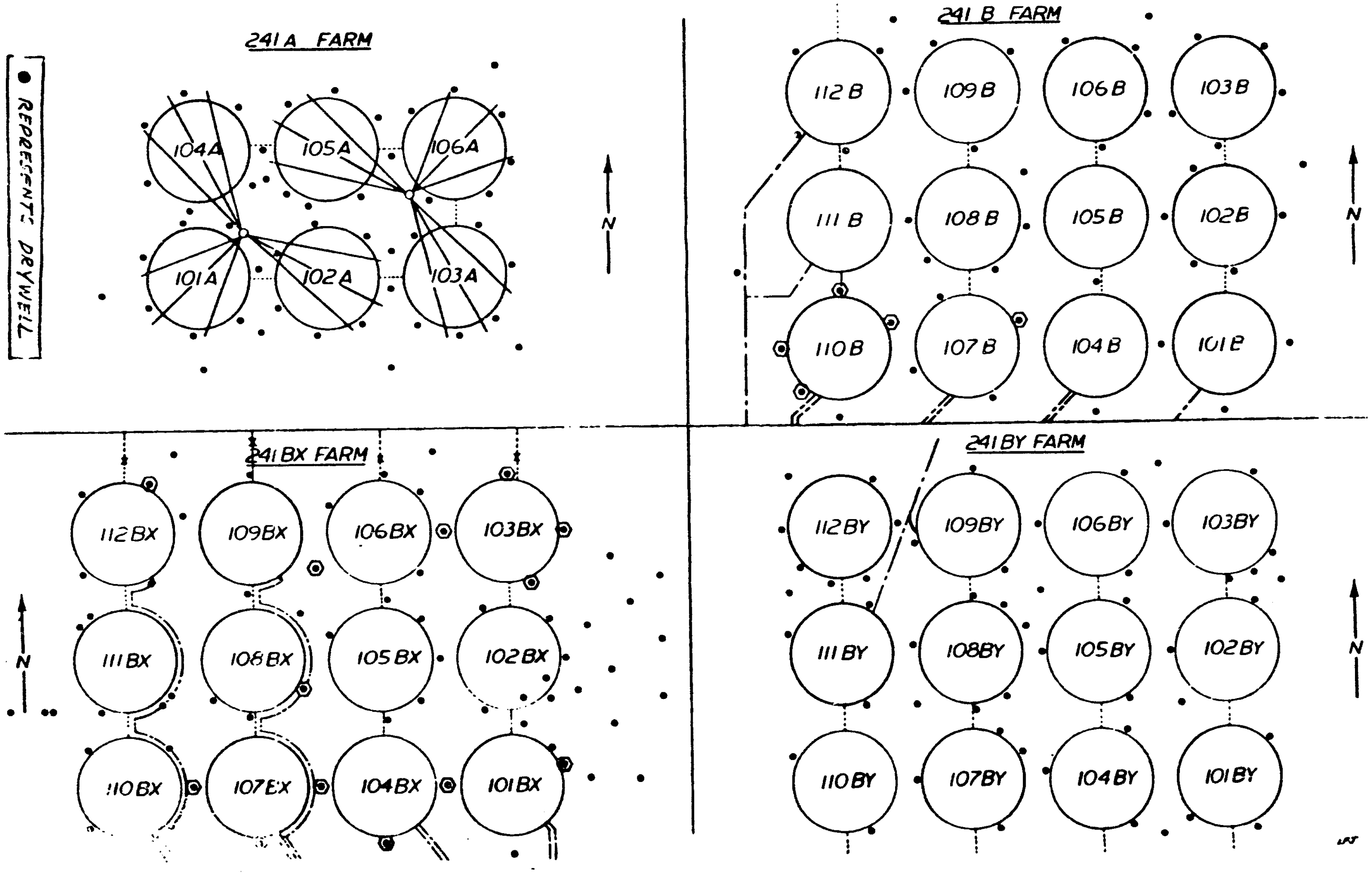


FIGURE 3a. ARHCO Waste Tank Layout

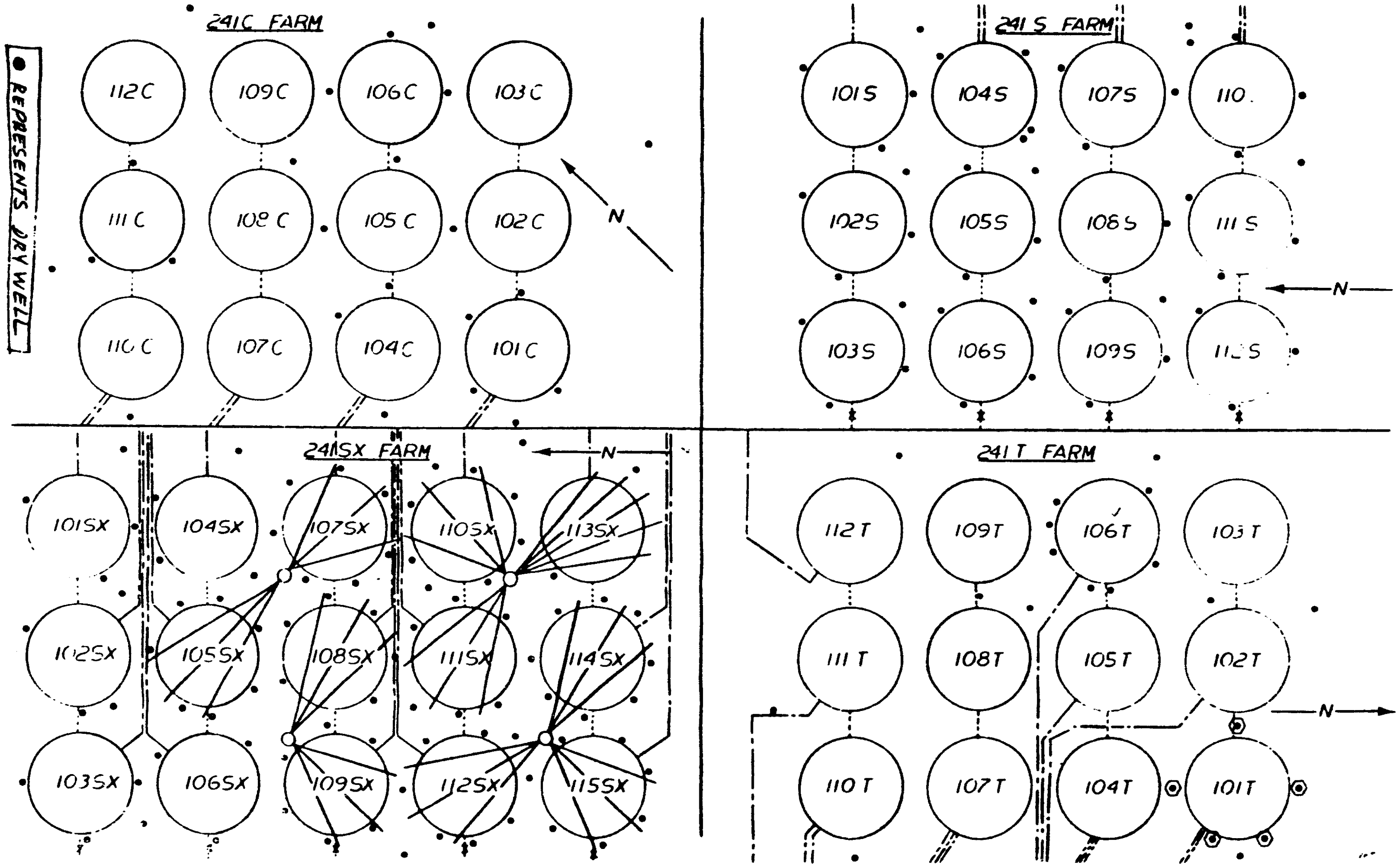


FIGURE 3b. ARHCO Waste Tank Layout

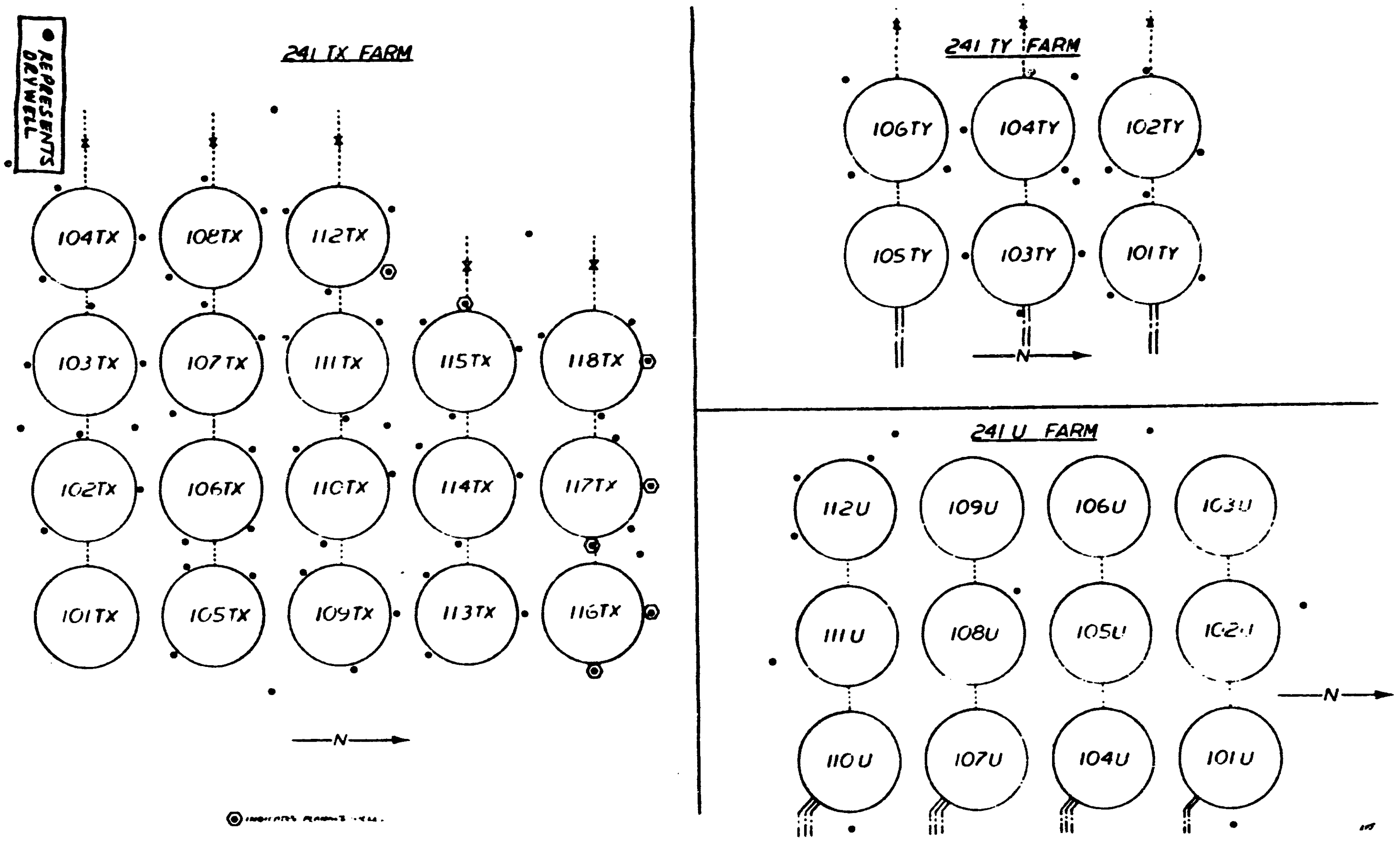


FIGURE 3c. ARHCO Waste Tank Layout

The volume of the leak at detection is then

MAXIMUM VOLUME OF LEAK AT DETECTION TIME = LEAK RATE * MONITORING INTERVAL +
DETECTABLE LEAK VOLUME

However the total volume of the leak by the time it is stopped is dependent on the sum of the travel time, the monitoring interval and the corrective response time.

MAXIMUM TIME TO STOP LEAK = MONITORING INTERVAL + TIME FOR LEAK TO REACH WELL +
TIME TO COMPLETE CORRECTIVE ACTION

MAXIMUM VOLUME OF LEAK = LEAK RATE * (MONITORING INTERVAL + TIME TO COMPLETE CORRECTIVE ACTION) + LEAK VOLUME AS IT REACHES WELL

Thus it does little good to reduce any one or two of these times if the third time factor remains large.

Response times to stop the leak are typically 12 hours to 3 or 4 days. With a leak rate of 1.6 gpm the incremental volume leaked during the response time is 1100 to 9200 gallons. A monitoring interval of one day (2300 gallons) or one shift (770 gallons) would seem acceptable. If the monitoring interval were reduced to once per day for 1000 wells, a total of 50 trucks would be required at the current duty of approximately 20 wells per truck per day!

Figure 4 shows the way in which the leak detection time for a leak at the edge of the tank varies with the monitoring frequency and the number of dry wells per tank for a cone angle of 45° and 50% saturation. As the number of dry wells per tank increases, short monitoring intervals become more important. For example, for 4 dry wells the maximum leak volume is 45,000 gallons with continuous monitoring. With once-per-week monitoring this is increased to 60,000 gallons. For 6 dry wells the maximum leak volume is 15,000 gallons with continuous monitoring and 30,000 gallons with once-per-week monitoring.

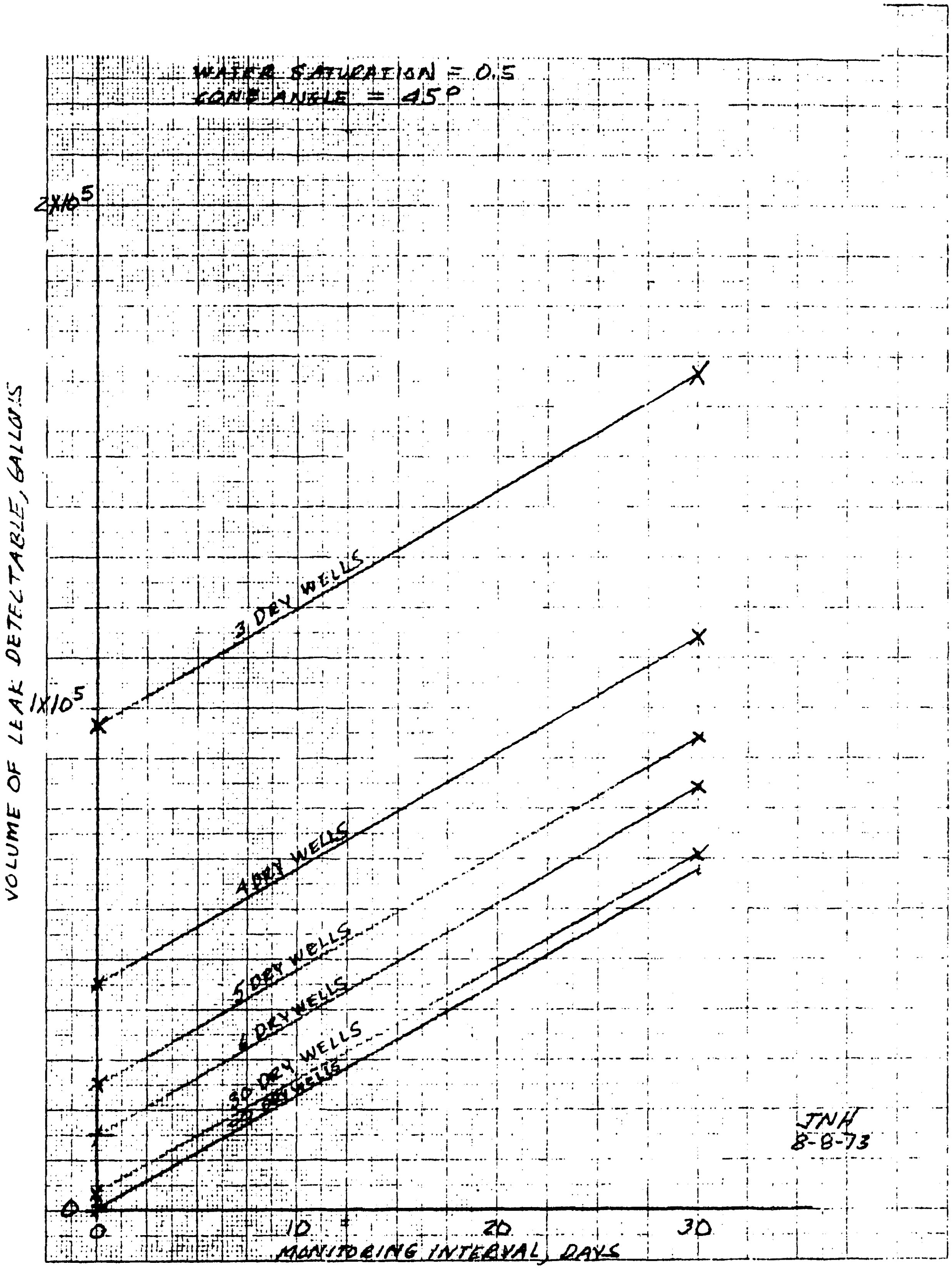


FIGURE 4. Drywell Monitoring Interval Requirement

Effect of Laterals on Leak Detection Capabilities

When leaks occur directly beneath a tank, dry wells may not detect them until the leaks are quite large. The use of laterals beneath the tanks has been proposed and shown to be feasible.(1)(2)(3) Laterals now exist beneath the A and SX tank farms and are monitored periodically. The size of conical leaks when they are detected by continuous monitoring is shown in Figures 5a, 5b and 5c (and in Appendix D) as a function of the depth of laterals below the tank. For example, laterals 10 feet below a tank could detect leaks with 50 percent saturation in the range of 410 to 3800 gallons.

The spacing between laterals is important because it is possible f conical leaks to pass between laterals and never be detected, no matter how large they become. (Dry wells are not expected to have this disadvantage so long as the leak continues to spread horizontally as it proceeds downward.) In Figure 6 the required spacing is shown as a function of lateral depth and cone angle. For example, a set of laterals 10 feet below a tank would have to have spacings less than 20 feet to detect the 1300 gallon leak for a 45° cone angle and 50% saturation.

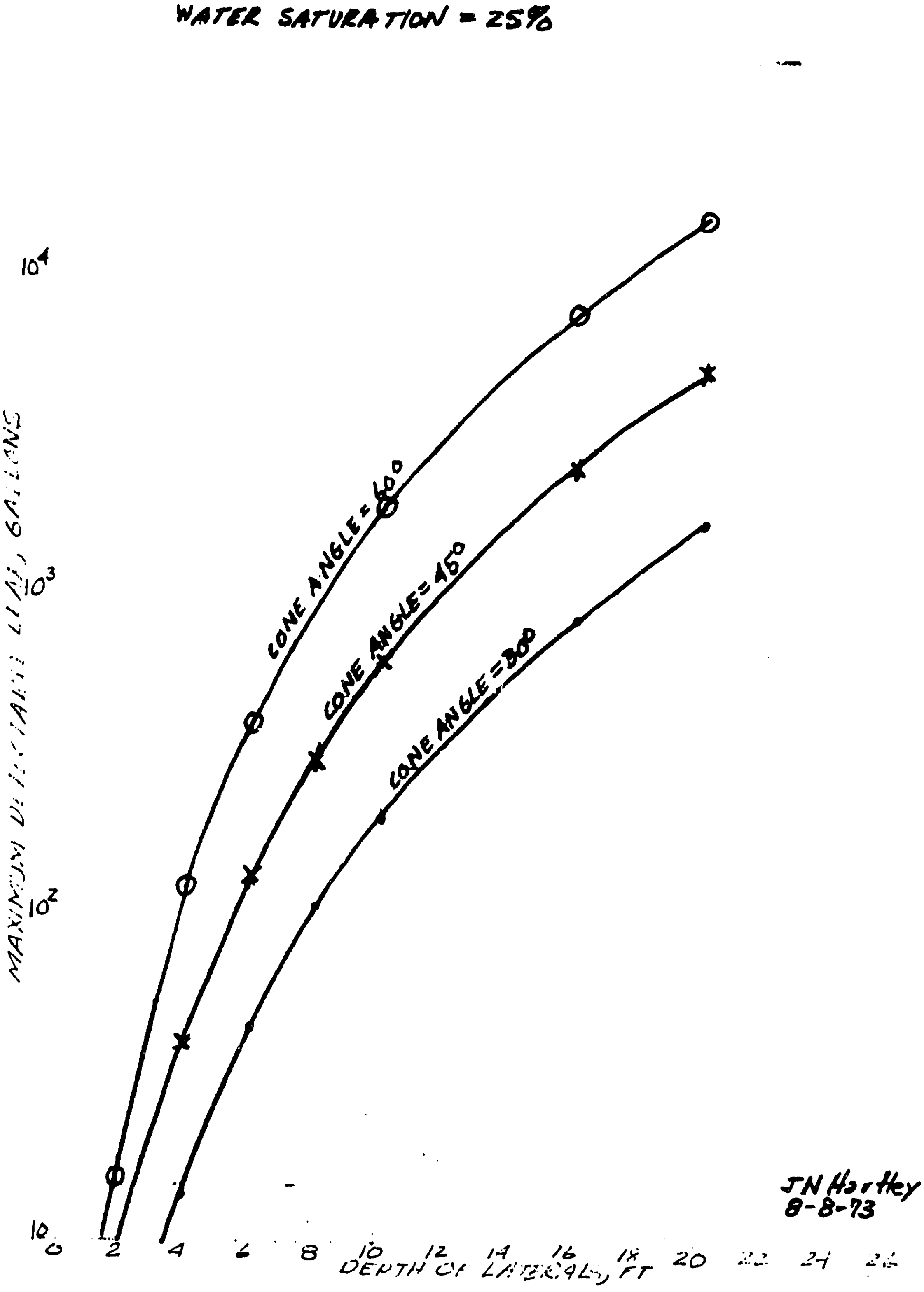
The laterals currently in place have been drilled as rays from a caisson so that they are not parallel. For example, the three-lateral systems beneath the A and SX tanks vary in spacing from about 13 to 38 feet, while the five-lateral system under Tank 113SX varies in spacing from about 7 to 11 feet for the segments directly beneath the tanks.

---

(1) H. W. Stivers, "Leak Detection System for Boiling, High Level Radioactive Waste Storage Tanks (Scope and Design Criteria", HW-57289, October 7, 1958.

(2) H. W. Stivers, "Leak Detection System for Active Tanks - Interim Report", HW-60749, June 16, 1959.

(3) W. A. Haney, "Leak Detection - Underground Storage Tanks", HW-51026, June 20, 1957.



JN Hartley
8-8-73

FIGURE 5a. Volume of Detectable Leak By Laterals

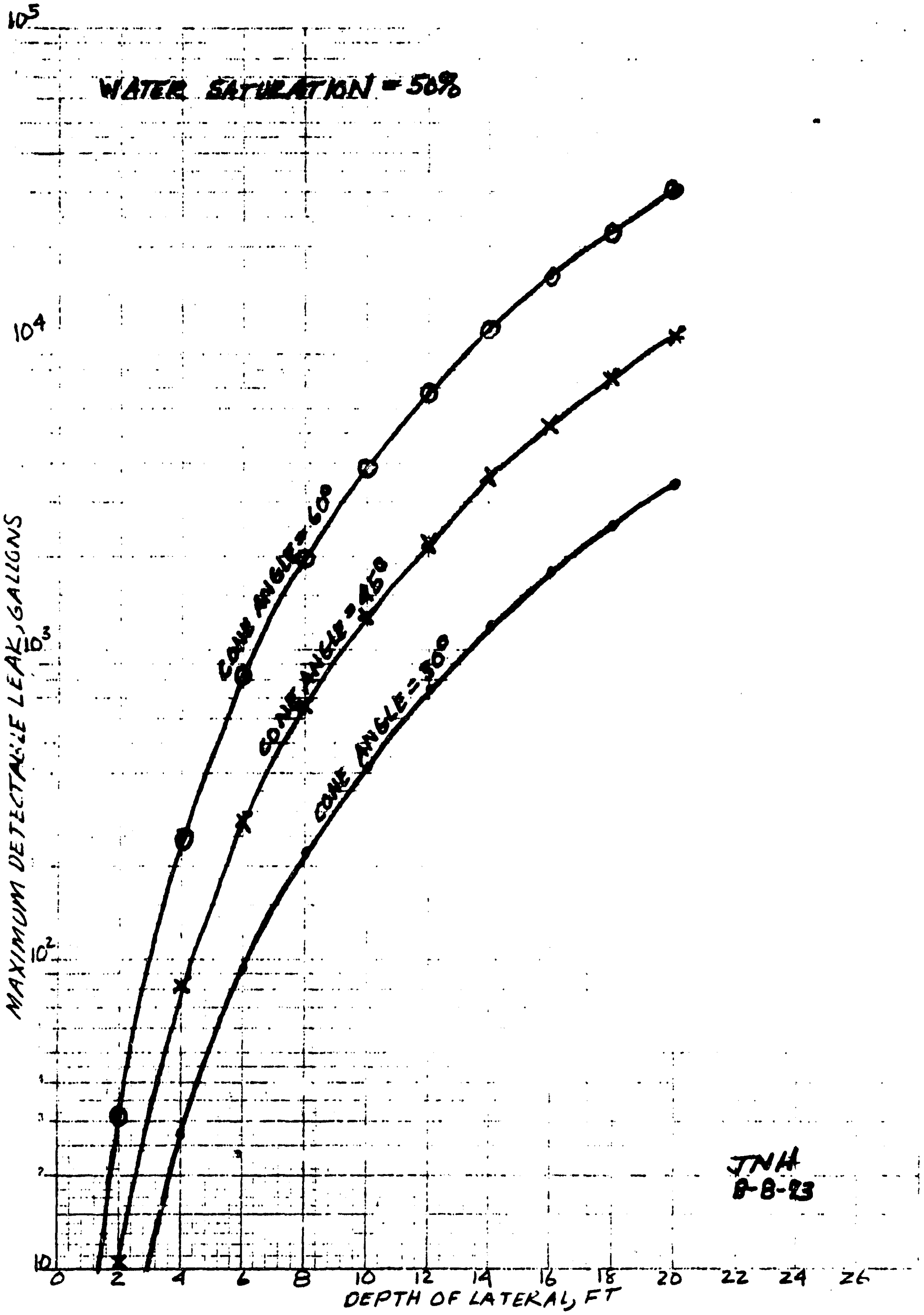


FIGURE 5b. Volume of Detectable Leak By Laterals

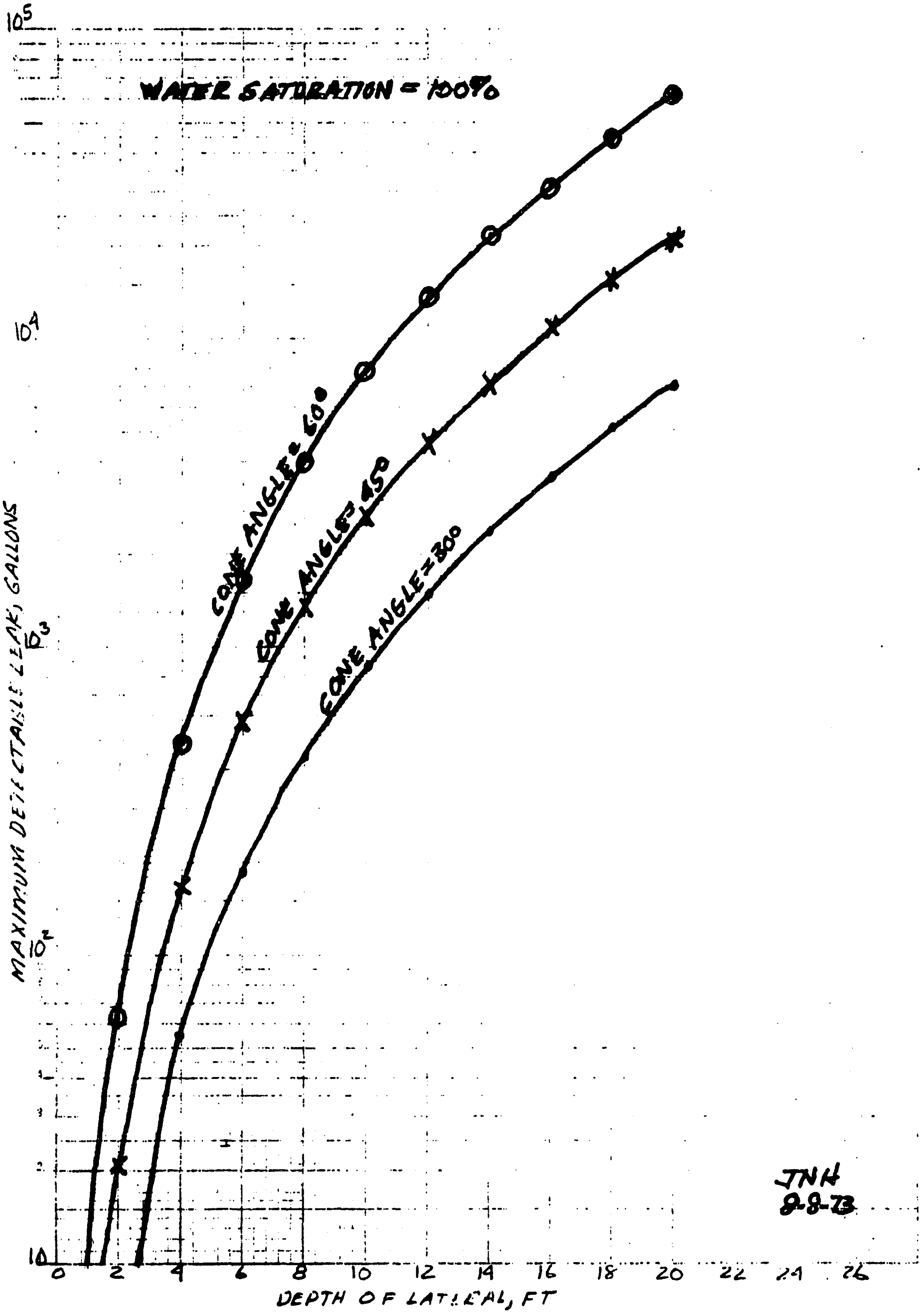
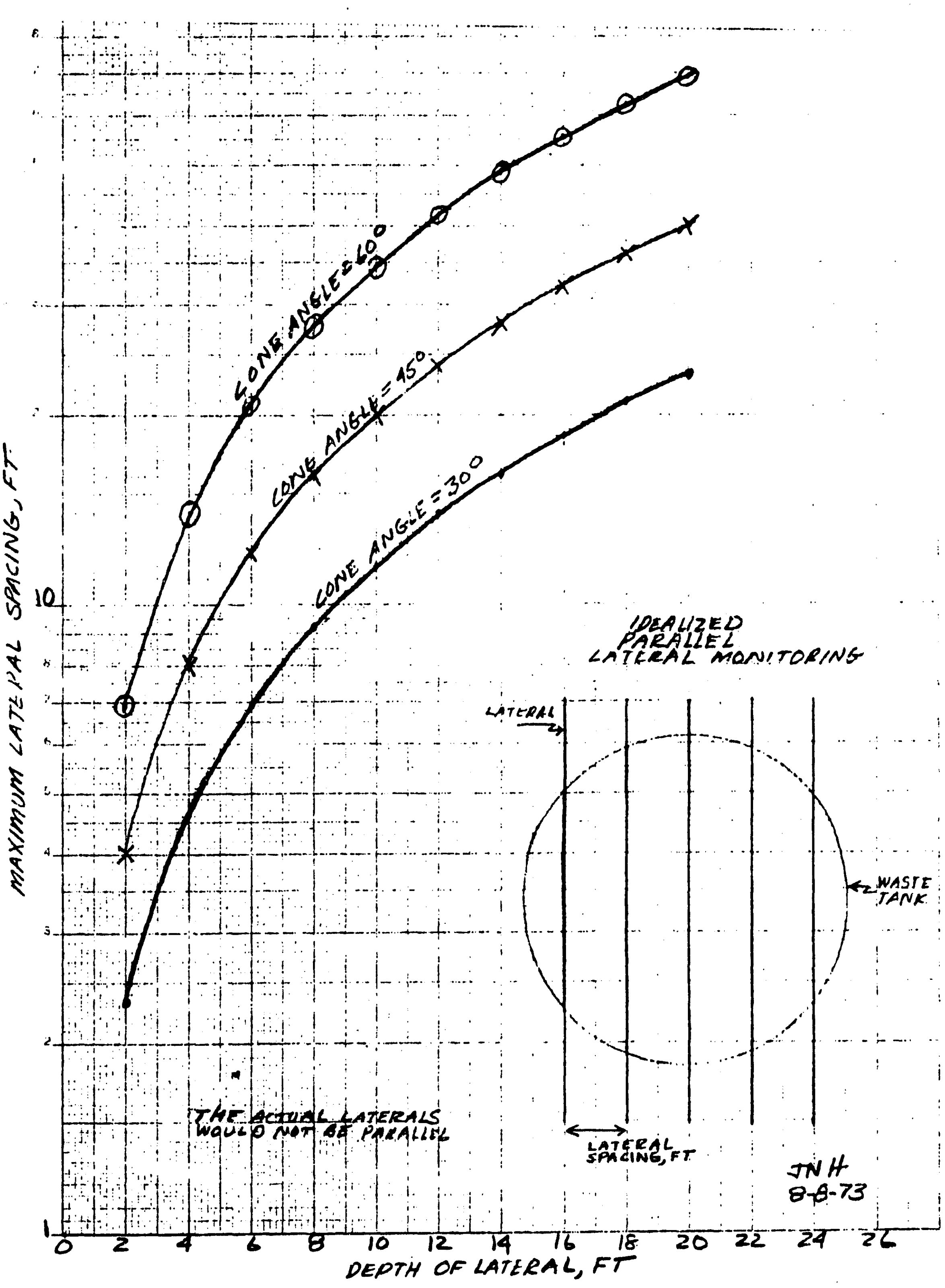


FIGURE 5c. Volume of Detectable Leak By Laterals



THE ACTUAL LATERALS WOULD NOT BE PARALLEL

JNH
8-8-73

FIGURE 6. Lateral Spacing Requirement

POSSIBLE SYSTEMS IMPROVEMENTS

The current dry well monitoring system consists of a scintillation probe, hoisting winch, analyzer and a paper punch or recorder. This equipment is housed in a carryall truck. When the well is to be monitored the truck is positioned next to a dry well and the operator lowers the probe to the bottom of the well. The probe is then raised from the well at a constant rate while measuring the radiation levels in the well. These levels are recorded on paper punch in the 200-East tank farm and on a strip chart in the 200-West tank farm. At the end of each day the data are delivered to the data analysis personnel for processing. The paper punch tape is sent to the UNIVAC 1108 in the Federal Building for processing and the computed results are returned to the data analysis personnel.

After reviewing the flow of data from the monitoring site to the decision makers it became apparent that several potential improvements could be made. These are discussed in the following paragraphs.

- Two independent and redundant paths for the flow of data from the monitor to data analysis would improve the reliability of the current dry well monitoring system. One of these paths could be a personnel-activated system such as a strip chart recorder, data logging book, etc., while the other system should be a nonpersonnel automatic system such as keypunch, computer analysis and storage of data. Reproducibility of the automatic system could be analyzed statistically. Currently its output is devalued because of system glitches and slow turn-around times up to 3 of 4 days. Current practice for the nonautomatic system does not provide total operator awareness of the data being recorded.

- The computer could be better utilized to analyze the data from the dry well. This could include comparison of data with baseline data indicating only where a change occurred. Also trends could be followed and analyzed and leak volumes could be estimated from simplified models. The current system takes the data provided on the paper punch and converts it to graphs of depth of well in feet versus radiation readings in counts per minute. Therefore, the computer is being used only as a strip chart recorder. Also data are printed out that show changes in radiation levels.
- Improved measuring techniques would allow for more reliable data. Well depth could be measured more accurately so that there is a better reference point for radiation measurements and data analysis.
- The paper tape could be checked at least once per day on a teletype to be sure that the paper punch is functioning correctly.
- Improved data analysis and data handling would greatly help in detecting leaks faster. The present system allows for too much time to pass before a leak can be detected. The operator monitoring dry wells could have baseline information on each tank so that he can observe and report immediately any changes that have occurred since his last monitoring. Where strip charts are used these could be reviewed after each day's monitoring. Improved data analysis could be done by the computer to show trends and changes.
- Improved equipment such as airconditioned trucks would help the operator make improved measurements. The instrumentation would function more reliably if it were kept at a reasonable temperature and kept free of dust and dirt.

ALTERNATIVES TO THE CURRENT DRY WELL MONITORING SYSTEM

The use of stationary monitors in the dry wells that would detect changes would considerably reduce the time that it takes to detect a leak. This monitor could be automated for telemetering and analysis by the computer with very short intervals between monitoring. As an example a radiation-sensitive tape or a string of small GM tubes electrically in parallel with a count rate meter at the wellhead could be permanently left in each dry well to measure the total radiation in the well but not the location of the activity. This could be monitored on demand by the ARHCO process control computer. Also it could be attached to an alarm system that would immediately make people aware of a radiation change in the well. At this time the regular dry well monitoring system could be used to quantitatively measure the levels that are present, and the location of the activity.

Development of such a sensor and system would require further research. It has been estimated that such a system might be developed and put in place (if an accelerated program is carried out) within about one year of the onset of the research. The general program could consist of (1) evaluating potential sensors and system and develop a conceptual design; (2) design, build and test prototype system; (3) develop full-scale system and test; (4) define specifications for the total system; and (5) install total permanent monitoring system in all dry wells.

Another alternative that could be further evaluated is the use of moisture monitors such as a neutron probe. It is generally believed that the water and nitrates present in the waste will progress ahead of the radionuclide thus permitting earlier detection of a leak. Also the volume of liquid in a leak could possibly be more accurately determined by measurements of the level of moisture in the leak.

The use of laterals as previously discussed in conjunction with dry wells provides for a more effective leak detection system. The dry wells probably cannot detect leaks from the bottom of the tanks until they are very large.

R&D PROGRAMS

The following paragraphs discuss potential R&D programs that could be considered to improve the detection of leaks, size of leak, shape of leak, and improve the accuracy of the present system.

- Soil Characterization - The current effort to better characterize the soil in the tank farms could be accelerated to provide more accurate data on the strata layers, thus a better model of the tank farms can be developed. The current dry well drilling effort by ARHCO R&D to characterize the strata beneath the tank farms in terms of type, location and particle size could be accelerated.

- Leak Models - Water permeability measurements could be made to correlate permeability with type of soil layers. This would permit use of BNW's water flow models to predict leak shape and motion. Enough hypothetical cases could be run to provide a background of understanding of leak mechanisms and characteristics.

- Sensor Evaluation and Calibration - The scintillation probe used for dry well monitoring could be calibrated in the idealized dry wells that have been set up in 200-East Area. The soil attenuation factors could be determined from this system and personnel could be trained there. The proposed GM tube for high-level readings could also be calibrated there. The neutron moisture monitor could also be adapted for routine use in dry well monitoring. This would allow early detection of leaks in which the moisture precedes the radioactivity and determinant of which leaks have dried up.

- <u>Background Information</u> - A data accumulation and display capability comparable to what now available within BNW for the hydrology of the Hanford water table could provide readily accessible background information against which to evaluate changes in radiation levels in dry wells. The monitoring data from laterals could be integrated with the dry well data.

- <u>Data Analysis</u> - A capability for data interpretation could be developed to go beyond just noting changes in readings. An individual in the operating component could be trained to do "quick and dirty" engineering analysis of the data and modeling based on the data that includes development of techniques using the full range of knowledge developed by ARHCO's R&D component about soil geology and BNW's knowledge of water hydrology.

REVIEW OF MATERIAL BALANCE TECHNIQUES (TASKS 2 and 3)

D. P. Granquist and J. A. Merrill

Tasks two and three are concerned with an evaluation of material balance accounting methods for the purpose of tank leak detection. The tasks can be briefly described as follows:

Task 2. To evaluate the accuracy (and precision) of material balance calculations for transfers from one tank to another tank. A necessary part of this task is to evaluate the precision of the two liquid level measurement devices and to estimate the size of leak that should be detectable when monitoring static tanks.

Task 3. To evaluate the capabilities of material balance techniques for the detection of leaks in evaporator-bottoms loop systems.

SUMMARY

Based on current state of knowledge about the height versus volume calibrations for the various tanks, the use of material balance type calculations to monitor tank transfers for small liquid losses using liquid level measurements does not appear to be very promising. From information gathered to date, a possible worst case type transfer between a clean tank and one with a large amount of salt cake is estimated to differ by a factor of 1.5 between the inches transferred and inches received. Of course, one case where the method should meet with reasonable success is when the two tanks involved are known to be clean tanks without salt cake formation on the walls. For such a situation and if FIC instruments are used on both tanks, then a one standard deviation uncertainty for a transfer might be expected to be within 3000 gallons. From this it can be seen that the magnitude of a loss that can be detected is very dependent upon the current state of knowledge concerning

the amount and location of salt buildup on the walls of each tank involved in transfers.

The detection of liquid losses from static tanks probably can be improved by continuous liquid level monitoring, development of more quantitative statistical criteria, and improvement of the FIC to avoid false readings from salt structures.

Based on the data examined for the 242-T System, it appears possible to form volume balances with a limit of error of from 10,000 to 20,000 gallons. Limits of error of this order of magnitude will require improvements in the accuracy of raw data measurements, especially liquid level measurements and estimates of salt buildup on tank walls. Greater attention to the accurate reading and transcription of data will minimize the occasional extraneous result.

In the short time available insufficient data were obtained to permit an assessment of the overall ITS System.

A Brief Outline of the Evaporator Systems

There are two operational evaporator-bottoms-loop systems. The primary objective of these systems is to convert the high-level waste solutions into a relatively immobile salt cake. Even though a tank containing a salt cake develops a "leak", the possibility of the contained radionuclides reaching the ground water table is much reduced from when the tank contained a liquid waste. A second benefit is that the concentration process reduces the volume of high-level wastes and thereby makes available additional storage space.

The first In-Tank Solidification (ITS) unit was installed in tank 101 of the BY Tank Farm in 200 East Area. In the present system there are two ITS units. Fresh feed and recycled supernate are pumped continuously to the ITS-2 unit located in tank 241-BY-112. The hot bottoms concentrate is then pumped batchwise through tank 241-BY-102, where the ITS-1 unit is now operated as a cooler, to the bottoms system. The bottoms system is a series of underground storage tanks and interconnecting pipelines that are used to transfer and cool the ITS bottoms concentrate, precipitate salt solids, and recycle supernate. The bottoms tanks are located in three tank farms, 241-B, 241-BX, and 241-BY.

The second evaporative system is now known as the 242-T evaporator facility. Fresh feed from outside the facility and recycled supernate from within the facility are fed to a steam-heated concentrator. The condensed overheads, when within radioactivity limits, are sent to crib and the concentrated bottoms are routed back to a system of about 10 bottoms tanks. Cooling in these storage tanks causes solids to drop out and the remaining supernate can be fed back to the feed stream for recycle.

Evaluation of the Existing Systems

Under Task 2, the first effort was devoted to determining the precision (or reproducibility) of the two liquid level measuring devices now in use.* The majority of the data used came from the T, TX, and TY tank farms and were collected during the last half of June and the first three weeks of July this year. The tanks were in an inactive status during most of the time period covered by the data and only data obtained when the tanks were on inactive status were used in this part of the study. The tanks all exhibited either no time trending or very minor time trending during those periods. The first observation is that

---

* The two liquid level measuring devices now in use are the tape and the FIC system. Technical discussions of these instrument systems are presented under the fourth task in this study.

the two liquid level measuring systems have different inherent variabilities. The standard deviations obtained for the tape system varied between 0.2 and 0.4 inches (or ± 2σ limits of ± .4 and ± .8 inches) and for the FIC system they varied between 0.05 and 0.25 inches (or ± 2σ limits of ± .1 and ± .5 inches). Also, the two systems not only have different precisions but for each type of device the precision appears to depend on the particular tank being measured. For self-boiling tanks, the standard deviations for the two instrument types may or may not be in the above ranges. However, more time will be required to analyze the time trend data from such tanks and to separate out the information about instrument precision.

Based on current state of knowledge about the height vs. volume calibrations for the various tanks, the use of material balance type calculations to monitor tank transfers for small liquid losses using liquid level measurements does not appear to be very promising. From information gathered to date, a possible worst case type transfer between a clean tank and one with a large amount of salt cake is estimated to differ by a factor of 1.5 between the inches transferred and inches received. Of course, one case where the method should meet with reasonable success is when the two tanks involved are known to be clean tanks without salt cake formation on the walls. For such a situation and if FIC instruments are used on both tanks, then a one standard deviation uncertainty for a transfer might be expected to be within 3000 gallons. From this it can be seen that the magnitude of a loss that can be detected is very dependent upon the amount of salt buildup on the walls of the tanks.

In some of the examined transfer data for "static" tanks, it was found that a second transfer was started before the first one had ended. This, of course, makes it impossible to perform a volume balance calculation from the tank liquid-level measurements which were recorded at shift change.

In the short time available, no attempt was made to perform a material balance on the ITS system. The necessary condensate records for use in such a balance were not located and it is our understanding that little, if any, psychrometric data exist that would permit the independent calculation of water vapor carried off from the tanks.

An examination of the liquid-level data for the tanks in the ITS system was not very helpful. In trying to evaluate the transfer of supernate between tanks by a comparison of liquid-level differences, it was almost impossible to find a transfer where a second transfer was not done during a part of the time period of the first transfer, i.e., most tanks are pumped into and out of at the same time. In addition an unknown amount of flush water was often added as part of the transferred volume. In summary, it does not seem possible to construct meaningful volume balances (in reference to leaks) for the ITS system with the present data collection system.

Several very preliminary monthly volume balances were tried for the 242-T Evaporation Facility. And while these approximate balances are, on the average, good in terms of the total flow (on the order of 2%), they would not seem to be entirely satisfactory for leak detection purposes at this stage of refinement. Shown in the table below are the results of our approximate volume balances. The numbers are arranged as in a material balance and the material unaccounted for (MUF, in gallons) was calculated using:

$$\text{MUF} = I_{\text{Start}} + \text{Receipts} - I_{\text{end}} - P_{\text{roduct}}$$

where

I_{start} = inventory, gallons, start of time period

I_{end} = inventory, gallons, end of time period.

TABLE I

APPROXIMATE MONTHLY VOLUME BALANCES

242-T Evaporator System
(All Volumes in Gallons)

Date	Beginning Inv.	Flush Water Added	New Feed from TK-101	Condensate Product	Ending Inventory	MUF
May 72	7,084,648	98,342	258,500	354,172	7,083,086	+ 4,232
June 72	7,083,086	97,683	265,375	329,114	7,097,041	+19,989
July 72	7,097,041	100,866	227,562	302,158	7,090,845	+32,466
Aug 72	7,090,845	130,598	250,250	350,280	7,116,319	+ 5,094
Sept 72	7,116,319	118,340	287,375 (225,827)*	350,280	7,350,409	+47,172
Oct 72	7,350,409	105,686	437,250	365,848	7,556,958	-29,461
Nov 72	7,556,958	123,621	294,250	358,064	7,598,268	+18,497
Dec 72	7,598,268	112,957	316,250	358,064	7,645,086	+24,325

[*] Tank 103 TX was brought into the system with about 6 feet 10 inches of material:

In this formalism, a positive MUF means that some material is lost (unaccounted for) from the process. In our application a positive MUF (volume balance) could indicate a leak from the system. A negative volume balance indicates an unmeasured addition to the system such as a leak of condenser cooling water into the condensate or additional feed batches which were not included.

The absolute values of the indicated MUF should not be taken too seriously, since several corrections to the data would be required to obtain an "accurate" number. No attempt was made to correct for water lost from the bottoms tanks by evaporation, for volume changes due to temperature changes, or for partial molal volume changes resulting from mixing dilute and concentrated solutions.

In Table I, primary concern is with the variability of the MUF values on a month-to-month basis. Generally, it is believed that the system can be treated as being at a pseudo-equilibrium state so that the MUF values would be expected to be relatively constant, barring errors or missing data. The standard deviation for the MUF values in Table I (excluding the high value where a tank was added to the system) is 20,400 gallons. If the negative MUF value of -29,461 is also excluded, the standard deviation of the remaining MUF values is 11,050 gallons. Considering the probable errors in the raw data and our broad-brush treatment of it, this is a good result. It offers some promise that leaks could be detected in this sytem using better data and a more precise material balance approach.

POSSIBLE SYSTEMS IMPROVEMENTS

The problem of detecting leaks by loss of volume can be divided into the three following cases:

I. Detection of liquid losses from static tanks.

II. Detection of losses from uncased pipes in tank-to-tank transfers.

III. Detection of liquid losses from systems operated with continuously changing volumes.

The detection of liquid losses from static tanks probably can be improved by continuous liquid level monitoring, development of more quantitative statistical criteria, and improvement of the FIC to avoid false readings from salt structures. These points are expanded on somewhat below:

(1) A digital printout (say once an hour) of the time and the liquid level measurement would go a long way toward eliminating data recording and data transposition errors. In combination with a simple computer program, an alarm system could be developed that would signal a malfunction in the system. FIC-quality instruments should be installed on each in-service tank. Also, the inclusion of a redundant or backup liquid level measurement system on each tank containing liquids would provide assurance that the primary measurement system is operational.

(2) The establishment of a group whose primary responsibility is the timely examination of all liquid level data and the analysis of such data. This group would establish warning and action limits within which each new measurement should fall. In addition to standard statistical methods of data analysis, the group will need to have capabilities for evaluating time trends in data, for forecasting levels at future times, and for the early detection of departures from the historical trend.

(3) The incorporation of additional equipment and/or procedures into the liquid level measuring systems to assure that the measuring instrument probes are actually contacting the liquid volume surface. To provide part of this assurance, it would appear worthwhile to obtain photographs of all tanks showing the liquid level probes in position. Photographs showing the liquid level probe

in contact with a "clean" liquid surface provide assurance that the liquid level measurements are reliable. Photographs showing the probe in contact with salt cakes will indicate where difficulties are to be expected when making liquid level measurements.

The second case for detecting losses during tank-to-tank transfers requires volume balances for each batch transfer. For the ideal situation, liquid level differences for the two tanks can be compared directly. However, for situations where the change in liquid levels cannot easily be related to volumes, considerable historical transfer data must be analyzed and transfer experiments may need to be performed to obtain reasonable relationships to convert liquid level to equivalent volume. In addition to the examination of historical data to obtain tank calibration information, the following new information would be desirable:

(1) Whenever flushes or other additions of water to a tank are made, the volumes of all such additions should be precisely measured and recorded along with the relevant before and after FIC liquid level measurements.

(2) Data should be taken from specially planned transfers from a known clean tank where special care is taken to obtain a large number of liquid level measurements from both tanks by stopping the pumping a number of times during the transfer.

The final case of detecting liquid loss from a dynamic system where continuous flow is the normal operating mode is the most difficult to treat.

To achieve the best sensitivity using material balance techniques would require a more formalized approach in terms of (1) revised SOPs which would not permit (within limits imposed by operational considerations) simultaneous transfers into and out of tanks, (2) comprehensive data collection procedures which provide all of the required data in one set of records, (3) measurement of all volumes and, (4) the development of corrections for such things as vapor losses and mixing nonlinearities. Additional instrumentation on the dynamic section of the system would supply helpful redundant information. As an example, specific gravity and flow measurements of feed to an evaporator (242-T) coupled with the specific gravity of the evaporator bottoms would provide the basis for an independent estimate of the split into condensate and bottoms.

With an improved data collection system, attempts should be made to form volume balances over shorter time periods. As the time period is shortened, it becomes increasingly important to measure the liquid-level in all dynamic tanks at the same time. As an example, the condensate catch tank will likely be only partially filled when it is required to determine its liquid level. In some cases, it may be possible to isolate a bottoms tank for a day or two by not adding or pumping out supernate. Such temporary isolation of different tanks from the dynamic system will provide information for the detection of leaks and should help to pin-point the location of a leak in the system. The detection of a possible leak in such an "isolated" tank would then be attempted by liquid level measurements as in the "static" tank case.

If it is not possible to form a volume balance within the limits required for leak detection, it may be necessary to shut the system down for short periods such as on Saturday and Sunday. While the system is in a static condition, liquid level measurements would be made. The evaluation of such data would indicate possible leakage from what are now static tanks.

FURTHER STUDIES RELATED TO MATERIAL BALANCE TECHNIQUES AS A METHOD OF DETERMINING LIQUID LOSSES

In addition to the suggested improvements in the waste system as described in the preceding section, Battelle-Northwest is capable of providing assistance in the following areas:

1. Develop statistically based criteria for detecting leaks from "static" tanks using liquid level measurements.
2. Develop from plant data and possible experimental data the relationships between liquid level and tank volume to establish criteria for detecting losses in tank transfers.
3. Develop material balance procedures, with the associated limits of error, and the necessary correction factors (vapor loss, mixing volume, changes, volume-temperature factors, etc.) for detecting liquid loss from dynamic waste systems. Assist in the application of such techniques to more fully establish the sensitivity of material balance techniques to such waste systems.

The manpower requirements for these studies is as yet quite tentative but it is estimated that 3 to 5 man-months of effort would be needed to complete them. Three to five man-months of effort would cost from 15 to 25 thousand dollars.

REVIEW OF WASTE TANK FARM LIQUID LEVEL MEASURING SYSTEMS (TASK 4)

R. D. Dierks, O. H. Koski and C. A. Ratcliffe

Task 4 is limited to an evaluation of the general operability of instrument systems that are being used to indicate the position of liquid levels within these storage tanks, and to modifications to these instruments, or new instrument systems that might provide improved operational characteristics, or avoid the problems of foams, crusts, or floating solids that might exist on the surface of these contained liquid wastes.

This task is based on information gathered during four days of observations of installed instrument systems, and discussions with ARHCO personnel associated with waste management and waste tank liquid level measuring systems.

Summary

The FIC liquid level instrument is an excellent system, offering many advantages over previous measuring devices. Bench top accuracy and repeatability to a liquid surface is ±0.01 inch; however, in-tank accuracy is unmeasurable and is compromised by temperature changes, foam layers, and surface crusting. In-tank repeatability appears to be about ±0.25 inches.

The hand-winched system has many advantages even though it is subject to parallax, operator bias and transcription errors. Being operator controlled, continuity indications can be discounted when the contact does not "feel" right, and crusts can be smashed through to get at the true liquid level. In-tank repeatabilities appear to be ± 1/2 inch.

There are several changes which could be made to the electronic and sensor portions of these systems that could improve their overall sensitivity and reliability. These are expanded on below.

Existing Systems Description

Electrical continuity-type instrument systems are used to sense the location of the air/aqueous interface in each of the 200 Area underground waste storage tanks. Three types of continuity instruments are employed: 1) the almost completely automatic FIC (Food Instrument Company) instrument; 2) a manually operated, winched steel tape system; and 3) a hand-held, "lamp cord" system.

The FIC instrument consists of a conically tipped stainless steel plummet, suspended through a tank roof nozzle to the surface of the liquid at the end of a stainless steel tape. The tape is wound on a motor-driven drum that raises and lowers the plummet at a rate of about 7-1/2 inches per minute. The tape is precision perforated at one-inch intervals and passes over a spoked sprocket wheel, which drives a mechanical turns counter, equipped with both a visual, digital readout for local observation, and an electronic encoder for remote data acquisition. The normal position of the instrument is with the tape drum braked and the tip of the plummet immersed in the liquid, establishing an electrical continuity between the insulated tape drum and the tank nozzle. At any moment that the electrical continuity is broken, as by a decrease in the liquid level, the plummet is dropped slowly until continuity is again established, at which time the tape drum is again braked. Rising liquid levels do not activate the instrument; however, periodically (about once per minute) the plummet is raised until continuity is broken, at which time the plummet is again allowed to slowly drop until continuity is reestablished. At a minimum frequency of once per year, or upon request, a "reference" or "zero" check of the instrument is effected by raising the plummet completely out of the tank and up into a glass section between tank top and the instrument housing. The tip of the plummet is aligned with marks scribed on the glass section, and the turns counter indication compared with a value previously established as being the distance in inches from the scribe marks to the bottom of the tank. Built-in sprays permit the plummet and tape to be flushed of deposits as the tape is withdrawn from the tank.

Seventy-four FIC instruments are currently installed in the following tanks:

	West						East			
	S	SX	U	TX	TY	T	B	BX	BY	C
101	X	X		X	X	X	X	X		
102	X	X	X		X	X	X			X
103	X	X	X	X	X	X	X	X		X
104		X		X	X			X		X
105	X	X	X			X				X
106	X	X	X			X	X			X
107	X		X	X		X		X		X
108	X		X	X		X	X	X		X
109	X		X	X		X	X	X	X	X
110	X		X			X				X
111	X		X			X	X			
112	X					X	X	X		X
113										
114										
115										
116										
117										
118				X						

The hand winched system consists of a standard steel measuring tape, marked off in feet, inches, and eighths of an inch, which is attached to a pointed plummet and lowered into the tank through a roof nozzle. The tape is insulated from the tank and a portable, battery-operated continuity checker, operated between the tape and the roof nozzle, indicates when continuity has been established between the plummet and the tank contents. A visual reading of the tape at a reference point on the winch when continuity is intermittent is indicative of the distance from the reference point to the top of the tank contents, and infers the depth of liquid in the tank.

The hand-held, "lamp cord" system consists of a length of insulated wire, fitted with a pointed plummet and lowered into the tank through a roof nozzle. A portable, battery-operated continuity checker, operated between the wire and the roof nozzle, indicates when continuity has been established between the plummet and the tank contents. Before its insertion into the tank a zero mark is attached to the wire at a point known to be equal to the distance from the roof nozzle to the bottom of the tank. Several additional marks are positioned at one-foot intervals from the zero mark toward the plummet. The depth of liquid within the tank is determined by establishing the point of intermittent continuity and reading the marks on the wire. Interpolation between marks is accomplished with a ruler. Tanks not equipped with automatic FIC instrument systems utilize the hand winched, tape system; the hand-held, "lamp cord" system; or are not being used as liquid waste storage tanks.

System Evaluation

The FIC liquid level instrument is an excellent system, offering many advantages over previous measuring devices. Bench top accuracy and repeatability to a liquid surface is ±0.01 inch; however, in-tank accuracy is unmeasurable and is compromised by temperature changes, foam layers, and surface crusting. In-tank repeatability appears to be about ±0.25 inches.

The hand-winched system has many advantages even though it is subject to parallax, operator bias and transcription errors. Being operator controlled, continuity indications can be discounted when the contact does not "feel" right, and crusts can be smashed through to get at the true liquid level. In-tank repeatabilities appear to be ± 1/2 inch.

The hand-held "lamp cord" system has many disadvantages and few, if any, real advantages. The repeatability appears to be about ± 1/2 inch, and while the accuracy is unmeasurable, the accuracy is probably compromised by inaccuracies in establishing the calibration marks on the wire and stretching of the wire with use.

Possible Systems Improvements

The following are suggested as improvements to the existing instrument systems. They are presented in a random manner, and no sequence with respect to importance, cost or ease of implementation is implied.

A. FIC instrument

1. Redesign the electronics to utilize today's modular, vice discrete component, techniques to minimize maintenance.
2. Redesign the electronics to tolerate -20 to +150 F temperatures; some component failure due to temperature extremes have already been noted.
3. Redesign the electronics layout to utilize plug-in modular circuit boards to facilitate field maintenance. Field maintenance on the presently designed data transmission electronics is going to be extremely difficult.
4. Add a tensiometer to the tape to sense the decrease in tape tension when the plummet makes contact with a salt cake without making electrical continuity. Modify the electronics to shut the instrument off when this occurs, and in addition turn on a "malfunction light" at the instrument and set an "all 1-s" malfunction signal on the data encoder.

5. Lower the liquid level and photograph the plummet in its low position when a no-continuity, solids contact is realized.
6. Optimize the location of the instrument to avoid contact with the salt cake that grows out from the tank walls. Photograph the inside of the tank periodically to validate the sensor location.
7. Adjust the conductance trip value to minimize foam incurred bias.
8. Install a redundant mechanical turns counter and remote data encoder, or a back-up instrument system to pick up any failures of the mechanical turns counter system, i.e. broken drive chain, loosened gear to shaft connection, broken decade drive spur on turns counter, etc.
9. Notch one edge of the tape sprocket wheel and with a tooth counter electronically follow the movement of the tape over the sprocket, thus eliminating mechanical failure problems.

B. Hand-Winched Tape

1. Raise winch to approximately eye level to minimize parallax and operator error.
2. Provide operator positioned electronic encoding thumb wheels at each winch to enable tape readings to be computer scanned.
3. Provide tapes marked in inches and 1/10ths of inches and install inverted to indicate liquid depth directly as with the FIC system.
4. Design a portable, battery-operated, continuity meter that would slip into a holder that would position the meter adjacent to the tape reference point, so the meter and tape

could be viewed simultaneously. In addition, design the meter and holder such that by inserting the meter into the holder the meter would automatically be connected to the tank and the tape lead wires. If operator-positioned thumb wheel data encoders are also designed as part of the meter holder, the time required to make the measurement and transcribe the data could be significantly reduced.

Alternative Systems

The spectrum of physical phenomenon that have been explored by instrument designers as means to detect the position of an air/liquid interface within a storage tank is extremely broad, and many have been satisfactory for a wide variety of applications.

An evaluation of the host of instrument systems available to identify specific systems that will provide "improved" liquid level measurements over the existing FIC instrument was not realized, primarily because the required performance criteria of an acceptable instrument system was not clearly established. However, systems based on time domain reflectometry or radio frequency radiation absorptometry appear to be capable of matching the range and accuracy of the FIC instrument, may possibly be insensitive to salt incrustations - or at least salt cake and liquids may be distinguishable, and may have an additional advantage in that a multiplicity of inexpensive sensors possibly can be "read" sequentially by a single, switched, read-out instrument

APPENDIX A

EFFECT OF LEAK LOCATION AND SHAPE ON DRY WELL DETECTION CAPABILITIES

```
DRYDE2      08:39      08/01/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO     CONE          CONE        BASE          WATER       LIQUID
 LEAK      ANGLE         HEIGHT      WIDTH       SATURATION     VOLUME
  FT        DEG            FT          FT          FRAC.         GAL

       DRYWELL ADJACENT TO LEAK AT EDGE OF TANK
  8.000      30.00        13.86       8.000          .25          575
  8.000      30.00        13.86       8.000          .50         1149
  8.000      30.00        13.86       8.000         1.00         2298

  8.000      45.00         8.00       8.000          .25          332
  8.000      45.00         8.00       8.000          .50          664
  8.000      45.00         8.00       8.000         1.00         1327

  8.000      60.00         4.62       8.000          .25          192
  8.000      60.00         4.62       8.000          .50          383
  8.000      60.00         4.62       8.000         1.00          766


       LEAK AT EDGE OF TANK BETWEEN TWO WELLS OF FOUR
 32.611      30.00        56.48      32.611          .25        38923
 32.611      30.00 @      56.48      32.611          .50        77847
 32.611      30.00        56.48      32.611         1.00       155693

 32.611      45.00        32.61      32.611          .25        22472
 32.611      45.00        32.61      32.611          .50        44945
 32.611      45.00        32.61      32.611         1.00        89889

 32.611      60.00        18.83      32.611          .25        12974
 32.611      60.00        18.83      32.611          .50        25949
 32.611      60.00        18.83      32.611         1.00        51898


       LEAK AT CENTER OF TANK
 45.000      30.00        77.94      45.000          .25       102269
 45.000      30.00        77.94      45.000          .50       204537
 45.000      30.00        77.94      45.000         1.00       409074

 45.000      45.00        45.00      45.000          .25        59045
 45.000      45.00        45.00      45.000          .50       118090
 45.000      45.00        45.00      45.000         1.00       236179

 45.000      60.00        25.98      45.000          .25        34090
 45.000      60.00        25.98      45.000          .50        68179
 45.000      60.00        25.98      45.000         1.00       136358

NOW AT END

08:42   RAN 0 MINS  0.24 SECS
```

```
DRYDE2      10:46      08/01/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO     CONE           CONE         BASE          WATER        LIQUID
 LEAK       ANGLE          HEIGHT       WIDTH      SATURATION      VOLUME
 FT          DEG            FT           FT           FRAC.          GAL

      LEAK AT EDGE OF TANK ON OPPOSITE SIDE FROM A SINGLE WELL
 83.000        30.00        143.76       83.000          .25       641710
 83.000        30.00        143.76       83.000          .50      1283420
 83.000        30.00        143.76       83.000         1.00      2566839

 83.000        45.00         83.00       83.000          .25       370491
 83.000        45.00         83.00       83.000          .50       740983
 83.000        45.00         83.00       83.000         1.00      1481965

 83.000        60.00         47.92       83.000          .25       213903
 83.000        60.00         47.92       83.000          .50       427807
 83.000        60.00         47.92       83.000         1.00       855613


    @ LEAK AT
ATTENTION
NOW AT 550
READY
```

```
DRYDE2      10:20      08/01/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO     CONE           CONE        BASE         WATER        LIQUID
 LEAK       ANGLE         HEIGHT       WIDTH      SATURATION     VOLUME
 FT          DEG            FT          FT           FRAC.         GAL

      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF TWO
 58.962      30.00        102.12      58.962         .25       230048
 58.962      30.00        102.12      58.962         .50       460095
 58.962      30.00        102.12      58.962        1.00       920191

 58.962      45.00         58.96      58.962         .25       132818
 58.962      45.00         58.96      58.962         .50       265636
 58.962      45.00         58.96      58.962        1.00       531272

 58.962      60.00         34.04      58.962         .25        76683
 58.962      60.00         34.04      58.962         .50       153365
 58.962      60.00         3  .04     58.962        1.00       306730


      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF THREE
 42.074      30.00         72.87      42.074         .25        83590
 42.074      30.00         72.87      42.074         .50       167181
 42.074      30.00         72.87      42.074        1.00       334362

 42.074      45.00         42.07      42.074         .25        48261
 42.074      45.00         42.07      42.074         .50        96522
 42.074      45.00         42.07      42.074        1.00       193044

 42.074      60.00         24.29      42.074         .25        27863
 42.074      60.00         24.29      42.074         .50        55727
 42.074      60.00         24.29      42.074        1.00       111454


      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF FOUR
 32.611      30.00         56.48      32.611         .25        38923
 32.611      30.00         56.48      32.611         .50        77847
 32.611      30.00         56.48      32.611        1.00       155693

 32.611      45.00         32.61      32.611         .25        22472
 32.611      45.00         32.61      32.611         .50        44945
 32.611      45.00         32.61      32.611        1.00        89889

 32.611      60.00         18.83      32.611         .25        12974
 32.611      60.00         18.83      32.611         .50        25949
 32.611      60.00         18.83      32.611        1.00        51898

NOW AT END

10:24   RAN 0 MINS  0.25 SECS
```

```
DRYDE2      10:27      08/01/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO    CONE          CONE        BASE          WATER        LIQUID
 LEAK     ANGLE         HEIGHT       WIDTH      SATURATION      VOLUME
 FT        DEG            FT          FT           FRAC.          GAL

       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF FIVE
 26.753       30.00        46.34       26.753           .25         21490
 26.753       30.00        46.34       26.753           .50         42979
 26.753       30.00        46.34       26.753          1.00         85958

 26.753       45.00        26.75       26.753           .25         12407
 26.753       45.00        26.75       26.753           .50         24814
 26.753       45.00        26.75       26.753          1.00         49628

 26.753       60.00        15.45       26.753           .25          7163
 26.753       60.00        15.45       26.753           .50         14326
 26.753       60.00        15.45       26.753          1.00         28653


       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF SIX
 22.830       30.00        39.54       22.830           .25         13354
 22.830       30.00        39.54       22.830           .50         26707
 22.830       30.00        39.54       22.830          1.00         53414

 22.830       45.00        22.83       22.830           .25          7710
 22.830       45.00        22.83       22.830           .50         15419
 22.830       45.00        22.83       22.830          1.00         30839

 22.830       60.00        13.18       22.830           .25          4451
 22.830       60.00        13.18       22.830           .50          8902
 22.830       60.00        13.18       22.830          1.00         17805


       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF SEVEN
 20.049       30.00        34.73       20.049           .25          9044
 20.049       30.00        34.73       20.049           .50         18088
 20.049       30.00        34.73       20.049          1.00         36175

 20.049       45.00        20.05       20.049           .25          5221
 20.049       45.00        20.05       20.049           .50         10443
 20.049       45.00        20.05       20.049          1.00         20886

 20.049       60.00        11.58       20.049           .25          3015
 20.049       60.00        11.58       20.049           .50          6029
 20.049       60.00        11.58       20.049          1.00         12058

 NOW AT END

 10:31    RAN 0 MINS  0.25 SECS
```

```
DRYDE2      10:33      08/01/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO     CONE          CONE         BASE          WATER        LIQUID
 LEAK       ANGLE         HEIGHT       WIDTH       SATURATION     VOLUME
  FT         DEG            FT          FT            FRAC.         GAL

       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF EIGHT
 17.993       30.00        31.17       17.993           .25         6538
 17.993       30.00        31.17       17.993           .50        13076
 17.993       30.00        31.17       17.993          1.00        26152

 17.993       45.00        17.99       17.993           .25         3775
 17.993       45.00        17.99       17.993           .50         7549
 17.993       45.00        17.99       17.993          1.00        15099

 17.993       60.00        10.39       17.993           .25         2179
 17.993       60.00        10.39       17.993           .50         4359
 17.993       60.00        10.39       17.993          1.00         8717


       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF NINE
 16.426       30.00        28.45       16.426           .25         4974
 16.426       30.00        28.45       16.426           .50         9947
 16.426       30.00        28.45       16.426          1.00        19894

 16.426       45.00        16.43       16.426           .25         2871
 16.426       45.00        16.43       16.426           .50         5743
 16.426       45.00        16.43       16.426          1.00        11486

 16.426       60.00         9.48       16.426           .25         1658
 16.426       60.00         9.48       16.426           .50         3316
 16.426       60.00         9.48       16.426          1.00         6631


       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF TEN
 15.199       30.00        26.33       15.199           .25         3941
 15.199       30.00        26.33       15.199           .50         7881
 15.199       30.00        26.33       15.199          1.00        15763

 15.199       45.00        15.20       15.199           .25         2275
 15.199       45.00        15.20       15.199           .50         4550
 15.199       45.00        15.20       15.199          1.00         9101

 15.199       60.00         8.78       15.199           .25         1314
 15.199       60.00         8.78       15.199           .50         2627
 15.199       60.00         8.78       15.199          1.00         5254

NOW AT END

10:37   RAN 0 MINS  0.26 SECS
```

```
DRYDE2      10:39      08/01/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO      CONE          CONE         BASE         WATER          LIQUID
 LEAK       ANGLE         HEIGHT        WIDTH      SATURATION       VOLUME
 FT          DEG            FT           FT           FRAC.          GAL

      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF FIFTEEN
 11.772      30.00         20.39        11.772           .25          1831
 11.772      30.00         20.39        11.772           .50          3661
 11.772      30.00         20.39        11.772          1.00          7323

 11.772      45.00         11.77        11.772           .25          1057
 11.772      45.00         11.77        11.772           .50          2114
 11.772      45.00         11.77        11.772          1.00          4228

 11.772      60.00          6.80        11.772           .25           610
 11.772      60.00          6.80        11.772           .50          1220
 11.772      60.00          6.80        11.772          1.00          2441


      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF TWENTY
 10.296      30.00         17.83        10.296           .25          1225
 10.296      30.00         17.83        10.296           .50          2450
 10.296      30.00         17.83        10.296          1.00          4900

 10.296      45.00         10.30        10.296           .25           707
 10.296      45.00         10.30        10.296           .50          1415
 10.296      45.00         10.30        10.296          1.00          2829

 10.296      60.00          5.94        10.296           .25           408
 10.296      60.00          5.94        10.296           .50           817
 10.296      60.00          5.94        10.296          1.00          1633


      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF THIRTY
  9.094      30.00         15.75         9.094           .25           844
  9.094      30.00         15.75         9.094           .50          1688
  9.094      30.00         15.75         9.094          1.00          3376

  9.094      45.00          9.09         9.094           .25           487
  9.094      45.00          9.09         9.094           .50           975
  9.094      45.00          9.09         9.094          1.00          1949

  9.094      60.00          5.25         9.094           .25           281
  9.094      60.00          5.25         9.094           .50           563
  9.094      60.00          5.25         9.094          1.00          1125

NOW AT END

10:43   RAN 0 MINS  0.26 SECS
```

```
DRYDE2      10:49      08/01/73

[illegible] B=37.5
67 C=45.5
80 DEF FNA(B,C,N)=SQR(B↑2+C↑2-2*B*C*COS(2*&PI/2/N))
100 PRINT "VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS"
110 PRINT
120 S=3
130 T=3
140 U=3
150 DIM  W(10)$(72)
160 W(1)$="      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF FIVE
170 W(2)$="      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF SIX"
180 W(3)$="      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF SEVE
    "
190 U(1)=30
200 U(2)=45
210 U(3)=60
220T(1)=U(1)*2*&PI/360
230 T(2)=U(2)*2*&PI/360
240 T(3)=U(3)*2*&PI/360
250 S(1)=.25
260 S(2)=.50
270 S(3)=1
280 L(1)=FNA(B,C,5)
290 L(3)=FNA(B,C,7)
300 E1=.33
310 A1=45.5/SQR(2)
320 A2=37.5-A1
330 L(2)=FNA(B,C,6)
340 H1=60
350 PRINT USING 360
360 :WELL TO    CONE         CONE        BASE         WATER       LIQUID
370 PRINT USING 380
380 : LEAK      ANGLE       HEIGHT       WIDTH       SATURATION   VOLUME
390 PRINT USING 400
400 : FT         DEG          FT          FT           FRAC.        GAL
410 PRINT
420 FOR N=1 TO S
430 PRINT W(N)$
440 FOR M=1 TO T
450 H4=0
460 H4=H4+1000
470 FOR O=1 TO U
480 H3=L(N)/TAN(T(M))
490 IF H4<H3 GO TO 510
```

```
500 H4=H3
510 CONTINUE
520 L1=H4*TAN(T(M))
530 V1=1/3*&PI *L1↑2*H4*E1*S(O)
540 PRINT USING 550,L(N),U(M),H4,L1,S(O),V1*7.5
550 :###.###     ####.##      ####.##      ###.###             #.##    ########
560 NEXT O
570 IF H4=H3  GO TO 590
580 GO TO 460
590 CONTINUE
600 PRINT
610 NEXT M
620 PRINT
630 NEXT N
READY
```

APPENDIX B

EFFECT OF NUMBER OF DRY WELLS ON LEAK DETECTION CAPABILITY

```
JRYDEI      08:43      08/02/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO     CONE        CONE       BASE        WATER        LIQUID
 LEAK      ANGLE       HEIGHT      WIDTH    SATURATION      VOLUME
  FT        DEG          FT         FT         FRAC.         GAL

      DRYWELL ADJACENT TO LEAK AT EDGE OF TANK
  8.000     30.00       10.00       5.774        .25           216
  8.000     30.00       13.86       8.000        .25           575

  8.000     45.00        8.00       8.000        .25           332

  8.000     60.00        4.62       8.000        .25           192


      LEAK AT EDGE OF TANK BETWEEN TWO WELLS OF FOUR
 32.611     30.00       10.00       5.774        .25           216
 32.611     30.00       20.00      11.547        .25          1728
 32.611     30.00       30.00      17.321        .25          5832
 32.611     30.00       40.00      23.094        .25         13823
 32.611     30.00       50.00      28.868        .25         26998
 32.611     30.00       56.48      32.611        .25         38923

 32.611     45.00       10.00      10.000        .25           648
 32.611     45.00       20.00      20.000        .25          5184
 32.611     45.00       30.00      30.000        .25         17495
 32.611     45.00       32.61      32.611        .25         22472

 32.611     60.00       10.00      17.321        .25          1944
 32.611     60.00       18.83      32.611        .25         12974


      LEAK AT CENTER OF TANK
 45.000     30.00       10.00       5.774        .25           216
 45.000     30.00       20.00      11.547        .25          1728
 45.000     30.00       30.00      17.321        .25          5832
 45.000     30.00       40.00      23.094        .25         13823
 45.000     30.00       50.00      28.868        .25         26998
 45.000     30.00       60.00      34.641        .25         46653
 45.000     30.00       70.00      40.415        .25         74083
 45.000     30.00       77.94      45.000        .25        102269

 45.000     45.00       10.00      10.000        .25           648
 45.000     45.00       20.00      20.000        .25          5184
 45.000     45.00       30.00      30.000        .25         17495
 45.000     45.00       40.00      40.000        .25         41469
 45.000     45.00       45.00      45.000        .25         59045

 45.000     60.00       10.00      17.321        .25          1944
 45.000     60.00       20.00      34.641        .25         15551
 45.000     60.00       25.98      45.000        .25         34090

NOW AT END

08:47    RAN 0 MINS  0.34 SECS
```

```
DRYDEI      13:51      08/01/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO     CONE          CONE         BASE         WATER        LIQUID
 LEAK       ANGLE        HEIGHT        WIDTH      SATURATION     VOLUME
 FT          DEG           FT           FT           FRAC.         GAL

        DR.WELL ADJACENT TO LEAK AT EDGE OF TANK
  8.000      30.00        10.00        5.774          .50           432
  8.000      30.00        13.86        8.000          .50          1149

  8.000      45.00         8.00        8.000          .50           664

  8.000      60.00         4.62        8.000          .50           383


        LEAK AT EDGE OF TANK BETWEEN TWO WELLS OF FOUR
 32.611      30.00        10.00        5.774          .50           432
 32.611      30.00        20.00       11.547          .50          3456
 32.611      30.00        30.00       17.321          .50         11663
 32.611      30.00        40.00       23.094          .50         27646
 32.611      30.00        50.00       28.868          .50         53996
 32.611      30.00        56.48✓      32.611          .50         77847

 32.611      45.00        10.00       10.000          .50          1296
 32.611      45.00        20.00       20.000          .50         10367
 32.611      45.00        30.00       30.000          .50         34989
 32.611      45.00        32.61✓      32.611          .50         44945

 32.611      60.00        10.00       17.321          .50          3888
 32.611      60.00        18.83✓      32.611          .50         25949


        LEAK AT CENTER OF TANK
 45.000      30.00        10.00        5.774          .50           432
 45.000      30.00        20.00       11.547          .50          3456
 45.000      30.00        30.00       17.321          .50         11663
 45.000      30.00        40.00       23.094          .50         27646
 45.000      30.00        50.00       28.868          .50         53996
 45.000      30.00        60.00       34.641          .50         93305
 45.000      30.00        70.00       40.415          .50        148165
 45.000      30.00        77.94       45.000          .50        204537

 45.000      45.00        10.00       10.000          .50          1296
 45.000      45.00        20.00       20.000          .50         10367
 45.000      45.00        30.00       30.000          .50         34989
 45.000      45.00        40.00       40.000          .50         82938
 45.000      45.00        45.00       45.000          .50        118090

 45.000      60.00        10.00       17.321          .50          3888
 45.000      60.00        20.00       34.641          .50         31102
 45.000      60.00        25.98       45.000          .50         68179

NOW AT END
```

```
DRYDE1      13:56      08/01/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO     CONE         CONE        BASE         WATER        LIQUID
 LEAK       ANGLE       HEIGHT       WIDTH      SATURATION     VOLUME
  FT         DEG          FT           FT          FRAC.         GAL

         DRYWELL ADJACENT TO LEAK AT EDGE OF TANK
  8.000      30.00        10.00       5.774         1.00          864
  8.000      30.00        13.86       8.000         1.00         2298

  8.000      45.00         8.00       8.000         1.00         1327

  8.000      60.00         4.62       8.000         1.00          766


         LEAK AT EDGE OF TANK BETWEEN TWO WELLS OF FOUR
 32.611      30.00        10.00       5.774         1.00          864
 32.611      30.00        20.00      11.547         1.00         6912
 32.611      30.00        30.00      17.321         1.00        23326
 32.611      30.00        40.00      23.094         1.00        55292
 32.611      30.00        50.00      28.868         1.00       107992
 32.611      30.00        56.48√     32.611         1.00       155693

 32.611      45.00        10.00      10.000         1.00         2592
 32.611      45.00        20.00      20.000         1.00        20735
 32.611      45.00        30.00      30.000         1.00        69979
 32.611      45.00        32.61√     32.611         1.00        89889

 32.611      60.00        10.00      17.321         1.00         7775
 32.611      60.00        18.83√     32.611         1.00        51898


         LEAK AT CENTER OF TANK
 45.000      30.00        10.00       5.774         1.00          864
 45.000      30.00        20.00      11.547         1.00         6912
 45.000      30.00        30.00      17.321         1.00        23326
 45.000      30.00        40.00      23.094         1.00        55292
 45.000      30.00        50.00      28.868         1.00       107992
 45.000      30.00        60.00      34.641         1.00       186611
 45.000      30.00        70.00      40.415         1.00       296331
 45.000      30.00        77.94      45.000         1.00       409074

 45.000      45.00        10.00      10.000         1.00         2592
 45.000      45.00        20.00      20.000         1.00        20735
 45.000      45.00        30.00      30.000         1.00        69979
 45.000      45.00        40.00      40.000         1.00       165876
 45.000      45.00        45.00      45.000         1.00       236179

 45.000      60.00        10.00      17.321         1.00         7775
 45.000      60.00        20.00      34.641         1.00        62204
 45.000      60.00        25.98      45.000         1.00       136358

NOW AT END
```

```
DRYDE1      08:48      08/02/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO     CONE          CONE         BASE         WATER        LIQUID
 LEAK       ANGLE        HEIGHT        WIDTH      SATURATION     VOLUME
 FT          DEG           FT           FT           FRAC.         GAL

        DRYWELL ADJACENT TO LEAK AT EDGE OF TANK
  8.000      30.00        10.00        5.774          .50           432
  8.000      30.00        13.86        8.000          .50          1149

  8.000      45.00         8.00        8.000          .50           664

  8.000      60.00         4.62        8.000          .50           383


        LEAK AT EDGE OF TANK BETWEEN TWO WELLS OF FOUR
 32.611      30.00        10.00        5.774          .50           432
 32.611      30.00        20.00       11.547          .50          3456
 32.611      30.00        30.00       17.321          .50         11663
 32.611      30.00        40.00       23.094          .50         27646
 32.611      30.00        50.00       28.868          .50         53996
 32.611      30.00        56.48       32.611          .50         77847

 32.611      45.00        10.00       10.000          .50          1296
 32.611      45.00        20.00       20.000          .50         10367
 32.611      45.00        30.00       30.000          .50         34989
 32.611      45.00        32.61       32.611          .50         44945

 32.611      60.00        10.00       17.321          .50          3888
 32.611      60.00        18.83       32.611          .50         25949


        LEAK AT CENTER OF TANK
 45.000      30.00        10.00        5.774          .50           432
 45.000      30.00        20.00       11.547          .50          3456
 45.000      30.00        30.00       17.321          .50         11663
 45.000      30.00        40.00       23.094          .50         27646
 45.000      30.00        50.00       28.868          .50         53996
 45.000      30.00        60.00       34.641          .50         93305
 45.000      30.00        70.00       40.415          .50        148165
 45.000      30.00        77.94       45.000          .50        204537

 45.000      45.00        10.00       10.000          .50          1296
 45.000      45.00        20.00       20.000          .50         10367
 45.000      45.00        30.00       30.000          .50         34989
 45.000      45.00        40.00       40.000          .50         82938
 45.000      45.00        45.00       45.000          .50        118090

 45.000      60.00        10.00       17.321          .50          3888
 45.000      60.00        20.00       34.641          .50         31102
 45.000      60.00        25.98       45.000          .50         68179

NOW AT END

08:52   RAN 0 MINS  0.28 SECS
```

```
DRYDE1     08:56     08/02/73

VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

WELL TO     CONE          CONE        BASE        WATER       LIQUID
 LEAK       ANGLE        HEIGHT       WIDTH     SATURATION    VOLUME
 FT          DEG           FT          FT          FRAC.        GAL

       DRYWELL ADJACENT TO LEAK AT EDGE OF TANK
  8.000      30.00        10.00       5.774        1.00          864
  8.000      30.00        13.86       8.000        1.00         2298

  8.000      45.00         8.00       8.000        1.00         1327

  8.000      60.00         4.62       8.000        1.00          766


       LEAK AT EDGE OF TANK BETWEEN TWO WELLS OF FOUR
 32.611      30.00        10.00       5.774        1.00          864
 32.611      30.00        20.00      11.547        1.00         6912
 32.611      30.00        30.00      17.321        1.00        23326
 32.611      30.00        40.00      23.094        1.00        55292
 32.611      30.00        50.00      28.868        1.00       107992
 32.611      30.00        56.48      32.611        1.00       155693

 32.611      45.00        10.00      10.000        1.00         2592
 32.611      45.00        20.00      20.000        1.00        20735
 32.611      45.00        30.00      30.000        1.00        69979
 32.611      45.00        32.61      32.611        1.00        89889

 32.611      60.00        10.00      17.321        1.00         7775
 32.611      60.00        18.83      32.611        1.00        51898


       LEAK AT CENTER OF TANK
 45.000      30.00        10.00       5.774        1.00          864
 45.000      30.00        20.00      11.547        1.00         6912
 45.000      30.00        30.00      17.321        1.00        23326
 45.000      30.00        40.00      23.094        1.00        55292
 45.000      30.00        50.00      28.868        1.00       107992
 45.000      30.00        60.00      34.641        1.00       186611
 45.000      30.00        70.00      40.415        1.00       296331
 45.000      30.00        77.94      45.000        1.00       409074

 45.000      45.00        10.00      10.000        1.00         2592
 45.000      45.00        20.00      20.000        1.00        20735
 45.000      45.00        30.00      30.000        1.00        69979
 45.000      45.00        40.00      40.000        1.00       165876
 45.000      45.00        45.00      45.000        1.00       236179

 45.000      60.00        10.00      17.321        1.00         7775
 45.000      60.00        20.00      34.641        1.00        62204
 45.000      60.00        25.98      45.000        1.00       136358

NOW AT END

09:01   RAN 0 MINS  0.28 SECS
```

APPENDIX C

EFFECT OF MONITORING FREQUENCY ON LEAK DETECTION CAPABILITY

```
DRYDE3       14:53      08/08/73

   VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

     LEAK RATE =  1.600 GALLONS PER MINUTE

LEAK TO    CONE   WATER  DETECT         MONITORING INTERVAL,DAYS
  WELL    ANGLE    SAT.   TIME             0          1          7          30
  FT       DEG    FRAC.    DAYS     MAX. DETECTED LIQUID VOLUME,GALLONS

       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF TWO
 58.96     30.0     .25     99.85    230048     232352     246176     299168
 58.96     30.0     .50    199.69    460095     462399     476223     529215
 58.96     30.0    1.00    399.39    920191     922495     936319     989311

 58.96     45.0     .25     57.65    132818     135122     148946     201938
 58.96     45.0     .50    115.29    265636     267940     281764     334756
 58.96     45.0    1.00    230.59    531272     533576     547400     600392

 58.96     60.0     .25     33.28     76683      78987      92811     145803
 58.96     60.0     .50     66.56    153365     155669     169493     222485
 58.96     60.0    1.00    133.13    306730     309034     322858     375850


       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF THREE
 42.07     30.0     .25     36.28     83590      85894      99718     152710
 42.07     30.0     .50     72.56    167181     169485     183309     236301
 42.07     30.0    1.00    145.12    334362     336666     350490     403482

 42.07     45.0     .25     20.95     48261      50565      64389     117381
 42.07     45.0     .50     41.89     96522      98826     112650     165642
 42.07     45.0    1.00     83.79    193044     195348     209172     262164

 42.07     60.0     .25     12.09     27863      30167      43991      96983
 42.07     60.0     .50     24.19     55727      58031      71855     124847
 42.07     60.0    1.00     48.37    111454     113758     127582     180574


       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF FOUR
 32.61     30.0     .25     16.89     38923      41227      55051     108043
 32.61     30.0     .50     33.79     77847      80151      93975     146967
 32.61     30.0    1.00     67.58    155693     157997     171821     224813

 32.61     45.0     .25      9.75     22472      24776      38600      91592
 32.61     45.0     .50     19.51     44945      47249      61073     114065
 32.61     45.0    1.00     39.01     89889      92193     106017     159009

 32.61     60.0     .25      5.63     12974      15278      29102      82094
 32.61     60.0     .50     11.26     25949      28253      42077      95069
 32.61     60.0    1.00     22.53     51898      54202      68026     121018

NOW AT END

14:57   RAN 0 MINS  0.28 SECS
```

```
DRYDE3      14:44     08/08/73

   VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

      LEAK RATE =  1.600 GALLONS PER MINUTE

LEAK TO     CONE   WATER   DETECT          MONITORING INTERVAL,DAYS
  WELL     ANGLE    SAT.    TIME            0           1          7          30
   FT       DEG    FRAC.     DAYS     MAX. DETECTED LIQUID VOLUME,GALLONS

      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF FIVE
 26.75      30.0     .25      9.33       21490       23794      37618      90610
 26.75      30.0     .50     18.65       42979       45283      59107     112099
 26.75      30.0    1.00     37.31       85958       88262     102086     155078

 26.75      45.0     .25      5.38       12407       14711      28535      81527
 26.75      45.0     .50     10.77       24814       27118      40942      93934
 26.75      45.0    1.00     21.54       49628       51932      65756     118748

 26.75      60.0     .25      3.11        7163        9467      23291      76283
 26.75      60.0     .50      6.22       14326       16630      30454      83446
 26.75      60.0    1.00     12.44       28653       30957      44781      97773


      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF SIX
 22.83      30.0     .25      5.80       13354       15658      29482      82474
 22.83      30.0     .50     11.59       26707       29011      42835      95827
 22.83      30.0    1.00     23.18       53414       55718      69542     122534

 22.83      45.0     .25      3.35        7710       10014      23838      76830
 22.83      45.0     .50      6.69       15419       17723      31547      84539
 22.83      45.0    1.00     13.38       30839       33143      46967      99959

 22.83      60.0     .25      1.93        4451        6755      20579      73571
 22.83      60.0     .50      3.86        8902       11206      25030      78022
 22.83      60.0    1.00      7.73       17805       20109      33933      86925


      LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF SEVEN
 20.05      30.0     .25      3.93        9044       11348      25172      78164
 20.05      30.0     .50      7.85       18088       20392      34216      87208
 20.05      30.0    1.00     15.70       36175       38479      52303     105295

 20.05      45.0     .25      2.27        5221        7525      21349      74341
 20.05      45.0     .50      4.53       10443       12747      26571      79563
 20.05      45.0    1.00      9.07       20886       23190      37014      90006

 20.05      60.0     .25      1.31        3015        5319      19143      72135
 20.05      60.0     .50      2.62        6029        8333      22157      75149
 20.05      60.0    1.00      5.23       12058       14362      28186      81178

NOW AT END

14:48   RAN 0 MINS  0.35 SECS
```

```
DRYDE3      15:04      08/08/73

   VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

     LEAK RATE =  1.600 GALLONS PER MINUTE

LEAK TO    CONE   WATER   DETECT          MONITORING INTERVAL,DAYS
 WELL     ANGLE    SAT.    TIME           0          1          7          30
  FT       DEG    FRAC.    DAYS     MAX. DETECTED LIQUID VOLUME,GALLONS

        LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF FIFTEEN
 11.77     30.0     .25      .79       1831       4135      17959       70951
 11.77     30.0     .50     1.59       3661       5965      19789       72781
 11.77     30.0    1.00     3.18       7323       9627      23451       76443

 11.77     45.0     .25      .46       1057       3361      17185       70177
 11.77     45.0     .50      .92       2114       4418      18242       71234
 11.77     45.0    1.00     1.83       4228       6532      20356       73348

 11.77     60.0     .25      .26        610       2914      16738       69730
 11.77     60.0     .50      .53       1220       3524      17348       70340
 11.77     60.0    1.00     1.06       2441       4745      18569       71561


        LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF TWENTY
 10.30     30.0     .25      .53       1225       3529      17353       70345
 10.30     30.0     .50     1.06       2450       4754      18578       71570
 10.30     30.0    1.00     2.13       4900       7204      21028       74020

 10.30     45.0     .25      .31        707       3011      16835       69827
 10.30     45.0     .50      .61       1415       3719      17543       70535
 10.30     45.0    1.00     1.23       2829       5133      18957       71949

 10.30     60.0     .25      .18        408       2712      16536       69528
 10.30     60.0     .50      .35        817       3121      16945       69937
 10.30     60.0    1.00      .71       1633       3937      17761       70753


        LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF THIRTY
  9.09     30.0     .25      .37        844       3148      16972       69964
  9.09     30.0     .50      .73       1688       3992      17816       70808
  9.09     30.0    1.00     1.47       3376       5680      19504       72496

  9.09     45.0     .25      .21        487       2791      16615       69607
  9.09     45.0     .50      .42        975       3279      17103       70095
  9.09     45.0    1.00      .85       1949       4253      18077       71069

  9.09     60.0     .25      .12        281       2585      16409       69401
  9.09     60.0     .50      .24        563       2867      16691       69683
  9.09     60.0    1.00      .49       1125       3429      17253       70245

NOW AT END

15:09   RAN 0 MINS  0.34 SECS
```

```
DRYDE3      14:58     08/08/73

   VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS

     LEAK RATE =  1.600 GALLONS PER MINUTE

LEAK TO    CONE   WATER   DETECT          MONITORING INTERVAL,DAYS
  WELL    ANGLE    SAT.    TIME             0          1          7          30
   FT      DEG    FRAC.    DAYS       MAX. DETECTED LIQUID VOLUME,GALLONS

       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF EIGHT
  17.99     30.0     .25     2.84      6538       8842      22666      75658
  17.99     30.0     .50     5.68     13076      15380      29204      82196
  17.99     30.0    1.00    11.35     26152      28456      42280      95272

  17.99     45.0     .25     1.64      3775       6079      19903      72895
  17.99     45.0     .50     3.28      7549       9853      23677      76669
  17.99     45.0    1.00     6.55     15099      17403      31227      84219

  17.99     60.0     .25      .95      2179       4483      18307      71299
  17.99     60.0     .50     1.89      4359       6663      20487      73479
  17.99     60.0    1.00     3.78      8717      11021      24845      77837


       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF NINE
  16.43     30.0     .25     2.16      4974       7278      21102      74094
  16.43     30.0     .50     4.32      9947      12251      26075      79067
  16.43     30.0    1.00     8.63     19894      22198      36022      89014

  16.43     45.0     .25     1.25      2871       5175      18999      71991
  16.43     45.0     .50     2.49      5743       8047      21871      74863
  16.43     45.0    1.00     4.99     11486      13790      27614      80606

  16.43     60.0     .25      .72      1658       3962      17786      70778
  16.43     60.0     .50     1.44      3316       5620      19444      72436
  16.43     60.0    1.00     2.88      6631       8935      22759      75751


       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF TEN
  15.20     30.0     .25     1.71      3941       6245      20069      73061
  15.20     30.0     .50     3.42      7881      10185      24009      77001
  15.20     30.0    1.00     6.84     15763      18067      31891      84883

  15.20     45.0     .25      .99      2275       4579      18403      71395
  15.20     45.0     .50     1.97      4550       6854      20678      73670
  15.20     45.0    1.00     3.95      9101      11405      25229      78221

  15.20     60.0     .25      .57      1314       3618      17442      70434
  15.20     60.0     .50     1.14      2627       4931      18755      71747
  15.20     60.0    1.00     2.28      5254       7558      21382      74374

NOW AT END

15:03    RAN 0 MINS  0.35 SECS
```

```
DRYDE3     14:48     08/08/73

65 B=37.5
67 C=45.5
69 G1=1.6
80 DEF FNA(B,C,N)=SQR(B↑2+C↑2-2*B*C*COS(2*&PI/2/N))
100 PRINT "    VOLUME OF CONICAL LEAKS DETECTABLE BY DRYWELLS"
110 PRINT
112 PRINT USING 113,G1
113 :       LEAK RATE =###.### GALLONS PER MINUTE
114 PRINT
120 S=3
130 T=3
140 U=3
150 DIM  W(10)$(72)
160 W(1)$="       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF FIVE"
170 W(2)$="       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF SIX"
180 W(3)$="       LEAK AT EDGE OF TANK HALFWAY BETWEEN TWO WELLS OF SEVEN
    "

190 U(1)=30
200 U(2)=45
210 U(3)=60
220T(1)=U(1)*2*&PI/360
230 T(2)=U(2)*2*&PI/360
240 T(3)=U(3)*2*&PI/360
250 S(1)=.25
260 S(2)=.50
270 S(3)=1
280 L(1)=FNA(B,C,5)
290 L(3)=FNA(B,C,7)
300 E1=.33
310 A1=45.5/SQR(2)
320 A2=37.5-A1
330 L(2)=FNA(B,C,6)
340 H1=60
350 PRINT USING 360
360 :LEAK TO   CONE  WATER  DETECT        MONITORING INTERVAL,DAYS
370 PRINT USING 380
380 :  WELL   ANGLE   SAT.   TIME          0         1         7
     30
390 PRINT USING 400
400 :  FT      DEG   FRAC.    DAYS    MAX. DETECTED LIQUID VOLUME,GALLON
     S
410 PRINT
```

```
420 FOR N=1  TO S
430 PRINT W(N)$
440 FOR M=1  TO T
450 H4=0
460 H4=H4+1000
470 FOR O=1  TO U
480 H3=L(N)/TAN(T(M))
490 IF H4<H3  GO TO 510
500 H4=H3
510 CONTINUE
520 L1=H4*TAN(T(M))
530 V1=1/3*&PI *L1 ↑2*H4*E1*S(O)
539 V2=V1*7.5
540 PRINT USING 550,L(N),U(M),S(O),V2/G1/1440,V2,V2+G1*1440,V2+G1*1440*7
    ,V2+G1*1440*30
550 :###.##   ###.#   #.##   ###.##   #######   #######   #######   ####
    ###
560 NEXT O
570 IF H4=H3  GO TO 590
580 GO TO 460
590 CONTINUE
600 PRINT
610 NEXT M
620 PRINT
630 NEXT N
READY
```

APPENDIX D

EFFECT OF LATERALS ON LEAK DETECTION CAPABILITIES

```
LATERI      21:05      08/07/73

VOLUME OF CONICAL LEAKS DETECTABLE BY PARALLEL LATERALS

LATERAL      CONE        MAXIMUM       WATER       LIQUID       DAYS TO
 DEPTH       ANGLE       LATERAL    SATURATION     VOLUME       DETECT
  FT        DEGREES      SPACING     FRACTION      GALLONS     AT 1.6 GPM
                           FT
  2.00       30.00         2.31         .25           1.73        .001
  2.00       30.00         2.31         .50           3.46        .001
  2.00       30.00         2.31        1.00           6.91        .003

  4.00       30.00         4.62         .25          13.82        .006
  4.00       30.00         4.62         .50          27.65        .012
  4.00       30.00         4.62        1.00          55.29        .024

  6.00       30.00         6.93         .25          46.65        .020
  6.00       30.00         6.93         .50          93.31        .040
  6.00       30.00         6.93        1.00         186.61        .081

  8.00       30.00         9.24         .25         110.58        .048
  8.00       30.00         9.24         .50         221.17        .096
  8.00       30.00         9.24        1.00         442.34        .192

 10.00       30.00        11.55         .25         215.98        .094
 10.00       30.00        11.55         .50         431.97        .187
 10.00       30.00        11.55        1.00         863.94        .375

 12.00       30.00        13.86         .25         373.22        .162
 12.00       30.00        13.86         .50         746.44        .324
 12.00       30.00        13.86        1.00        1492.88        .648

 14.00       30.00        16.17         .25         592.66        .257
 14.00       30.00        16.17         .50        1185.32        .514
 14.00       30.00        16.17        1.00        2370.65       1.029

 16.00       30.00        18.48         .25         884.67        .384
 16.00       30.00        18.48         .50        1769.34        .768
 16.00       30.00        18.48        1.00        3538.69       1.536

 18.00       30.00        20.78         .25        1259.62        .547
 18.00       30.00        20.78         .50        2519.24       1.093
 18.00       30.00        20.78        1.00        5038.49       2.187

 20.00       30.00        23.09         .25        1727.88        .750
 20.00       30.00        23.09         .50        3455.75       1.500
 20.00       30.00        23.09        1.00        6911.50       3.000
```

```
LATER1      08:01      08/08/73

VOLUME OF CONICAL LEAKS DETECTABLE BY PARALLEL LATERALS

LATERAL       CONE       MAXIMUM        WATER       LIQUID        DAYS TO
 DEPTH        ANGLE      LATERAL     SATURATION     VOLUME        DETECT
  FT         DEGREES     SPACING      FRACTION      GALLONS      AT 1.6 GPM
                           FT


   2.00       45.00        4.00          .25           5.18          .002
   2.00       45.00        4.00          .50          10.37          .004
   2.00       45.00        4.00         1.00          20.73          .009

   4.00       45.00        8.00          .25          41.47          .018
   4.00       45.00        8.00          .50          82.94          .036
   4.00       45.00        8.00         1.00         165.88          .072

   6.00       45.00       12.00          .25         139.96          .061
   6.00       45.00       12.00          .50         279.92          .121
   6.00       45.00       12.00         1.00         559.83          .243

   8.00       45.00       16.00          .25         331.75          .144
   8.00       45.00       16.00          .50         663.50          .288
   8.00       45.00       16.00         1.00        1327.01          .576

  10.00       45.00       20.00          .25         647.95          .281
  10.00       45.00       20.00          .50        1295.91          .562
  10.00       45.00       20.00         1.00        2591.81         1.125

  12.00       45.00       24.00          .25        1119.66          .486
  12.00       45.00       24.00          .50        2239.33          .972
  12.00       45.00       24.00         1.00        4478.65         1.944

  14.00       45.00       28.00          .25        1777.98          .772
  14.00       45.00       28.00          .50        3555.97         1.543
  14.00       45.00       28.00         1.00        7111.94         3.087

  16.00       45.00       32.00          .25        2654.02         1.152
  16.00       45.00       32.00          .50        5308.03         2.304
  16.00       45.00       32.00         1.00       10616.07         4.608

  18.00       45.00       36.00          .25        3778.86         1.640
  18.00       45.00       36.00          .50        7557.73         3.280
  18.00       45.00       36.00         1.00       15115.46         6.561

  20.00       45.00       40.00          .25        5183.63         2.250
  20.00       45.00       40.00          .50       10367.25         4.500
  20.00       45.00       40.00         1.00       20734.51         8.999
```

```
LATER1     21:16     08/07/73

100 PRINT "VOLUME OF CONICAL LEAKS DETECTABLE BY PARALLEL LATERALS"
110 PRINT
120 S=1
130 T=3
140 U=3
150 DIM  W(10)$(72)
190 U(1)=30
200 U(2)=45
210 U(3)=60
220T(1)=U(1)*2*&PI/360
230 T(2)=U(2)*2*&PI/360
240 T(3)=U(3)*2*&PI/360
250 S(1)=.25
260 S(2)=.50
270 S(3)=1
280 L(1)=8
290 L(3)=45
300 E1=.33
310 A1=45.5/SQR(2)
320 A2=37.5-A1
330 L(2)=SQR(A1 ↑2+A2 ↑2)
340 H1=60
350 PRINT USING 360
360 :LATERAL     CONE       MAXIMUM      WATER     LIQUID      DAYS TO
370 PRINT USING 380
380 : DEPTH     ANGLE      LATERAL    SATURATION  VOLUME       DETECT
390 PRINT USING 400
400 :  FT       DEGREES    SPACING     FRACTION   GALLONS     AT 1.6 GPM
410 PRINT "                        FT"
420 FOR N=1 TO S
440 FOR M=1 TO T
450 H4=0
460 H4=H4+2
470 FOR O=1 TO U
480 H3=20
490 IF H4<H3 GO TO 510
500 H4=H3
510 CONTINUE
520 L1=H4*TAN(T(M))
530 V1=1/3*&PI *L1 ↑2*H4*E1*S(O)
540 PRINT USING 550,H4,U(M),2*L1,S(O),V1*7.5,V1*7.5/1.6/1440
550 : ##.##     ####.##     ####.##      #.##      ######.##  #####.###
560 NEXT O
565 PRINT
570 IF H4=H3 GO TO 590
580 GO TO 460
590 CONTINUE
600 PRINT
610 NEXT M
620 PRINT
630 NEXT N
```

```
LATER1      08:02      08/08/73

VOLUME OF CONICAL LEAKS DETECTABLE BY PARALLEL LATERALS

LATERAL      CONE       MAXIMUM       WATER      LIQUID      DAYS TO
 DEPTH       ANGLE      LATERAL    SATURATION    VOLUME       DETECT
  FT        DEGREES     SPACING     FRACTION     GALLONS    AT 1.6 GPM
                          FT

  2.00        60.00        6.93         .25         15.55        .007
  2.00        60.00        6.93         .50         31.10        .013
  2.00        60.00        6.93        1.00         62.20        .027

  4.00        60.00       13.86         .25        124.41        .054
  4.00        60.00       13.86         .50        248.81        .108
  4.00        60.00       13.86        1.00        497.63        .216

  6.00        60.00       20.78         .25        419.87        .182
  6.00        60.00       20.78         .50        839.75        .364
  6.00        60.00       20.78        1.00       1679.50        .729

  8.00        60.00       27.71         .25        995.26        .432
  8.00        60.00       27.71         .50       1990.51        .864
  8.00        60.00       27.71        1.00       3981.03       1.728

 10.00        60.00       34.64         .25       1943.86        .844
 10.00        60.00       34.64         .50       3887.72       1.687
 10.00        60.00       34.64        1.00       7775.44       3.375

 12.00        60.00       41.57         .25       3358.99       1.458
 12.00        60.00       41.57         .50       6717.98       2.916
 12.00        60.00       41.57        1.00      13435.96       5.832

 14.00        60.00       48.50         .25       5333.95       2.315
 14.00        60.00       48.50         .50      10667.91       4.630
 14.00        60.00       48.50        1.00      21335.81       9.260

 16.00        60.00       55.43         .25       7962.05       3.456
 16.00        60.00       55.43         .50      15924.10       6.912
 16.00        60.00       55.43        1.00      31848.21      13.823

 18.00        60.00       62.35         .25      11336.59       4.920
 18.00        60.00       62.35         .50      22673.19       9.841
 18.00        60.00       62.35        1.00      45346.37      19.682

 20.00        60.00       69.28         .25      15550.88       6.750
 20.00        60.00       69.28         .50      31101.76      13.499
 20.00        60.00       69.28        1.00      62203.53      26.998
```

DISTRIBUTION

No. of Co
Copies

ONSITE

10 **Atlantic Richfield Hanford Co.**

M. D. Alford
G. L. Borsheim
D. J. Larkin (3)
W. D. Leuning
C. W. Malody
A. E. Smith
P. W. Smith
D. D. Wodrich

No. of
Copies

ONSITE

14 **Battelle-Northwest**

R. D. Dierks
D. P. Granquist
J. N. Hartley
G. Jansen
O. H. Koski
M. R. Kreiter
J. L. McElroy
J. A. Merrill
A. M. Platt
A. K. Postma
G. J. Posakony
C. A. Ratcliff
K. J. Schneider
Technical Information Files

END

DATE
FILMED
3/16/94