DOE/LC/10787-109
(DE83010197)

FOSSIL ENERGY

# INVESTIGATION OF THE GEOKINETICS HORIZONTAL IN SITU OIL SHALE RETORTING PROCESS

Sixth Annual Report

By
Lee Wege

April 1983
Date Published

Work Performed Under Contract No. FC20-78LC10787

Geokinetics, Inc.
Salt Lake City, Utah

U. S. DEPARTMENT OF ENERGY

DOE/LC/10787-109
(DE83010197)
Distribution Category UC-91

# INVESTIGATION OF THE GEOKINETICS HORIZONTAL IN SITU OIL SHALE RETORTING PROCESS

**SIXTH ANNUAL REPORT**

1982

by

LEE WEGE
Editor

JAMES M. LEKAS
Project Manager

**GEOKINETICS INC.**

391 Chipeta Way, D-2
Salt Lake City, Utah 84108

Date Published - April 1983

**PREPARED FOR THE UNITED STATES DEPARTMENT OF ENERGY**

Under Cooperative Agreement #DE-FC20-78LC10787

# TABLE OF CONTENTS

## LIST OF PHOTOS

## LIST OF FIGURES

## LIST OF FIGURES (con't.)

## LIST OF FIGURES (con't.)

# LIST OF TABLES

# LIST OF TABLES (con't.)

## SUMMARY

The Geokinetics in situ shale oil project is a cooperative venture between Geokinetics and the U.S. Department of Energy. The project is governed by DOE Cooperative Agreement #DE-FC20-78LC10787. The objective is to develop a true in situ process for recovering shale oil using a fire front moving in a horizontal direction. The project is being conducted at a field site, Kamp Kerogen, located 70 miles south of Vernal, Utah.

This 6th Annual Report covers work completed during the calendar year 1982. During 1982, two 2 acre retorts were blasted and two 1 acre retorts were burned. A total of 33,232 barrels of crude shale oil were produced.

## INTRODUCTION

The Geokinetics horizontal in situ oil shale recovery project is a cooperative venture between Geokinetics Inc. and the U.S. Department of Energy governed by DOE Agreement #DE-FC20-78LC10787. As the process was developed by private funds for a period of over two years prior to the contract, certain data are proprietary for a limited period of time.

The process is a true in situ process for extracting oil from oil shale. In the Geokinetics Process, a pattern of blastholes is drilled from the surface, through the overburden, and into the oil shale bed. The holes are loaded with explosives and fired, using a carefully planned blast system. The blast results in a fragmented mass of oil shale with high permeability. The void space in the fragmented zone comes from lifting the overburden, producing a small uplift of the surface (Figures 1-5 illustrate the fragmentation process.)

The fragmented zone constitutes an in situ report. The bottom of the retort is sloped to provide drainage for the oil to a sump where it is lifted to the surface by a number of oil production wells. Air injection holes are drilled at the other end. The oil shale is ignited at the air injection wells and air is injected to establish and maintain a burning front that occupies the full thickness of the fragmented zone.

The front is moved in a horizontal direction through the fractured shale towards the off gas wells at the far end of the retort. The hot combustion gases from the burning front heat the shale ahead of the front, driving out the oil, which drains to the bottom of the retort where it flows along the sloping bottom to the oil production wells. As the burn front moves from the air-in to the off gas wells, it burns the residual carbon in the retorting shale as fuel. The combustion gases are recovered at the off gas wells. This gas is combustible and could be used for power generation (Figure 6 shows a typical operating Geokinetics retort.)

After the detonation, core samples are taken to evaluate the effectiveness of the blast and the quality of fracturing.

The next phase is re-entry drilling. Wells are drilled into the retort for air injection, off gas removal and oil production. A fire is ignited at one end of the retort and its horizontal progess through the bed is monitored by a series of thermocouple wells. Progress of the fire front is regulated by varying the air injection rates through a row of air-in wells located at one end of the retort.

Upon completion of the burn when the fire front has reached the far end of the retort, the retort is shut in and the process wells and equipment are removed. The surface is recontoured and revegetated to restore the aesthetic and ecological value of the landscape. In addition to these activities, prior to, during and after retort burn, environment studies are conducted in such areas as air quality, fugitive emissions, hydrology, wildlife and ecology to assess the impact of the project upon the ecosystem and mitigate adverse effects.

In the following sections of the report, the various aspects of the project are reported in fuller detail with a description of activities, experiments, data and findings.

The project site is located 70 miles south of Vernal, Utah, on Section 2, R22E, T14S. The oil shale rights are leased from the State of Utah. The oil shale bed, known as the Mahogany Zone, is approximately 30 feet thick and has an average grade of 23 gallons/ton. The beds strike in an east-west direction and dip to the north at about 120 feet/mile. Overburden ranges from zero where the shale outcrops to a maximum of 110 feet (Figure 7 shows the Geokinetics field site).

## GEOKINETICS

Prior to 1981, 25 retorts had been blasted and 14 retorts had been burned. This work has established the technical viability of the basic process, as follows:

1. It is possible to drill a pattern of blastholes from the surface into the oil shale and fracture the shale to establish a zone of high permeability with a relatively impermeable zone between the fragmented shale and the surface.

2. It is possible to drill through the rubblized material and construct the various wells necessary for the operation, including air-in holes, off gas holes, oil recovery well and instrumental wells.

3. A point ignition can be made in the rubblized shale and expanded into a burn front that covers the cross section of the retort.

4. The burn front can be moved down the length of the retort as a cohesive temperature front, with satisfactory sweep efficiency.

5. Produced oil can be recovered from a well drilled to the bottom of the rubblized zone.

6. Recovery of in place oil of up to 50 percent can be achieved.

In addition, basic retorting parameters such as air injection pressures, air injection rates, rates of fire front advance, retort pressure and recovery factors were established on one acre retorts. The continued development of the Walking "W" blast design was also accomplished during this period. The environmental impacts of the process upon air, water, land, vegetation and animal life were under investigation. Geokinetics' Analytical Laboratory has been routinely running analyses of retort stack gas, retort and ground water, and the produced oil.

During 1981, the following experiments were conducted:

1. The post-burn coring program was completed on Retort #18.

2. Equipment was installed and tested on Retort #23 and the retort was ignited and burned.

3. The burn of Retort #24 was completed on July 23, after 234 continuous days of operation.

4. Re-entry drilling, equipment installation and testing were completed on Retort #25. The retort was ignited and was operated for 77 days during the year.

5. A blast experiment was designed and conducted which was used in the development of the Retort #26 blast design.

6. Retort #26 was drilled and blasted.

7. Retort #27 was designed and blasthole drilling started during the last quarter of the year.

11,814.4 barrels were sold to a refinery, where it was blended with #5 light fuel oil and sold to selected customers, and 4,807.36 barrels were sold to the Department of Defense (DOD). This oil will be refined into jet fuel and used in the DOD program to evaluate the use of fuels derived from shale oil for military applications.

Total oil production for the year came to 18,799 barrels. The following is a breakdown of oil produced in Retorts #23, #24 and #25:

Retort #23 - 1,762 barrels
Retort #24 - 9,768 barrels
Retort #25 - 7,269 barrels

# GEOKINETICS

During 1982, the following experiments were conducted:

1. The burn of Retort #25 was terminated in June 1982 after 243 elapsed days. Total oil production was 20,956 barrels, an average of 86 barrels per day over the eight month period. Final oil recovery was 59 percent, Geokinetics' highest yield for a retort of this size. Retort #25 has been dismantled and recontoured, and post-burn environmental studies are continuing.

2. Re-entry drilling of process and instrumentation wells on Retort #26 was carried out during January through March. Instrumentation and process manifolding began that same month. Manifold installation was completed in May, instrumentation installation in early July, and the retort was ignited July 8, 1982. Retort #26 has produced 19,545 barrels of oil, measured in the storage tanks, as of December 1982.

3. The Retort #27 site was drilled and prepared for blasting during January and February, being detonated February 25. Retort #27 was Geokinetics' first two acre retort. Post-blasting coring was carried out in March and April to determine the blast's success. Recontouring and compaction of the retort surface was completed by June and re-entry drilling began in July and has continued into December.

4. Preliminary site preparation for Retort #28, Geokinetics' second two acre retort, began in May; blast hole drilling started in June and was completed by August. Detonation of the retort occurred August 18, 1982. Post-blast contouring was carried out in September. Coring began in September also, and was accomplished in November. Re-entry drilling began in October, and to this point all air-in and air-out wells are complete.

5. Environmental studies in the areas of land rehabilitation and revegetation, wildlife monitoring, meteorological monitoring, soil temperature, retort process water characterization, retort peripheral well water quality and emissions have been underway throughout 1982.

6. In addition to routine testing of oil, water and gas samples, the analytical laboratory has been involved in studies to develop a process and equipment for the removal of hydrogen sulfide from retort process gas, and the development of a thermosludge boiler and ammonia stripper.

7. A variety of support projects have also been undertaken in 1982, including the construction of a new tank battery and accompanying emulsion line and steam tracer, upgrading electrical generation capacity, construction of an off gas recirculation line on Retort #26, and the continuation of the health and safety program.

# DESCRIPTION OF 1982 TECHNICAL PROGRESS

## I. RETORT #25

### A. Oil, Water and Gas Production

1. Oil and Water Production - Retort #25 was ignited in October of 1981 and burned continuously until being shut-in on June 15, 1982. Total oil production for the entire burn, as measured in the storage tanks, was 20,956 barrels. Based on a retort volume of 1,140,578 cubic feet and an average grade of 18.3 gallons per ton of oil shale, total calculated oil in place was 35,483 barrels. The percent recovery from Retort #25 (actual yield/oil in place) was 59 percent. The good recovery was largely due to the high air injection rates maintained during this burn. On all previous retorts, we were limited in our ability to inject air at the design rate by equipment limitations or by channeling that required a reduction of the air injection rates.

Water production over the life of the Retort #25 burn totalled 39,723 barrels, an average of 256 barrels per day.

A summary of oil and water production for Retort #25 is presented in Table 1.

2. Gas Production - The numerous gases produced by retorting were analyzed daily to identify and quantify constituents and their relative abundance. Table 2 presents the process gas constituents and their respective percentages of the process gas by 10-day intervals over the life of the burn. Process gas was vacuumed out of Retort #25 at an average rate of 5,327 scfm.

Because the process gas is combustible and therefore has a potential application as a fuel, its average heating value (BTU/scf) and the total amount of BTU's produced by Retort #25 process gas were calculated, recorded, and are presented in this report as Table 3. Hydrogen sulfide ($H_2S$) and ammonia ($NH_3$) are also present in the process gas in small amounts. The content of these constituents in the process is included in Table 3.

B. Air Injection and Fire Front Advance - Air is injected into a retort in order to supply oxygen for the fire front, enabling it to advance through the rubblized oil shale bed. Due to varying degrees of shale rubblization and resulting permeability, the fire front, of its own accord, does not advance uniformly; but uniform fire front advance is vital for optimum retort operation. In order to promote uniform fire front advancement, the individual flow rates of each injection and off gas well is monitored and adjusted, respective to fire front location. For example, if the fire front is leading along the outside edges, the corresponding injection wells can be partially or completely closed, forcing more air to be injected at the center and causing that part of the fire front to advance more quickly, until uniformity is achieved. The average air injection rate over the life of Retort #25 was 5,276 scfm, divided between the eight air injection wells.

In order to know how to correctly adjust the air injection wells, fire front location must be monitored. This is accomplished by an underground thermocouple network consisting of four thermocouples set at varying depths at 55 thermowell locations (see Figures 8 and 9).

By using the data collected by the thermocouple network, fire front location can be plotted in 800$^{\circ}$F isotherms; this is done on a regular basis. Figures 10 through 18 show the fire front location at various times throughout the burn of Retort #25. As demonstrated by these figures, uniform fire front advance was achieved throughout the burn by the modification of the injection and recovery scheme.

There is also a relationship between air injection and oil production; this relationship is shown in Figure 19.

## II. RETORT #26

A. Introduction - Re-entry drilling was carried out on Retort #26 during the months of January through March. By the end of February, all 33 process wells (air-in, air-out, and production wells) were completed (see Figure 20). Instrumentation drilling (for thermocouple and pressure wells) continued into March. A new technique for the installation of instruments using standard drilling equipment was tested and proved successful. Using the new method, each thermocouple well was drilled and left uncased. The thermocouples were then placed down the well bore and backfilled, thereby saving the cost of casing each well (see Figure 21 for locations).

Construction of process manifolding began during January in Geokinetics' shop. Installation of the process manifolding commenced in March (see Figure 22).

The majority of work on Retort #26 during the second quarter of 1982 consisted of process equipment and instrument installation preparatory to ignition of the retort upon completion of the Retort #25 burn.

Thermocouple installation began in the third week of April and continued into May, using the new installation method already described. By the end of May, instrument and surface manifold installation had been completed.

Activity increased in June as final preparations for ignition were completed. Special instrumentation was installed for permeability studies - a cold flow test by Geokinetics, and tracer tests by LETC. These tests determined fluid flow trends through the fractured shale bed of Retort #26. Preliminary results indicated that the north edge of the retort may have had fracturing that would encourage channeling of the fire front. This channeling did occur during the burn of Retort #26, as had been anticipated.

Retort #26 was successfully ignited on July 8 and 9 using the Geokinetics charcoal point ignition technique. Pre-ignited charcoal was poured down the air injection wells to kindle the oil shale. Air injection was subsequently initiated, in order to supply the oxygen needed for ignition of the shale bed. Air injection flows were closely monitored and controlled to establish a uniform fire front extending the width of the retort. Oil production began on July 20, or day 12.

B. Oil, Water and Gas Production

1. Oil and Water Production - A summary of oil and water production for Retort #26, days 1-176, is presented in Table 4. As of day 176, Retort #26 had produced 19,545 barrels of oil, as measured in the storage tanks, as well as 23,313 barrels of water. At day 176 of the burn of Retort #25, it had produced 17,540 barrels of oil and 29,046 barrels of water. This comparison is significant because Retort #25 and #26 are of the same size, and Retort #25 had been Geokinetics' most successful retort. A comparison of Retorts #25 and #26 on a cumulative and daily basis in both oil and water production is presented in Figures 23 through 26.

Retorting efficiency can be quantified by percent oil yield and oil loss to coking and burning. The data are calculated by the Geokinetics analytical laboratory using the alkene/alkane and naphalene/alkane ratios.[1] Percent oil yield, as determined indirectly by the extrapolation of gas chromatographic data, is the percentage of oil yielded by retorting from the total theoretical amount of oil that could be recovered from the kerogen if retorting were carried out under ideal conditions, i.e. no loss to coking or burning. As of day 176, production oil yield for the life of Retort #26 has been 58 percent. Losses to coking and burning have been calculated to be 17 percent and 30 percent respectively. (These are approximate figures. Percent yield plus percent coked plus percent burned equals approximately 100 percent).

2. Gas Production - The numerous gases produced by retorting are analyzed daily to identify and quantify constituents and their relative abundance. Table 5 shows the process gas constituents and their respective percentages of the process gas, by 10-day intervals, for the life of the Retort #26 burn, and an average. The off gas flow rate has averaged 5,393 scfm over the 176 day burn life of this retort.

Because the process gas (off gas) can be combusted and therefore has a potential application as fuel, its average heating value (BTU/scf) and the total number of BTU's have been calculated, recorded, and are presented in this report as Table 6. As in the case of process gas from Retort #25, hydrogen sulfide and ammonia are present in small amounts; a record of their content in the process of Retort #26 is included in Table 6.

C. Air Injection and Fire Front Advance - The same types of measures taken to control fire front advance in Retort #25 have been implemented during the burn of Retort #26. As can be seen in Figures 27 through 32, the Retort #26 fire front has been leading along the entire north side. In order to correct this, the air injection rates of Air-in wells #5, #6, #7 and #8 have been reduced over the life of the burn to the point that 80 percent of the injected air is entering the retort through Air-in wells #1, #2, #3 and #4. In addition, off gas wells #13, #14, #15 and #16 have been closed off entirely, forcing all off gas recovery to take place on the south side. As can be seen by referring to the Figures, this intra-retort flow scheme has caused the fire front to progress towards the southwest corner of the retort and has been largely successful in stabilizing fire front advancement.

Air has been injected into Retort #26 at an average rate of 4,714 scfm, over the life of the burn. The relationship between oil production and air flow is presented in Figure 33.

D. Air Quality 1982 - Geokinetics has been required throughout 1982 by the existing Prevention of Significant Deterioration permit, issued by the EPA, and the State Air Construction Permit, issued by the Utah Bureau of Air Quality, to measure specific pollutants emitted by the afterburner on Retorts #25 and #26. These emissions are reported, in addition to the emissions from ancillary sources such as the electrical generators and vehicle traffic on the unpaved roads at the site. Emission levels from ancillary sources are based on established emission factors set forth in the PSD permit application. The individual pollutants and their respective rates are listed in Table 7.

Emission levels from Retorts #25 and #26 are determined by measurements taken from the effluent gas stream at a point ahead of the afterburner and also at the top of the afterburner after combustion.

Emission levels during 1982 have been within stipulated maximums except for a brief period during the burn of Retort #25 when we were operating under a temporary waiver of $SO_2$ and $NO_x$ standards in order to test an experimental wet scrubber. A comparison of the total emissions and the maximum allowable, measured in tons, as set forth in the PSD permit, is given in Table 8.

E. Process/Stack Gases - Retorts #25 and #26 - Process gases are produced by retorting; stack gases are produced by the combustion of the process gases in the afterburner. Analysis of process and stack gases are routine tests performed by the analytical laboratory, in order to determine the concentration of pollutants in both gas streams and the efficiency of the afterburner. Results of these analyses are presented in Tables 9 and 10. Comparison of the data presented in these tables indicates that the afterburner of Retort #25 and #26 have operated effectively.

F. Intra-Gas (RP Gas) Analysis - Intra-gas samples or gas samples from within the retort, are taken on a regular basis for analysis by the Geokinetics analytical laboratory. These samples are retrieved at specific locations by means of the retort pressure (RP) wells stationed at many thermowell locations.

By means of these samples, constituent make-up of the gas is determined. Particular attention is given to the percentages of oxygen ($O_2$), carbon monoxide (CO), carbon dioxide ($CO_2$), hydrogen ($H_2$) and methane ($CH_4$). This data gives insight to the conditions within the retort, relative to fire front location and combustion.

Changes occur to the gas stream as it progresses from injection to recovery. The oxygen is used up as the gas passes through the retort, especially at the fire front. Combustion by products are released at the fire front, and represent a proportionally higher percentage of the off gas on the recovery side of the fire front. The RP gas analysis, therefore, can be used in tandum with the thermocouple network to determine fire front location.

Figures 34, 35 and 36 show fire front location on days 85, 125, and 165 of Retort #26, respectively. These figures also contain graphs showing the relative percentages in the process gas of oxygen, carbon monoxide, carbon dioxide, hydrogen and methane on the same day, and graphically demonstrate the changes that occur to the gas stream as it passes through the retort.

## III. RETORT #27

A. Introduction - During late February, Geokinetics blasted its first two acre retort, Retort #27. Retort #27 was a two fold size increase over previous one acre retorts and an important step toward the development and use of larger retorts.

Through the detonation of Retort #27 and the subsequent coring and blast analysis, Geokinetics obtained valuable data concerning: 1) the relationship of retort size and blast efficiency, and 2) the effects of blast design modifications upon shale fracturing. During late March and early April, core sampling and post-blast analysis were done on Retort #27 to analyze the success of the blast as judged by the above mentioned objectives.

The Retort #27 post-blast coring program was designed to determine the effectiveness of the blast by physically observing shale fracturing characteristics from key core hole locations. Well chosen core hole locations, accompanied by post-blast surveying and high speed photography, provided the principle means of blast analysis.

B. Blast Efficiency vs. Size Increase - Previous blasting experience has shown that a large amount of explosive energy is required for flexing and displacing of shale at a retort's edge. Small retorts have a greater "edge effect" when compared to large retorts. This becomes evident when one remembers that for a given object, the proportion of the object's surface area to volume decreases as the object's size increases. Thus, more energy per unit volume is required to blast a small retort because the proportion of edge area compared to the retort's volume is large and the energy required at the retort's edge is also proportionally larger. Therefore, by increasing a retort's size, thus reducing the proportion of edge area to retort volume, the "edge effect" is lessened, (the amount of explosive energy required per unit volume decreases) and a greater blast efficiency is attained.

To test blast efficiency as its relates to retort size increases, a comparison between Retort #27 and Retort #24 was made. This comparison was useful because Retort #27 was twice the size of Retort #24 and the depth and distribution of overburden for the two retorts were similar. If equal or improved void and fracturing characteristics were obtained from the detonation of Retort #27 with less explosives used per amount of void induced in the shale bed, the increase in retort size from one acre to two acres did improve blast efficiency. In addition, blast design modifications were introduced in the detonation of Retort #27 and they must be considered for the contribution they may havē played in improved blast efficiency.

1. <u>Explosive Quantity vs. Void</u> - Void is the amount of space of volume increase induced in a shale bed by an explosion. The amount of void created by the blast is indicative of its success, since void creates permeability and permits access of air for combustion of the shale bed. It is possible to explosively fracture a bed without displacing the fragments and creating void. In this case, the particles which remain in an orderly arrangement and in contact with each other were not displaced sufficiently to allow the passage of air, and retorting becomes impossible. In order to have effective void, the shale fragments must be displaced, and not remain in tight contact with each other.

The amount of void or volume increase within a shale bed is calculated indirectly from the amount of surface uplift (heave) caused by the blast. The principle which illustrates the correlation between void and heave is relatively simple. Since the unblasted shale bed contains little or no void before detonation, any increase in volume must cause expansion and that expansion will manifest itself on the surface as uplift. Thus, by calculating the surface area bounded within the uplifted zone and multiplying that value by the amount of uplift, the increase in volume is calculated. Therefore, heave is useful as an indicator of blast performance and is used to determine void.

Figures 37 and 38-a show the degree of heave for Retort #24 and #27. Each contour line represents the amount of change in elevation pre-blast elevation to post-blast elevation (the amount of heave). Two items may be noted from the heave contour maps. First, the heave contour lines for Retort #24 are asymmetrical in relation to the retort boundary. The greatest uplift occurred on the IR (initiation round) side. This indicates that the initiation round, which is designed to create overburden uplift so that the "W"s (walking rounds) may have a free face to rubblize the remainder of the bed into the space vacated by the IR, sheared and lifted more or less as a block. The contour lines are more symmetrical on Retort #27 with the heave being distributed more towards the center. A probable cause of this configuration is the more gentle flexing of the shale beds by the detonation of the IR and less shearing on the IR side of the retort. Secondly, as seen from the Retort #27 heave contour map, a long depression developed on the walking round side of the retort. This region subsided as void was created underneath and the overburden lacked sufficient strength to support itself. As evidenced by the existence of the surface trough, the walking round in this region was very successful in creating void in the underlying beds.

Since void is indicative of blast performance and can be measured by surface heave, it will be used as a criteria for judging blast efficiency. As stated previously, if Retort #27 showed a decrease in the quantity of explosives used per unit volume of void created when compared to Retort #24, then the size increase from one acre to two acres may have improved blast efficiency. Table 11 gives important data pertaining to retort size, explosive quantity, void and percent void (percent of shale bed that contains void) for Retorts #24 and #27.

As noted from Table 11, Retort #24 had 224,595 cubic feet of void distributed throughout 1,622,075 cubic feet of the fragmented zone, which yielded a percent void of 13.8%. The amount of explosives used per volume of void created was 0.61 pounds per cubic foot. Retort #27 had 670,529 cubic feet of void distributed throughout 3,650,429 cubic feet of the fragmented retort zone which yielded a percent void of 18.4%. The amount of explosives used per volume of void created was 0.42 pounds per cubic foot.

Two important relationships can be seen from these figures: 1) the percent void within the shale bed increased as the retort's size increased, and 2) the quantity of explosives used per unit of volume of void created decreased as the retort's size increased. This suggests that as a retort's size increases, the amount of energy required at the retort's edge for shearing and flexing the shale consumes a decreasing proportion of the total explosive energy available during the blast. This reduction of the proportion of energy consumed by the "edge effect" liberates more energy for other purposes such as fracturing and creating void within the medial regions of the retort. The net gain is an increase in void. The final and most significant conclusion suggests that more void can be created in larger retorts than smaller retorts by using equivalent powder factors. (Powder factor, as used here, means the amount of explosives loaded into a retort per retort unit volume or size.)

2. Retort Size vs. Fracturing Characteristics - Fracturing within a shale bed is essential for retorting and thus it will also be used as criteria for assessing blast efficiency. The quality and distribution of fracturing, as well as void distribution, are revealed by core sampling. The locations of the core holes must be chosen carefully to obtain the most essential data and maximum benefit from a limited number of core holes. Figure 39 shows the core hole locations for Retort #27 and the following section explains the choice for each core hole location.

a. Post-Blast Coring Design

CH #1 - This core hole will reveal breakage in a typical trough area of the WR (walking round).

CH #2 - This core hole will determine breakage in a typical trough area of the IR (initation round).

CH #3 - This core hole will be compared with CH #5 to determine the effects of an increase in blast hole size from 8-3/4 inches to 9-7/8 inches on rock fracture characteristics.

CH #4 - This angled core hole will give evidence of lateral motion or lack of lateral motion associated with the transverse trough on the IR edge of the retort.

<u>CH #5</u> - This core hole of 8-3/4 inches diameter will be compared with CH #3.

<u>CH #6</u> - This angled core hole started outside the retort and was drilled at a right angle to the retort's edge it will yield information about the nature of the "edge effect" (shearing along edges) on Retort #27.

<u>CH #7</u> - This core hole will investigate the reason for the development of the surface trough on the eastern edge of the retort.

<u>CH #8</u> - This core hole will reveal what the retort zone looks like below the surface trough.

<u>CH #9</u> - This core hole will show the nature of shale fracturing at the WR edge of the retort.

Figures 40 through 42 show the fracturing as revealed by the core holes for Retort #27.

b. <u>Retort #24 vs. Retort #27 Fracturing Characteristics</u> - If better or improved fracturing characteristics were displayed in Retort #27 when compared to smaller retorts, especially Retort #24, then an additional evidence for improved blasting efficiency as a retort's size increases could be claimed.

1. <u>Retort #24 Fracturing Characteristics</u> - Retort #24 displayed inadequate fracturing in some regions near its bottom. This was attributed to the bottom being undershot (lack of adequate explosive energy to produce good fracturing) and as a result conditions detrimental to optimum retorting were suspected. The subsequent burning of Retort #24 confirmed this suspicion when certain regions at the bottom were poorly retorted or left unburned, as indicated by thermocouple data. An additional fracture

characteristic was observed on Retort #24 during its burn period. The sides of the retort had been overshot and excessive fracturing allowed a more rapid fire front advance along these margins. Blast design modifications were introduced for the detonation of Retorts #26 and #27 to address these regions and improve shale fracturing characteristics. These will be discussed in a subsequent section.

2. <u>Retort #27 Fracturing Characteristics</u> - Retort #27 showed improved fracturing over Retort #24. The most significant improvement was more uniform breakage in the bottom of the retort, a region which has been traditionally difficult to fracture. In addition, it appears that the excessive fracturing along the retort's edges which was noted in Retort #24 has been eliminated. The degree of improvement will be more evident once cold flow tests are run on Retort #27 to determine permeability.

Since the fracturing characteristics of both Retort #27 and #24 have already been compared, it remains to be determined if the retort size increase was the primary cause of improved fracturing within Retort #27 or if the improvements can solely be attributed to improved fracturing caused by the blast design modifications. To accomplish this, Retort #27 will be compared with the 3 previous retorts from which the blast design modifications evolved.

The blast design modifications consisted of: 1) the use of inert decks to address areas of over or under fracturing, 2) changes in the time delay for the detonation of certain holes to enhance shock wave interaction, and 3) the increase in hole size diameter of one row of the initiation round to monitor its effects on fracturing.

a. <u>Decking</u> - The ability to control energy propagation by using inert gravel decks is vital to vertical control of shale fracturing in a shale bed. Gravel decks change the distribution of explosive energy within the bed in two ways. First, they segment the blast hole into smaller columns which behave as individual charges thus creating directional shock waves and high velocity gas propagation, and greater shock wave interaction for regions that need improved fracturing. Second, they can be used to reduce the amount of explosive loaded into a blast hole and therefore decrease the specific charge and explosive energy in regions showing overfracturing. It was discovered from previous retort blasts that fracturing should be increased in the medial regions of the retort. Thus, certain holes in the initiation round were loaded with two gravel decks to encourage shock wave interaction. From post-blast analysis, the decks appeared to be successful in improving fracturing and void in Retort #27 middle regions. When compared with the core holes from the previously shot retort, Retort #26, Retort #27 had more uniform and evenly distributed void and fracturing characteristics with fewer unbroken sections occurring within the retort. In addition, the bottom confines of Retort #26 had been overshot (too much explosive energy) and excessive fracturing detrimental to proper fluid flow was suspected in this region. As a result, an inert deck was placed in the bottom five feet of certain roles to decrease the amount of specific charge and the degree of fracturing. Retort #27 displayed better void near the bottom with more uniformity and distribution than the previous three retorts, Retorts #24, #25 and #26. Communition (severly damaged and overfractured shale due to breakage by grinding) was reduced at the bottom of Retort #27 as compared to Retort #26, and more angular fracturing which creates better permeability was displayed.

b. Time delays - In addition to the use of decking on Retort #27, the time delays for the detonation of certain holes was extended to observe their effects on rock motion and assist in creating more shock wave interaction in order to improve fracturing.

c. Hole Size Increase - The increase in hole diameter from 8-3/4 to 9-7/8 inches in one row of the initiation round was a preparatory step toward using a large bore hole size on Retort #28. The larger holes detonated in the region sampled by core hole #3 increased the specific charge within the powder column indicating that the spacing between holes on future retorts could be increased without loss of fracturing quality. Naturally, this modification needed to be monitored on a small scale before its subsequent use on an entire retort. Both core holes appear to display about equal fracturing quality with the exception that the fracturing and void of core hole #3 is located at a greater depth.

All blast design modifications seemed successful in contributing to improved fracturing within Retort #27 and thus evidently played a role in the improved void and fracturing observed in Retort #27 when compared to Retort #24. But the significance of that role may be undeterminable due to the interaction of many variables which influence fracturing.

4. Blast Summary - Though absolute proof of increased blast efficiency for retort size increases can not be claimed for the comparison of Retort #24 and #27 due to the undetermined importance and role of certain factors (the effects of blast design modifications upon blast performance), it would appear that Retort #27 was a more efficient blast as judged by void created per explosive quantity used and the increased percent void displayed on Retort #27. In addition, past experience and the idea that the proportion of energy required for flexing and shearing at a retort's edge decreases as the retort's size increases, thus liberating more energy to improve fracturing and void within the retort, support this conclusion.

C. Re-entry Drilling and Retort Preparation - Re-entry drilling on Retort #27 began in July. During the first week of the month, all air-in and air-out holes were surveyed and staked. Drilling began the second week of July and continued into August. By the end of the third week of August, all air injection wells and off gas recovery wells had been completed. Drilling continued throughout the fourth quarter; twelve production wells and eleven observation wells are in partial completion. Production wells #9, #10 and #11 will be equipped with Johnson well screen on the bottom thirty feet, as opposed to the standard perforations on the other production wells. These screens are being installed in order to monitor effects on production, ease of operation,and required maintenance at the test wells, compared with the standard wells (see Figure 43 for process well locations).

Instrumentation and drilling began in November; by the end of the year, 55 instrumentation wells had been drilled and the accompanying instruments installed.

Stemming of the air-out and production wells has been initiated, as well as construction of the air injection and off gas manifolding. Construction of the mounting platform for the Roots off gas blower was completed and the blower mounted during December.

## IV. RETORT #28

Retort #28 will be Geokinetics' second 2 acre retort. A major experimental objective will be to design a blast under varying terrain. At the #28 site, overburden varies from 60 feet to 100 feet. Preliminary site preparation began on Retort #28 in May with the drilling of 5 holes to help locate the Mahogany zone (oil rich shale zone). Surface preparation was done in June so that blast hole drilling could begin in July. A blast design meeting ws also held in June to discuss the blast design and blast of Retort #28.

Blast hole drilling was completed on Retort #28 by the 11th of August with a total footage of 43,388 feet. The blast holes were then measured in order to determine the amount of water and drill cuttings that had filled the holes so as to verify actual hole depths before explosive loading. Final blast hole measuring was conducted on August 12-14. On August 15, the blast hole priming systems were installed. The explosive loading began on August 16. 354,349 pounds of Ireco aluminum nitrate slurry were loaded into 266 blast holes. By the morning of August 18, all holes had been loaded and stemmed to the surface, and the surface detonation systems were subsequently wired.

The blast was detonated at approximately 3:00 pm, August 18. Initial analysis indicated that the shot was successful. Post-blast surveying began on August 26 in order to assess the amount of surface displacement. This data will be correlated with high speed photography and other data to more fully evaluate the blast. The post-blast heave contours are displayed in Figure 38-b.

The detonation of the retort was significant because it tested Geokinetics' capability to blast a large size retort in an area with significant topographical changes and a non-uniform overburden. Since much of the Geokinetics-based land is found in terrain with varying topography, the capability and technology required for successfully blasting and retorting such areas will be vital for optimum land utilization and will increase the usable oil shale reserves.

A small hill located on the southwest section of the retort provided both topographical and overburden variance.

During the first week of September, post-blast surface contouring began on Retort #28. Contouring and leveling of the retort's surface was done so that the drill rigs could begin post-blast coring and re-entry drilling (i.e. drilling of retort process holes). By September 20, Geokinetics had begun coring various locations within the retort to assess the fracturing characteristics produced by the retort blast.

Post-blast core drilling continued throughout October and was completed in November. Analysis of the recovered cores will determine the effectiveness of the blast, and will be reported upon when completed.

Re-entry drilling of all air-in and air-out wells has also been completed.

A new procedure is being utilized to seal the annulus between the casing and the wall of the process wells to prevent gas leaks. A pilot hole 12-1/4 inches in diameters is drilled to within 10 feet of the oil shale bed. The remainder of the well is then drilled with a seven inch bit and cased with 6-5/8 inch pipe for air-in and off gas wells. A steel packing ring is welded to the casing at the level of the bottom of the pilot hole. The annulus is then packed with clay material and brought to optimum moisture content of 13-15 percent. The objective and advantage of the large pilot hole is to make available a large area for the repacking of earth around the pipe, enabling there to be a more effective seal against gas leaks from within the retort (see Figure 44).

## V. ENVIRONMENTAL SECTION

### A. Atmospheric and Ecologic Research

1. Meteorology - The goal of meteorological studies is to evaluate the existing microclimate and environment at the field site, and monitor any changes which might be induced by the retorting process. To this end, various and extensive meteorological readings are taken on a daily and weekly basis at several meteorological stations located at the research site (see Figures 45 and 46). Tables 12 and 13 describe the meteorological stations.

The monitoring equipment is serviced and calibrated at least quarterly, and a record of all adjustments is maintained, as well as an inventory of equipment in operation. In May, the Campbell Stokes sunshine duration recorder housed at station A-06 was permanently removed from the monitoring system. This instrument records the number of hours in one day during which sunshine intensity is above an amount equal to the duration of visible sunshine. Thus, only daily sunshine duration is recorded by the instrument, and as such, has more climatological value than meteorological. This action will not result in a loss of significant data because it is not currently applicable to Geokinetics research. If, for some future reason such data were deemed significant and directly useful to the environmental research, the sunshine recorder would be placed back into service and the data accumulated over the past 3-1/2 years would be utilized for any analytical and interpretive requirements.

With the end of calendar year 1982, the meteorological monitoring network that has been in operation since 1979 will be discontinued (see Table 12 for station descriptions). This network of individual meteorological stations (A-01 through A-07) was designed, at the time of implementation, to meet the research goals stated in the Geokinetics Environmental Research Plan (ERP). However, the meteorological system, particularly the two meteorological towers (stations A-04 and A-07), did not meet the necessary equipment specifications or monitoring requirements of the Prevention of Significant Deterioration (PSD) permit. It should be noted that the data collected by the former system provided climatological information rather than meteorological information.

Therefore, beginning in January of 1983, the meteorological monitoring system will be changed (new equipment added to existing 30-meter tower) in order to meet the PSD requirements. This change not only represents a savings in man-hours spent in maintaining (including data reduction) the individual stations, but also a corrective action that will align the purpose of Geokinetics' meteorological program with the requirements of the Utah Bureau of Air Quality. Data collected by the new system will establish a meteorological baseline for the air quality dispersion modeling stipulated by the PSD permit requirements.

Monitoring at the site will be conducted at two levels, 10 and 30 meters. Measurements at the 10-meter level will be used in estimating the dispersion of emissions from ground level sources such as fugitive dust from roads. Data collected at the 30-meter level will be used in a similar manner for modeling releases from elevated sources such as flares and stacks. Three basic parameters will be monitored at each level since, due to terrain complexities, significant differences may occur between sampling points, particularly in the case of atmospheric stability (see Table 13 for a description of the parameters monitored and equipment used at the new station).

2. Wildlife Monitoring Report and Field Manual - A draft report of the first year's wildlife monitoring data was completed by Dr. Robert E. Stoecker (Stoecker-Keammerer and Associates) during July. The report period extends from May 1981 through June 1982. Baseline investigations at the Seep Ridge site were conducted from May 1978 through May 1979. Some of the data obtained during the baseline period are presented in the report for purposes of comparison.

The main objectives of the wildlife monitoring program are to obtain data that will permit detection of substantial changes in important animal populations due to retorting or reclamation. As well, since monitoring studies are in a preliminary stage, an important additional objective is a critical evaluation of the efficacy of each component of the monitoring program.

Six wildlife studies are discussed in the accompanying text: 1) pellet transect studies, 2) pellet counts on revegetated surfaces, 3) road counts, 4) impact studies of open water impoundments, 5) raptor observations, and 6) threatened and endangered species.

In addition to the monitoring report, a field manual detailing the procedures for each of the component studies was presented to Geokinetics. This manual will be published along with the first year report in early 1983. Copies of the reports will be presented to the DOE after publication.

Summary of First Year Results

Pellet Transect Studies - Pellet transect studies are designed to obtain abundance data twice each year (spring-summer and fall-winter) on mule deer, elk, cottontails, coyotes, and pocket gophers, and also on the occurrence of domestic cattle.

Eight pellet transects in close proximity to Kamp Kerogen were set-up for the study (Figure 47).

The main objective of the pellet transect study is to check for indication of relative differences in animal abundance between areas located near retorting activities, and areas located some distance away.

Mule Deer - First year results of mule deer pellet counts suggest that deer are not being displaced from the project site. Wildlife pellet transect #6 (W-6) had the highest deer pellet group density (Figures 48 and 49) yet it is located nearest to active retorting facilities. In view of the relatively short time span involved with the results, a statistical evaluation of the findings was not performed, although it is entirely possible. A different pattern could occur next year due merely to changing habitat conditions resulting from grazing or other causes.

An obvious correlation of data points between the 1978-1979 and 1981-1982 periods suggest that deer usage of local sites is very similar. The correlation is highly significant (r=.84; df=8; PL.002). This is graphically shown in Figure 50.

Other Wildlife and Cattle - Data obtained on elk, cottontail, coyote, pocket gopher, and cattle for this year are presented in Table 14. Comparable data are not available from the baseline period.

Elk have rarely been observed near the Seep Ridge site, and it is somewhat surprising that two occurrences of elk pellet groups were identified along the transects. Data for the remaining species have little utility at this time apart from providing information on general levels of abundance, habitat affinities, and seasonal differences in population sizes. In the future, however, these data will be useful for evaluating differences between revegetated and control sites.

Road Counts

Wildlife Monitored - Road count studies are being conducted primarily to record numbers of deer, and deer road kills, in the vicinity of the Seep Ridge site (Figure 51). Sightings of raptorial birds are also recorded. Additionally, information is at least potentially available on elk, grouse, and other wildlife species of interest such as bobcats, and coyotes. All sightings of unusual or rare wildlife species are recorded.

The results of road counts conducted this past year (Table 15) suggest only moderate numbers of deer in the vicinity of the Seep Ridge site. These findings are consistent with the estimates of deer populations from pellet group densities. No indications at this point suggest important road crossing locations. One road killed deer was identified approximately 5 miles south of the Seep Ridge site on 3 June 1981. This was the first road count performed. No other road kills were observed during the following 22 counts of this past year.

Raptorial birds were observed on only five road counts. Three species were identified, the rough legged hawk (a winter resident), redtailed hawk (permanent resident), and the bad eagle (also a winter resident). This was the first sighting of a bald eagle in the vicinity of the Seep Ridge site. The bird was observed in flight on May 12, 1982, approximately 5 miles north of the Seep Ridge site.

Impact Studies of Open Water Impoundments - The wildlife species searched for near open water impoundments include dead specimens of birds and small mammals (Figures 52 and 53).

During the course of the investigations (a total of 20 separate observations) only one specimen was found. One unidentified bird (a passerine) was found dead in Pond #2. No other evidence of hazards to wildlife from these two open water impoundments was obtained.

In view of the almost total absence of observed mortalities near the two impoundments, it was decided to discontinue these studies.

However, unstructured observations in the course of other activities will be performed as a check on any conditions that are hazardous to wildlife.

Raptor Observations - In May 1981, attempts were made during mornings to locate nesting raptorial birds. The Seep Ridge site (Section 2 and a surrounding zone of approximately 1 mile) was searched on foot and from a vehicle. No nesting raptors were located. Similarly, results of baseline invesgations indicated no active raptor nests on the site. One redtailed hawk was seen during the course of observations made during May 1981. It is possible that this bird nested nearby, but since so few raptor observations are made by personnel working at the site, it seems unlikely that nesting raptors are at all common in the immediate vicinity of the retorting facilities.

Threatened and Endangered Species - Observations for threatened or endangered wildlife species conducted during the baseline period and during this past year have resulted in only one sighting, which was mentioned previously in the section on Road Counts. Namely, one wintering bald eagle winter roost sites are known for the vicinity. Bald eagles regularly occur during winter in this region, even at distances well away from large rivers. There is no reason to believe, however, that habitats are present within the 1 mile study area zone surrounding the Seep Ridge site that are of particular importance to bald eagles, or to any other endangered wildlife species currently on the federal list.

Field Observation/Pellet Transect Study - First year results of the pellet transect study were presented above. These results, although short term, suggest that deer and other wildlife are not being displaced by retorting activities. Field observations during the sampling indicate that very few deer were present at the site since the spring sampling. These observations, however, do not necessarily imply that deer are being displaced, but rather that the deer had not migrated through the area at the time of the sampling. Although the mule deer pellet counts were low, numerous elk counts were recorded at nearly every transect. The occurence of elk at the site has been regarded as rare from previous data. These sample results suggest that the occurrence of elk may vary from year to year, and not be as rare as previously indicated.

Pellet Counts on Revegetated Surfaces - Pellet counts on revegetated retorts are similar in design and purpose to the pellet transect studies. Field observations during this sampling did not differ from previous samplings. Deer and elk were not observed; domestic cattle and cottontails were common. Since the revegetated retorts are close to the work areas, this is to be expected.

3. Retort #25 Soil Temperature Study - Soil temperatures at various depths on Retort #25 and at a control location (Figure 54) were monitored during the burning process of the retort. Soil temperature has a direct influence upon several physical and biological factors in the soil. Increased temperatures have the potential to alter these factors so that the establishment of plants utilizing standard revegetation techniques may be less productive.

With this in mind, the study was designed to obtain data that would allow for a preliminary evaluation of the retorting effect upon soil temperature, as well as allow for the design of future studies to determine the effect of increased soil temperature upon revegetation practices.

The study was initiated in October 1981 during the first week of the Retort #25 burn. Soil temperature probes (type "T" thermocouples) were placed along the soil profile at 10, 50, 100 and 150 cm depths. Soil temperature data were collected automatically on a daily basis with the use of a data logging system. In order to avoid the effects of solar radiation upon soil temperature, data were collected during the early morning hours. Temperature data were recorded from the data logger to a magnetic tape which was transferred to a computer system for storage and analytical reduction.

Results

Retort #25 burned for a period of 243 days (Oct-June). Average monthly soil temperatures during this period are given in Table 16. In addition, difference among means per depth are graphically represented in Figure 55.

As shown, differences between mean temperatures occurred during March or approximately 150 days into the burn. Comparison of retort temperatures and control temperatures over time at each depth are given in Figure 56. Again, the separation in temperature curves displays the difference between locations during March.

Soil temperatures recorded on Retort #25 and at the control site were subjected to statistical analysis in order to assess any significance of change between locations.

Discussion

An increase in soil temperatures seems to be occurring on Retort #25 as compared to the control location, although statistically there is no significant difference at the 95% confidence interval for the tested periods. The analysis is somewhat misleading in that substantial differences did not occur until the latter two months, at which time the limited number of samples precludes statistical analysis. As represented by Figures 55 and 56, differences between locations seems to be increasing over time. Significant differences will most likely occur during post-burn recovery. Soil temperatures will continue to be monitored during this period to determine if differences are occurring, as well as to determine when the retort location begins to return to normalcy.

The recorded effect to date of the retorting process upon soil temperatures indicates that possibly a more in depth evaluation of this effect may be required prior to finalizing revegetation practices. Further analysis of post-burn data may determine this need.

4. Land Rehabilitation and Soil Temperature Study/Retort #24 - On November 9, 1982, a meeting was held with representatives from the U.S. Forest Service Intermountain Station (Logan, Utah) to discuss possible expansion of the on-going cooperative revegetation program.

The meeting resulted in an agreement to develop a study prospectus for revegetation research on Retort #24. The prospectus was received from the Forest Science Laboratory during December and will be forwarded to the DOE (LETC) for their review and comments.

In conjunction with the proposed revegetation study for Retort #24, A soil temperature study was initiated on Retort #24 during the first week of December. Sixteen soil thermocouples (bi-metallic type) were placed on the surface of Retort #24 in pre determined locations. An additional four thermometers were placed in separate locations away from the retort boundary. These "off-retort" thermometers will be used as control sites (see Figure 57 for locations).

Each thermometer will measure soil temperature at a depth of twelve inches. Manual readings from all thermometers will be taken weekly and kept by the environmental department.

Data obtained from this study will provide information regarding the possible impact of elevated soil temperatures on the establishment of selected plant species. This study is similar in scope to the Retort #25 soil temperature study but is specifically being conducted in association with the proposed U.S. Forest Service revegetation research study to be implemented on Retort #24, and will continue throughout the cooperative research project.

5. Plant Studies

a. Endangered Plant Species Study - Studies designed to monitor the occurrence and abundance of proposed rare, threatened or endangered plant species at the Seep Ridge research site were completed during June. It was originally believed that a few proposed endangered or threatened species might be affected by the retorting process. However, those species of concern were either found occurring only on roadsides and waste areas or had been removed from the threatened or endangered species lists. A listing of the status of the proposed threatened, rare or endangered plant species is presented in Table 17.

From all available information, it is not expected that the research activities will harm or disturb the existence of these plant species in any way.

b. USFS Plant Survival Studies - During September, plant survivial and growth measurements were taken on Retorts #10 and #18 following their second growing season and on Retort #11 following its third.

The plant survival study is a cooperative effort between Geokinetics and the USFS Intermountain Forest and Range Experiment Station, Provo, Utah. The main objective of the study is to provide information on the adaptability of several species of plant (trees, shrubs, forbs and grasses) established by transplanting container-grown planting stock. This information will be beneficial for the development of a successful and economically viable revegetation plan on burned in situ retorts.

Results/Discussion - Plant survival and growth measurements for Retorts #10 and #18, and Retort #11 are given in Tables 18 and 19, respectively. The tables depict the overall survival and growth measurements since the species were planted. A frequency distribution of overall plant survival for all the retorts is given in Figure 58.

The majority of the plant species alive during the spring sampling survived during the growing season. The only significant loss (>10%) occurred with the Oregon grape (Berberis fremontii) species. These plants were observed to be unhealthy during the spring sampling, and their loss may be contributed to low precipitation amounts occurring during the early growing months (Figures 59 and 60).

As shown in Figure 58, of the 39 species planted, 31 of them have a survival rate greater than 50%, while only 11 of the species have a survival rate of 80% or greater.

As yet, an acceptable survival rate has not been established, but species with less than 50% survival will most likely be questionable for utilization on retort surfaces.

Further analysis over longer periods of time will be necessary before final selections of the tested species are made. However, a preliminary evaluation will be conducted following the 1983 fall sampling in order to select favorable species for future studies.

Planted retorts will be sampled again in the spring of 1983 in order to determine if any loss occurred during the winter months.

B. Hydrologic Research - Hydrologic research has been focused on two acres throughout 1982: 1) peripheral well water quality studies on Retorts #23 and #24, and 2) process water characterization studies on Retorts #25 and #26. The following is an account of the work performed.

1. Peripheral Well Water Quality Studies - Retorts #23 and #24 - During October, the fifth (this year's final) suite of samples was collected from peripheral wells surrounding these two retorts as part of a long term study to determine changes in water quality during the post-burn phase of these retorts. Chemical analysis is being performed by the analytical laboratory. This data will be

compiled and analyzed, and conclusions drawn therefrom, by the Environmental Department. A report will be made at the conclusion of the study (see Figures 61 and 62 for well locations).

2. Process Water Characterization - Retorts #25 And #26 - An on-going comparative study of process waters from Retorts #25 and #26 has been under way since November 1981. This study will show the differences that occur in process waters over the life of each respective burn, as well as provide comparative data to investigate the differences between the process waters of the two retorts. The chemical constituents are to be identified, characterized and quantified, in order to provide data for future environmental fate studies.

The sample will be analyzed by the Geokinetics Analytical Laboratory, except for the following parameters:

- Total Organic Carbon (TOC)
- Total Inorganic Carbon (TIC)
- Biochemical Oxygen Demand (BOD)
- Total Kjeldehl Nitrogen (TKN)

These parameters will be analyzed by an outside laboratory.

Since this is part of an on-going study, individual sample results on Retort #26 have not been tabulated. Final results will be presented in a report after all samples have been taken and the study completed.

However, the report for Retort #25 is complete, and is summarized here.

The investigation was initiated in November 1981, one month into the burn of the retort. Samples were gathered from the water produced with the oil, and separated at the tank farm compound. Chemical analysis was performed by the laboratory in accordance with standard methods and methods adapted for retort wastewater. General statistical analysis was performed on the data and is reported in Table 20.

As would be expected, the water contains large concentrations of inorganic and organic compounds. A comparison of analytical results from Geokinetics and Monsanto Research Corporation is given in Table 21. A visual comparison of the data show the wide variability in results, especially between the analyses by Geokinetics. This variability is the result of many factors for which numerous researchers have reported upon (Fox, 1980; Farrier, 1979).

In order to decrease the variability within our own results, additional sampling is planned during the burn of Retort #26. In addition, variability over time will be addressed once analysis is completed.

More in-depth analysis will be performed on the results of both retorts once the studies are complete.

C. Permit Status and Environmental Research Record

1. Permit Status and Compliance Evalutions - During the burn of Retort #25, Geokinetics applied for and received a waiver of applicable regulations regarding $SO_2$ and $NO_x$ emissions in order to test an experimental wet scrubber. Since the expiration of that waiver, Geokinetics has operated under existing regulations, and within stipulated limits.

During March, reclamation officers from the State of Utah Division of Oil, Gas and Mining visited the field site to inspect Geokinetics' reclamation activities and land disturbance. These representatives indicated that Geokinetics was in compliance with reclamation regulations, in accordance with permit stipulations.

On October 27, George Chlarson of the Utah Bureau of Air Quality (UBAQ) Enforcement section conducted the annual air quality inspection of the research site.

The inspection consisted of a visual surveillance of all sources of emissions (retort afterburner, electrical generator and access roads) located at the field site and an opacity evaluation which was performed on the retort afterburner exhaust. No visible plume was observed, indicating compliance. The opacity limit is 20 percent.

Mr. Chlarson also noted that Geokinetics was in compliance with applicable standards of the Utah Air Conservation Regulations, revised July 1982, as well as conditions of the Utah Air Construction permit approval order issued to Geokinetics by the UBAQ in November 1980. A copy of the source evaluation is on file at the field site environmental office.

2. Environmental Research Records - Revisions to the preliminary draft Environmental Research Record were completed during November. Copies of the revision have been forwarded to the DOE.

The Environmental Research Plan is a two document plan composed of: 1) the Research Program Outline (RPO), and 2) the Research Record (RR). The RPO defines the general goals and objectives of the entire research program, whereas the RR describes the actual research performed, modifications, and conclusions and therefore is the dynamic segment of the ERP and not merely an addendum to the RPO. In tandem both documents comply with the provisions set forth in the Environmental Assessment (DOE 1979) and the Cooperative Agreement (DE-FC20-78LC10787). The RPO was published November 30, 1979.

## VI. ADDITIONAL ACTIVITIES

A. Hydrogen Sulfide Removal from Process Gas - Laboratory testing of a process to remove hydrogen sulfide ($H_2S$) from retort off gas has been underway throughout much of 1982. By October, this research had led to the construction of a hydrogen sulfide scrubber tower. The tower is 30 feet tall and 3-1/2 feet in diameter. The process gases are routed up through the tower from the bottom, while water flows down the tower from the top. The water and gases meet in and pass through a packing of stainless steel saddles, where they come in thorough contact one with another. By means of this contact, the hydrogen sulfide is removed from the process gas and is carried away by the water, which continues down through the scrubber. The process gas continues up the scrubber and is piped back into the manifolding system to be carried to the afterburner and combusted.

In bench scale testing, under optimum conditions, this process has been found to be as much as 88 percent efficient in removing the hydrogen sulfide.

Table 22 is a summary of testing during November and December (tests carried out in October were not valid due to analytical error). During December, a double-column laboratory scrubber was constructed. In column #1, gas and water enter the column and pass through the packing as previously described. The water then goes into a recycle reservoir for column #2, and the gas is routed to the bottom of column #2. In column #2, the gas, already scrubbed in column #1 by fresh water at a high flow rate, is scrubbed by recycle water at a slower flow rate. Testing has shown that when column #1 is operated at high flow rates, up to 88 percent of the $H_2S$ can be removed; when this already-scrubbed gas is introduced into column #2, results demonstrate that $H_2S$ is then added to the gas, and that the longer the gas is allowed to be in contact with the recycle water (or in other words, the slower the flow rate) the more $H_2S$ is released from the recycled water and returned to the gas (See Figures 63 and 64 for a representation of the single and double column laboratory scrubbers. Note the sample ports for sampling the gas at each step).

Flow rate and temperature are critical factors; when these are controlled, consistently good results can be achieved. Although not a critical factor, efficiency was optimum when water pH was between 9.5 and 10.

B. <u>Thermosludge Boiler and Ammonia Stripper</u> - At the end of

September, a bench scale ammonia stripper was constructed by the analytical laboratory. Testing was undertaken throughout October and November, and has indicated that ammonia can be stripped from retort water using steam, and that water concentrated by the thermosludge boiler will retain the acidic toxins such as arsenic, phenols and cyanide. This will allow direct venting of the steam to the atmosphere, without venting of the contaminants as well.

That data accumulated by these tests will assist KTI (of California) in the design and engineering of full-scale operational equipment.

C. Health and Safety - The management, staff and employees of Geokinetics are committed to insuring the health and safety of personnel in all aspects of our operation. In order to implement, administer and upgrade the safety program of the Company, a Safety Committee has been organized, composed of the Project Manager, four line supervisors, two field employees and one safety representative.

Throughout the year, this committee has made a number of decisions, and implemented them, regarding specific potential hazards and their elimination. In addition, regular safety meetings on a wide spectrum of safety issues have been conducted to raise the safety awareness, consciousness and knowledge of all employees. Fire extinguishers and other safety equipment is maintained and upgraded as necessary.

1. Industrial Hygiene and Medical Survey Study - The final review of the draft report for the Industrial Hygiene and Medical Survey Study was completed by Geokinetics personnel during October. Comments were sent to the Los Alamos National Laboratory for incorporation into the final report. After final in-house review by LANL, the report is due to be published early in 1983.

The study was conducted under the auspices of the DOE Oil Shale Task Force, and was designed to define and evaluate potential inhalation exposures associated with the horizontal in-situ process as well as update occupational health information pertaining to in-situ recovery of shale oil.

D. Electrical Generation - A 1,000 kilowatt diesel/natural gas-fueled generator was brought on line at the end of October for testing to determine fuel consumption rates, efficiency and emissions for the respective fuel options. Major rebuild work on the Cat G399 650 KW generator, the main power source, necessitated the utilization of the 1,000 KW generator and provided the opportunity for extensive on-line testing under primary service conditions.

Rebuild work on the Cat G399 took about three weeks, and included redesign and refabrication work on the cooling system to provide greater cooling capacity. Completion of this repair work was accomplished none too soon, as the 1,000 KW generator was taken out of service due to an overheating malfunction that caused extensive damage.

Power generation capacity is rounded out by two 700 KW diesel generators that are used as back-up.

E. Tank Battery Expansion - A tank battery expansion program has been underway since April. The objectives of the expansion are to increase and upgrade oil storage capacity, as well as to provide storage capacity closer to the production site.

At October's end, all earth preparation had been completed and two 10,000 barrel tanks had been constructed. A four-inch diameter emulsion line and steam tracer has been installed, connecting the retort sites to the new storage facility. The emulsion line will transport the oil/water emulsion, while the steam tracer will heat the pipeline and keep the emulsion above pour point (70°F), insuring that the oil will flow within the line.

Two 500 barrel wash tanks are also in place, awaiting construction of their respective heating units and the steam generator. These wash tanks will heat the oil prior to storage, thereby releasing any emulsified water and bringing it within refiner's specifications of not more than one percent bottom sediment and water.

In order to supply fuel for the steam generator, which will provide steam for the emulsion line and wash tanks, a natural gas pipeline was installed underground during December.

F. Process Gas Recycling Project - A ten inch diameter pipeline was constructed during November from a point before the afterburner back to the first set of off gas well on Retort #26.

This pipeline became operable during December for the purpose of reinjecting off gas into the retort in an experiment to monitor changes in retorting, fire front advance, oil production, etc.

The experiment was suspended when results demonstrated that the fire front was too close to the off gas wells where reinjection was taking place. Experimentation may resume at a future date (see Figure 65).

G. Recontouring - Recontouring and reclamation work was carried out in November on Retorts #15 and #19. Pipes protruding from the surface of Retort #15 were removed. The surfaces of the retorts were recontoured, as well as various locations surrounding the roadways of Kamp Kerogen.

H. Sandia Laboratories Experiments - During the second week of November, Ron Jacobsen and Lou Bartell from Sandia Laboratories conducted experiments in the determination of fire front location using electronic equipment coupled with radio transmission and reception.

The purpose was to test the accuracy of the method by comparison of the experiment records with the data gathered and recorded by the thermocouple network already in place on Retort #26.

Mr. Bartell indicated over the phone that preliminary results were encouraging and that final results will be made available to us as soon as possible. A copy of their findings will be forwarded to the DOE when it is received.

The experiment is significant because it could eventually lead to the obsolescence of the underground thermocouple system eliminating its expense and enabling fire front monitoring to be done from the surface.

I. Visit by Synthetic Fuels Corporation Officials - On Tuesday, November 16, Kamp Kerogen was visited by an entourage of officials from the Synthetic Fuels Corporation, who were given a tour of "the only oil shale project in Utah to produce any significant amount of shale oil," operating under the Cooperative Agreement with the Department of Energy.

While in the area, the officials were also given aerial overviews of other oil shale projects, enabling them to see and compare firsthand the varying degrees of operational readiness of the respective projects.

## REFERENCES

1 Burnham, A.K., J.E. Clarkson. "Determination of Process Yield for Oil Shale Retorting by Oil Analysis Using Capillary Column Chromatography." 13th Oil Shale Symposium, April 1980.

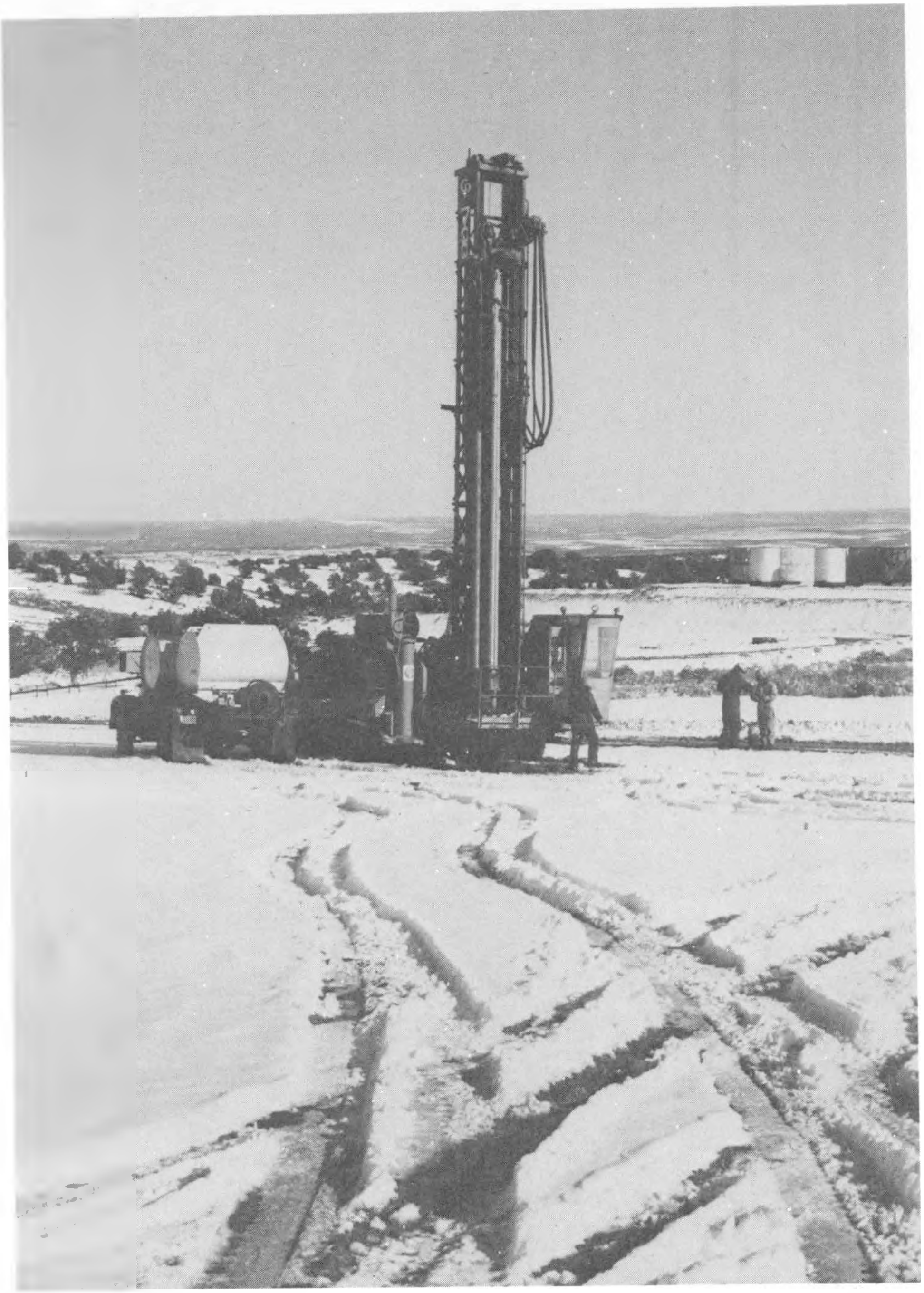
Day, D.R., G.D. Rawlins. Oil Shale Wastewater Analysis and Characteristics, Monsanto Research Corporation Contract No. 68-03-2801 (1981) - Draft Report.

Fox, J.P., "The Portioning of Major, Minor and Trace Elements During Simulated In Situ Oil Shale Retorting," Ph.D. Dissertation, University of California, Berkeley (1980).

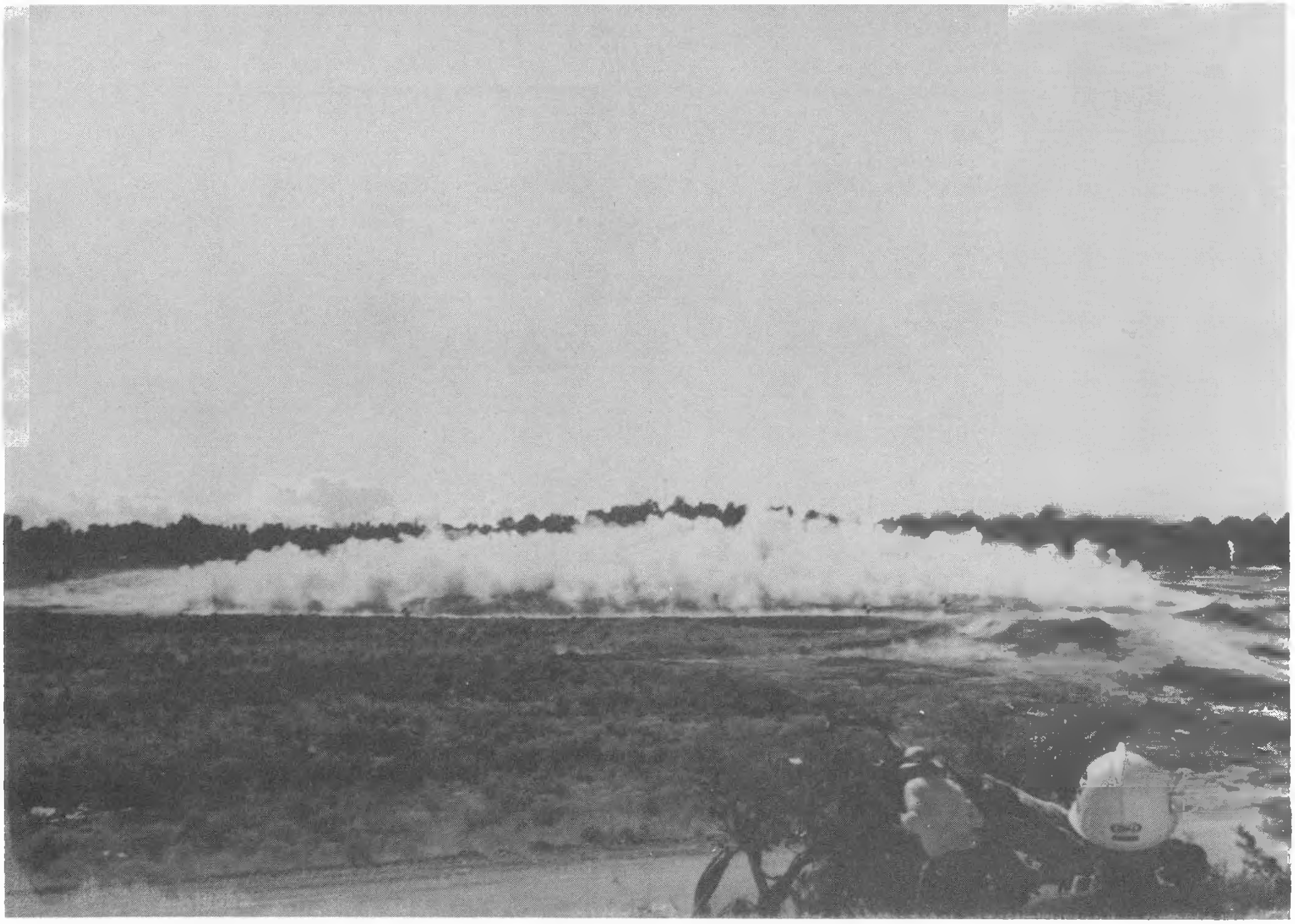
Farrier, D.S., J.P. Fox and R.E. Poulson. Interlaboratory, Multimethod Study of an In Situ Produced Oil Shale Process Water, "Proceeding of the Oil Shale Symposium: Sampling, Analysis and Quality Assurance," U.S. EPA - 600/0-80-022 (1979).

Spradlin, Hilding K.L., David L. Hutchinson, Steve G. Mankowski. "Environmental Research Plan for the Geokinetics Inc. Investigation of the Horizontal In Situ Oil Shale Retorting Process - Research Program Outline." Prepared under Department of Energy Cooperative Agreement #DE-FC20-78LC10787, Nov. 1979.

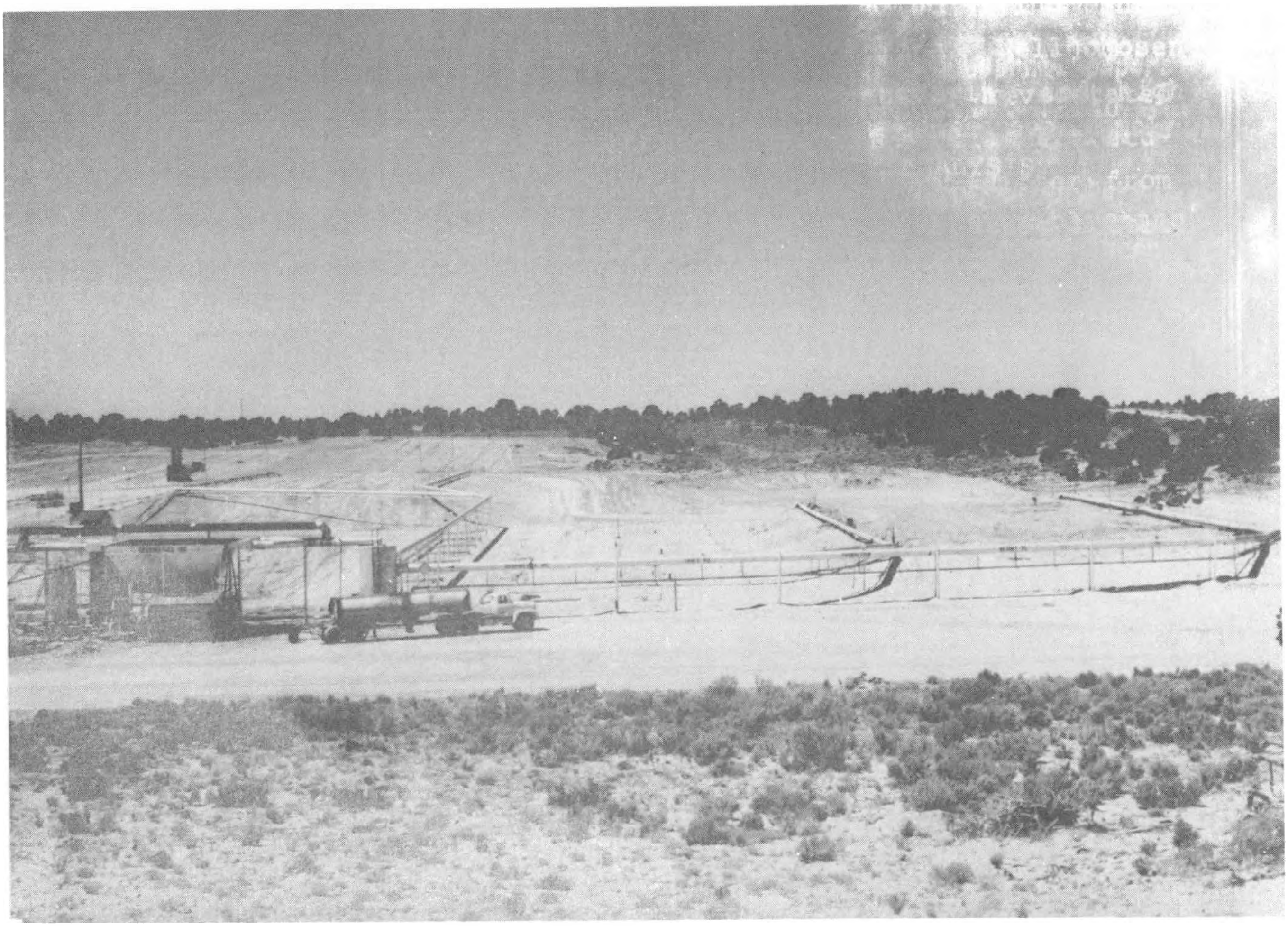
Stoecker, Robert E. Ph.D. "Wildlife Studies for the Hollberg Oil Shale Site, Uintah County Utah." Stoecker-Keammerer and Associates, Boulder, Colorado, 1979.



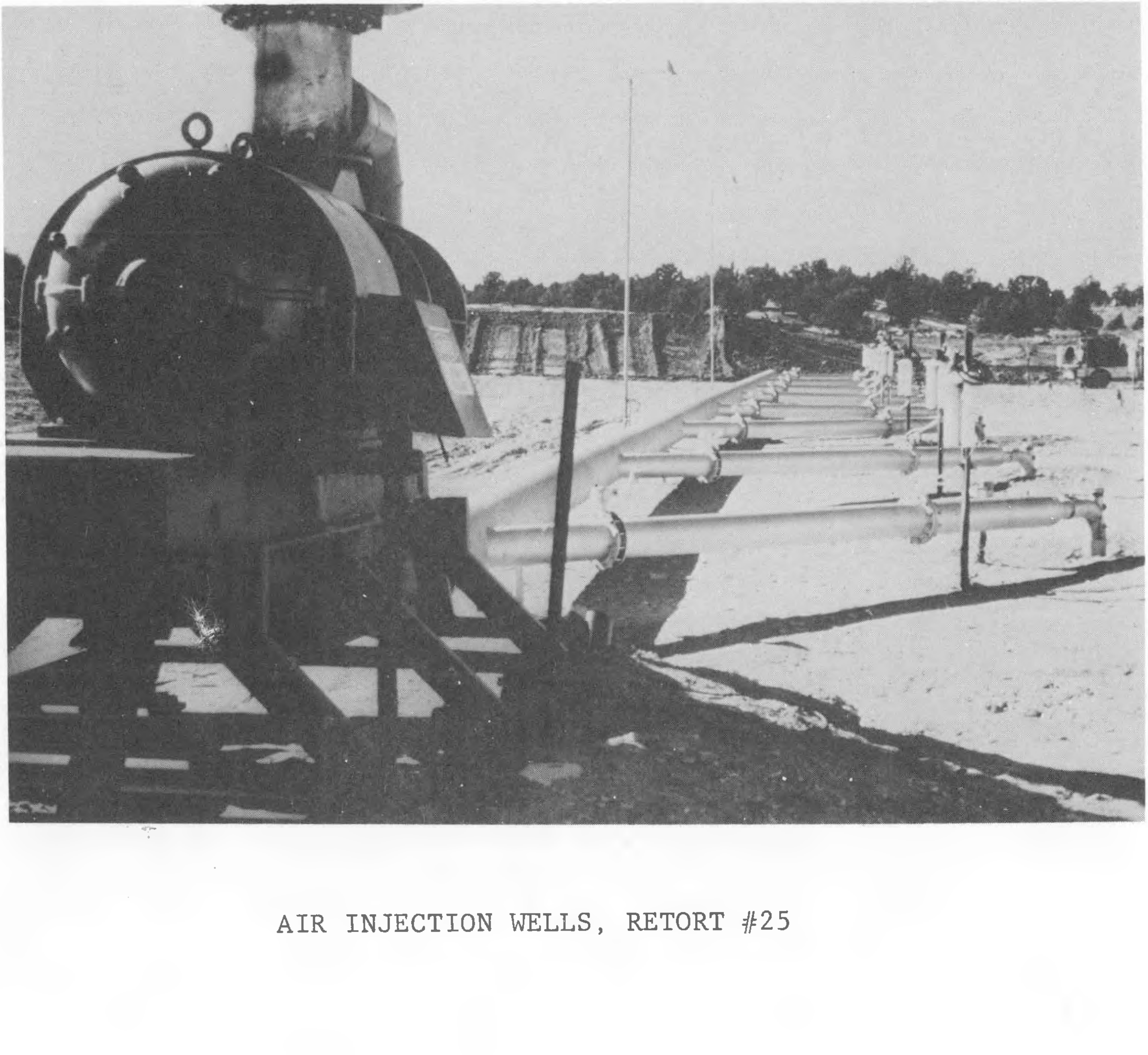
DRILLING PROCESS HOLES, RETORT #27



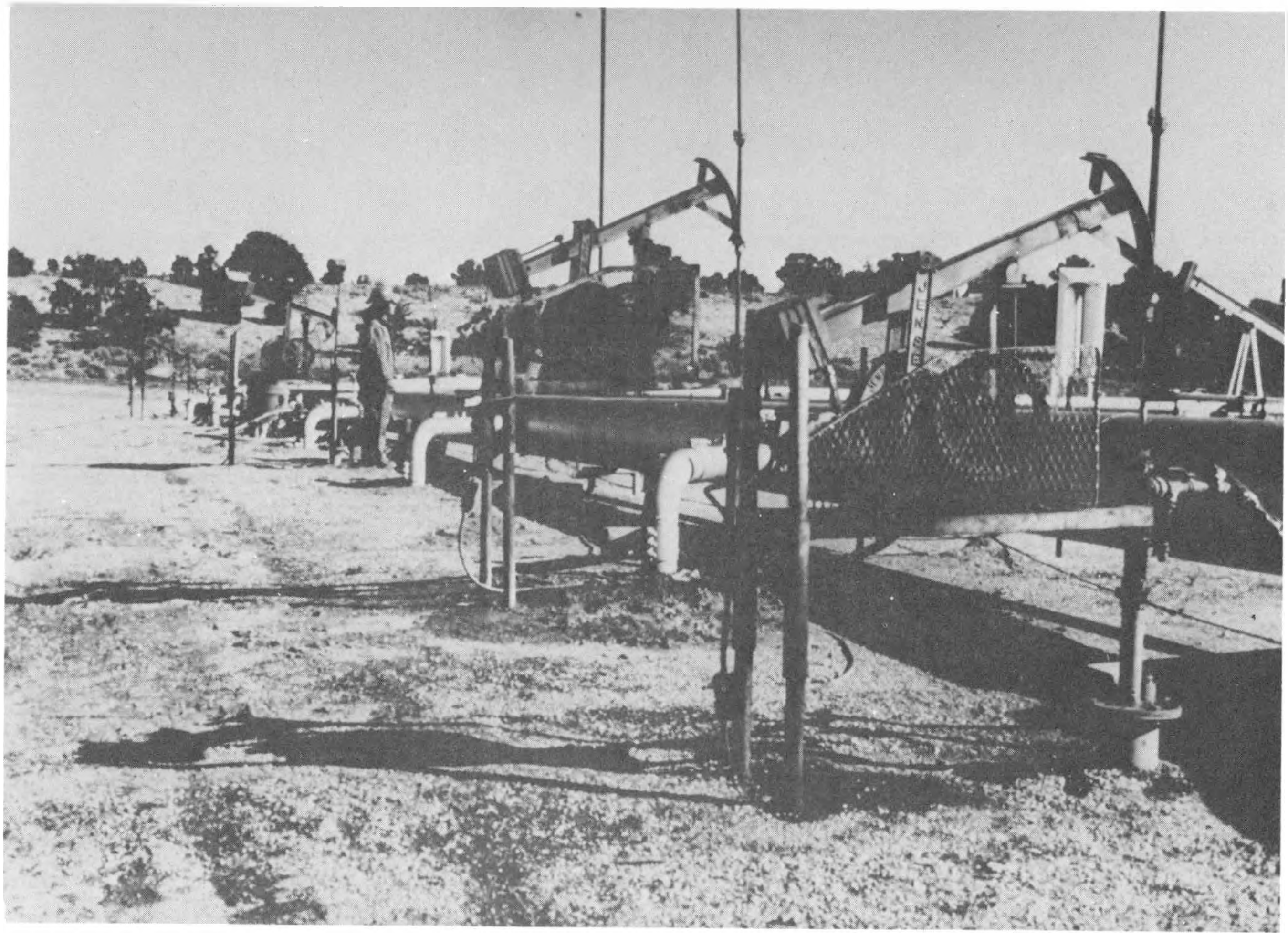
BLASTING RETORT #27



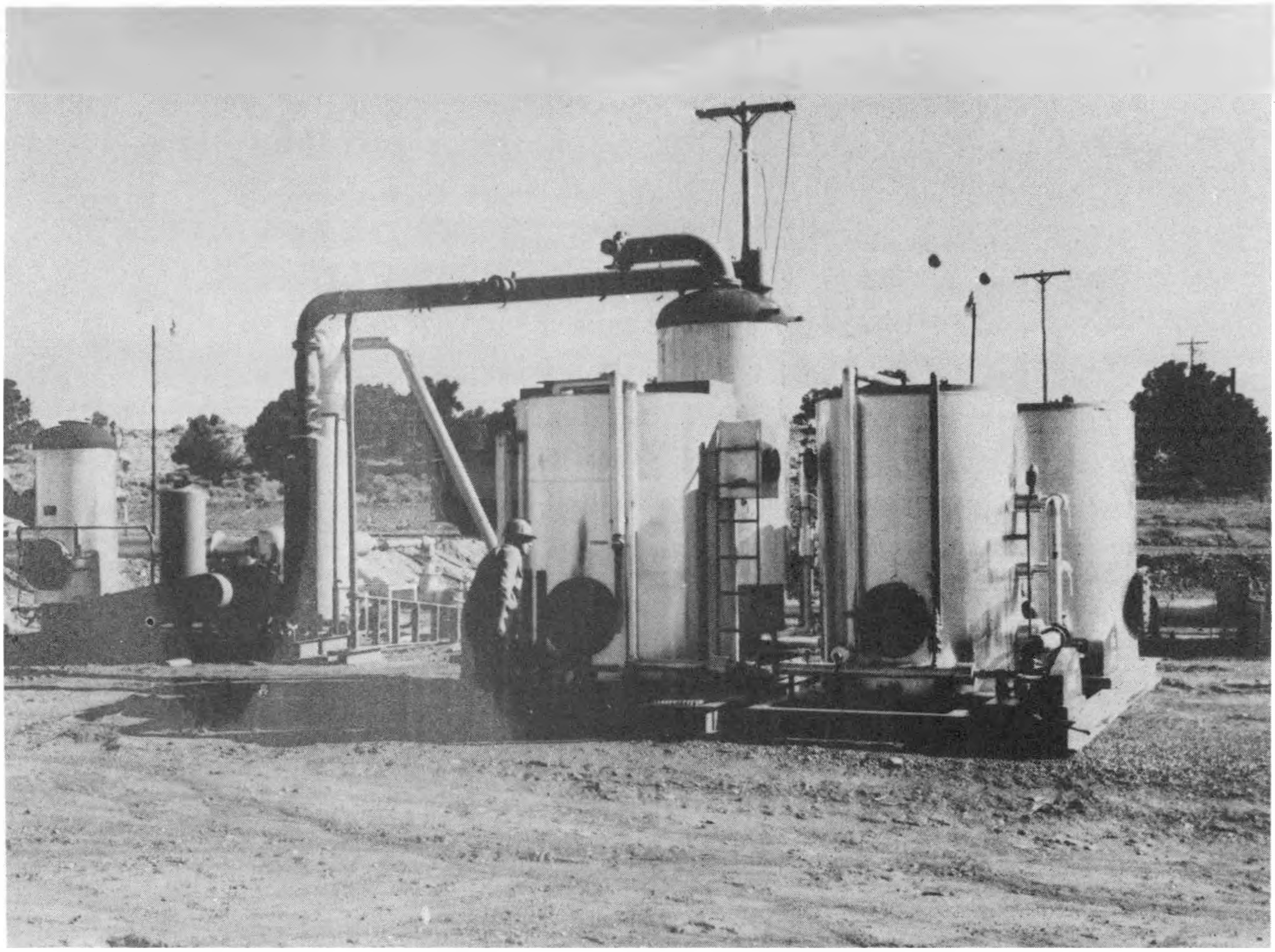
RETORT #25 IN OPERATION



AIR INJECTION WELLS, RETORT #25



PUMPING SHALE OIL, RETORT #25



PILOT GAS CLEANUP PLANT IN OPERATION

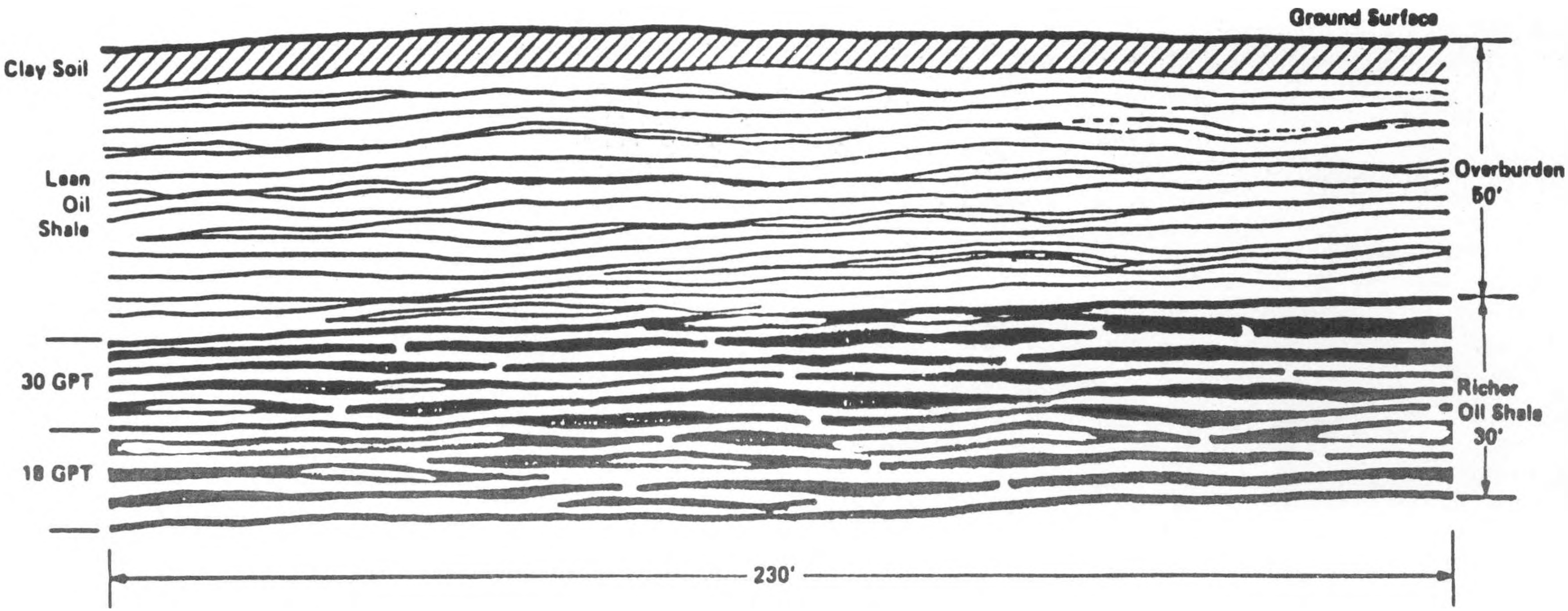



Figure 1. Initial Land Cross-Section

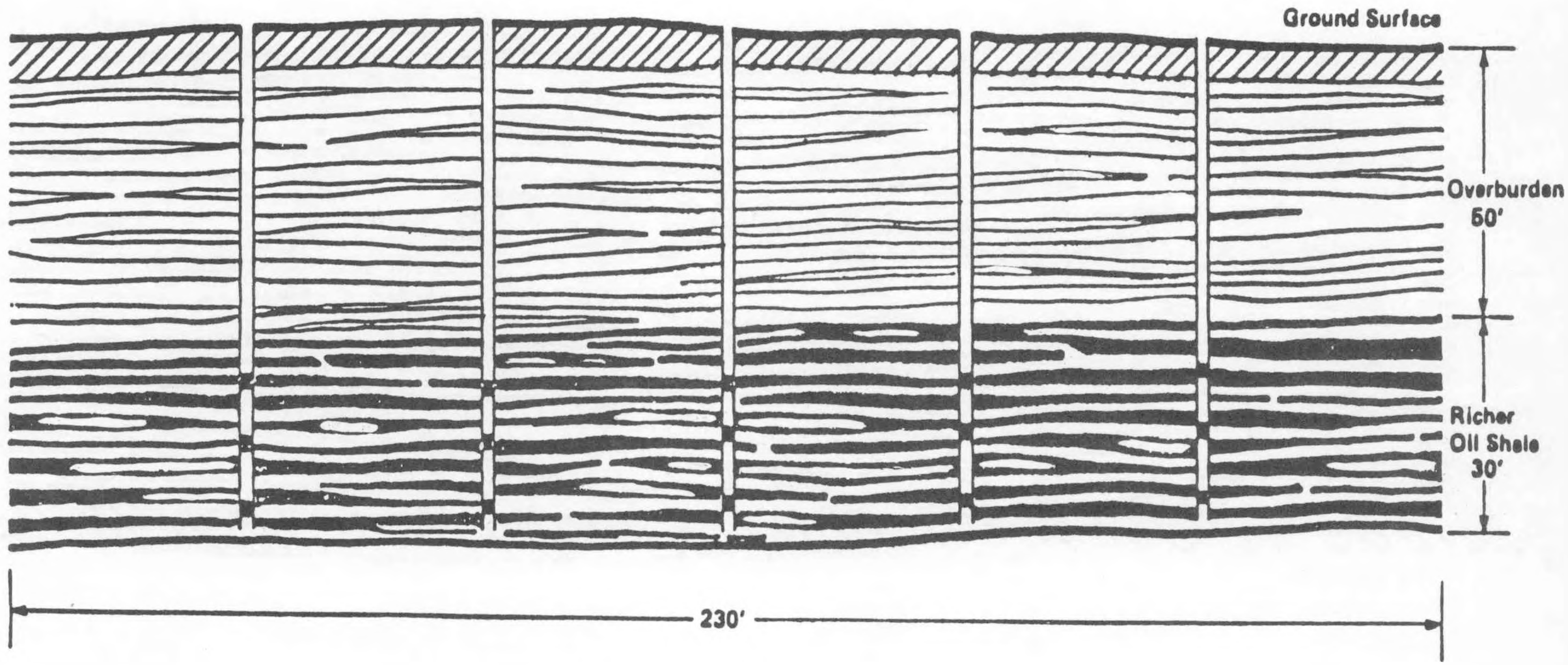
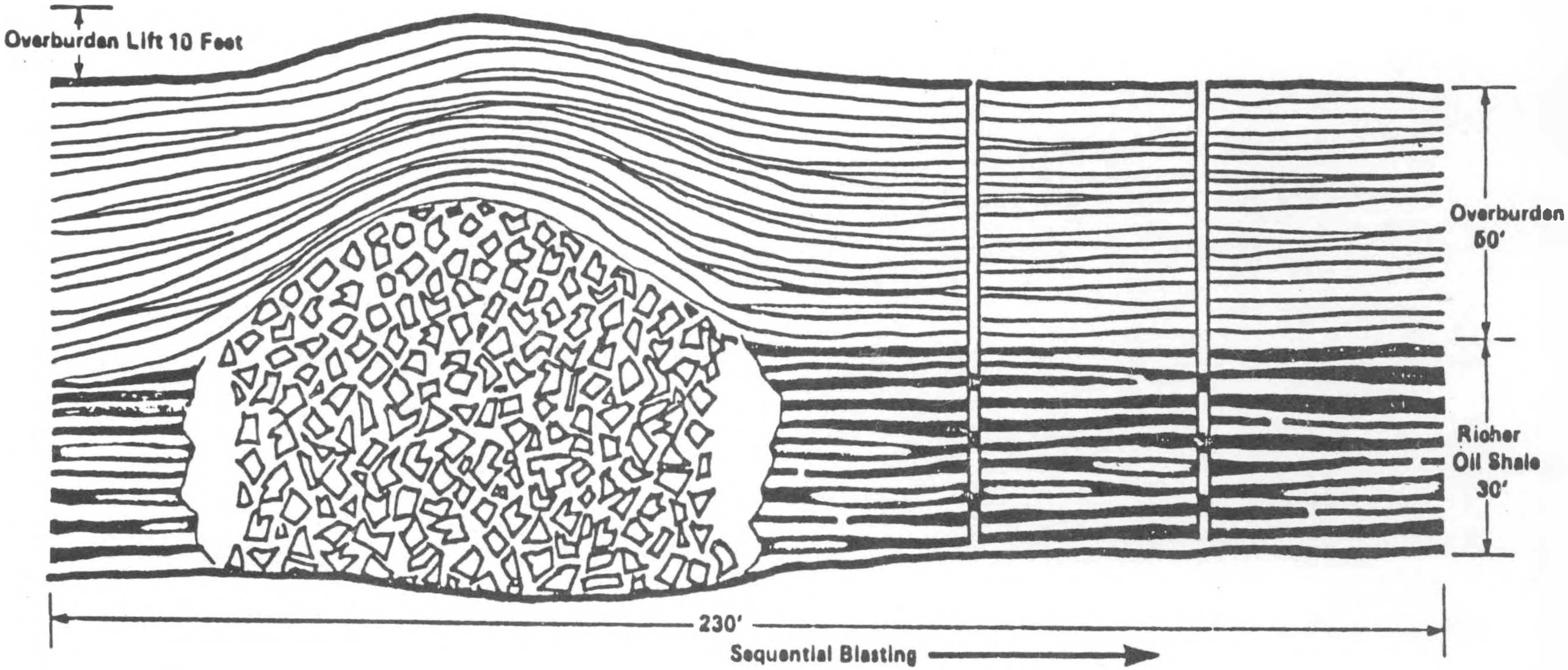
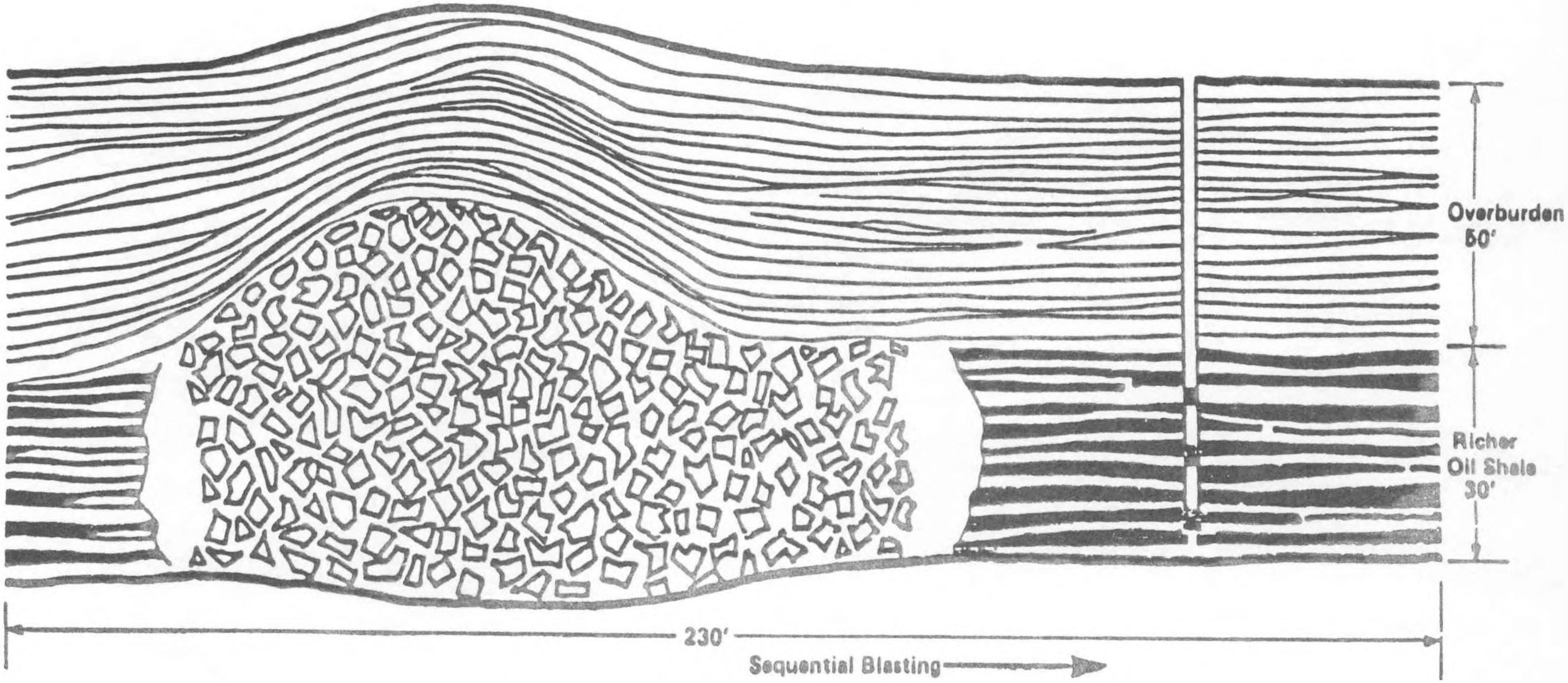



Figure 2. Drill Blasting Holes and Place Charges




Overburden lift provides space for displacement of fractured oil shale.
Displaced oil shale provides space for displacement of additional oil shale.

Figure 3. Blasting Sequence Overburden Lift and Start of Rubbling




Fractured oil shale displaced into created void space.

Figure 4. Blasting Sequence - Continued Rubbling

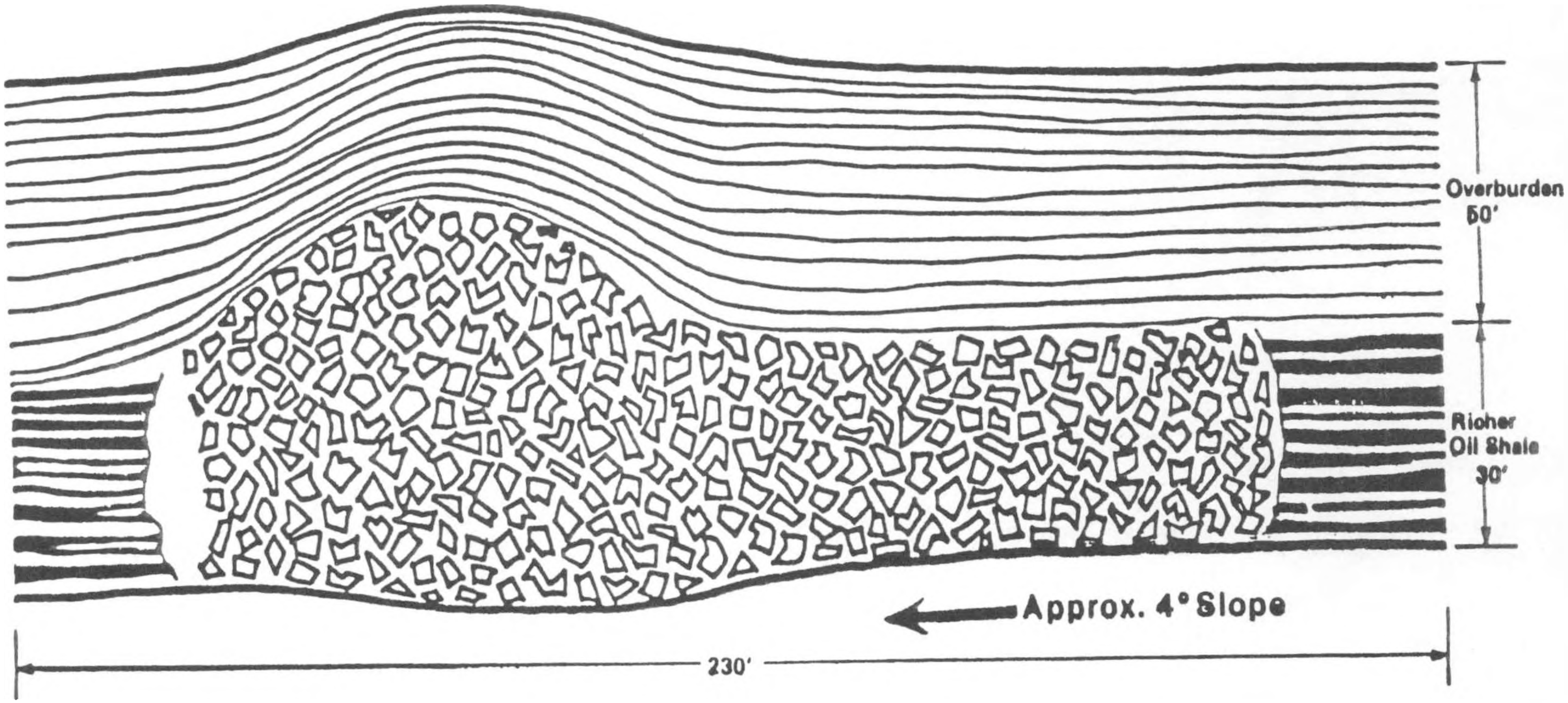



Figure 5. Developed Rubble Bed

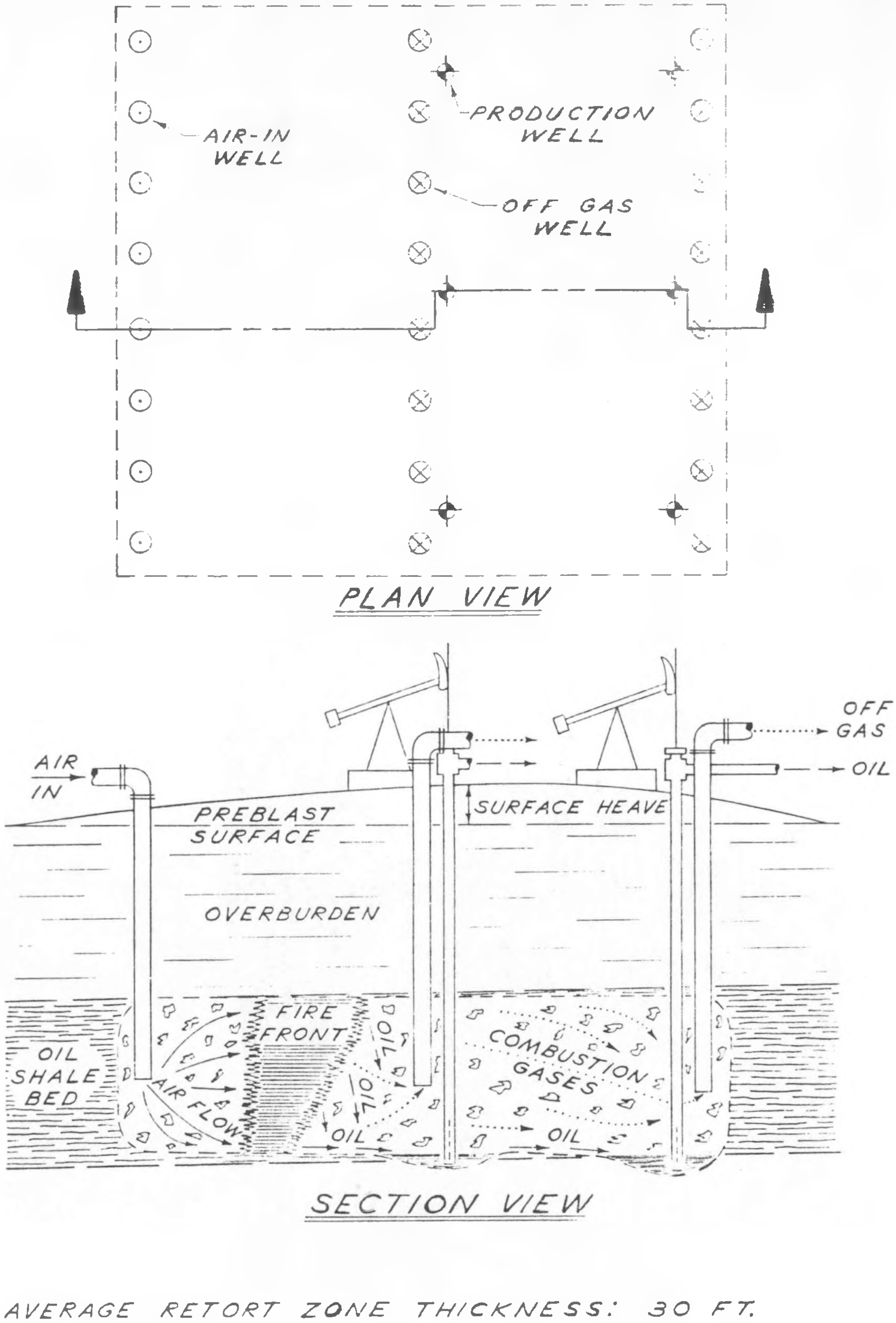



Figure 6. Typical Geokinetics In Situ Retort

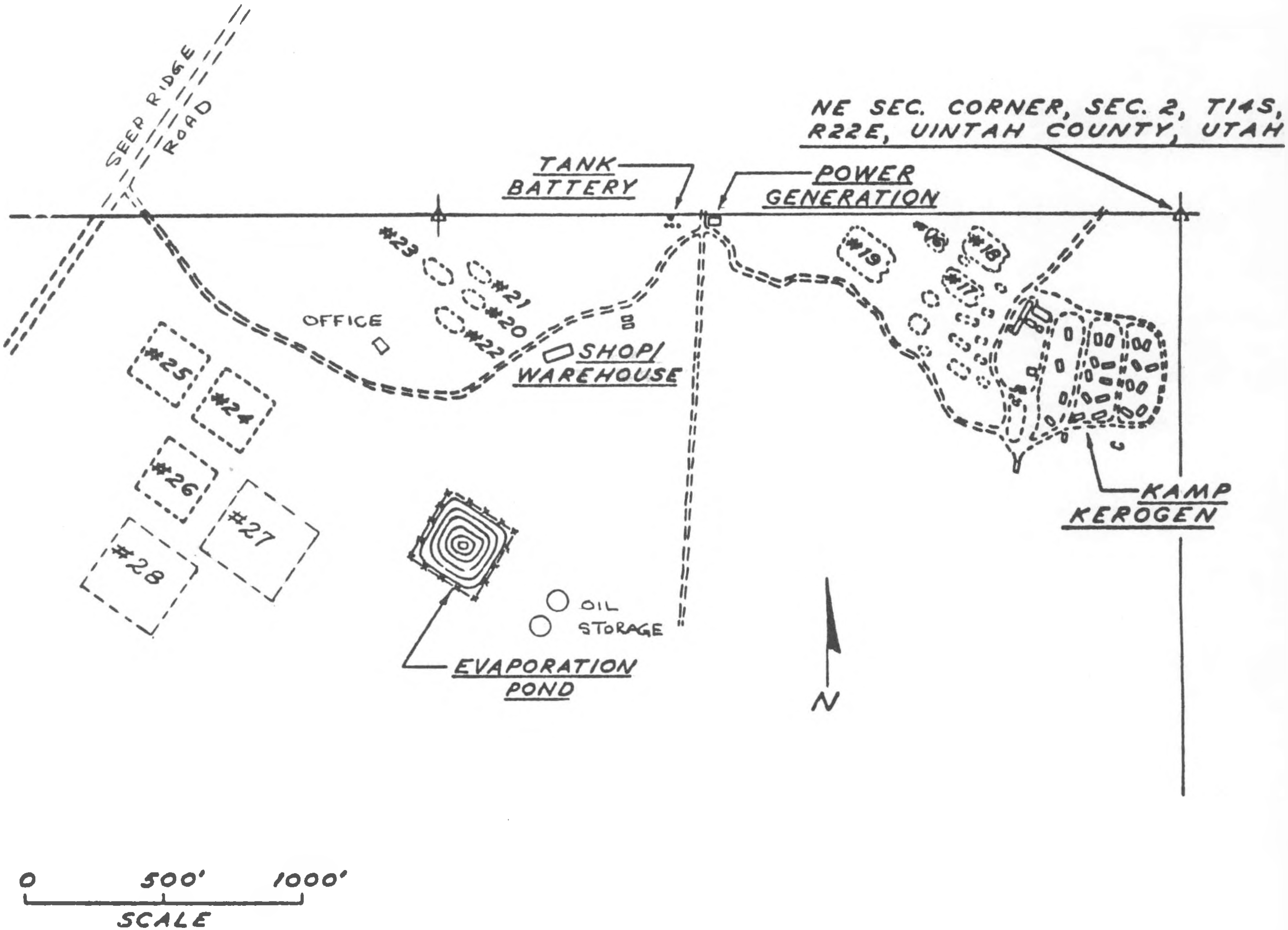



Figure 7. Geokinetics Inc. Field Site

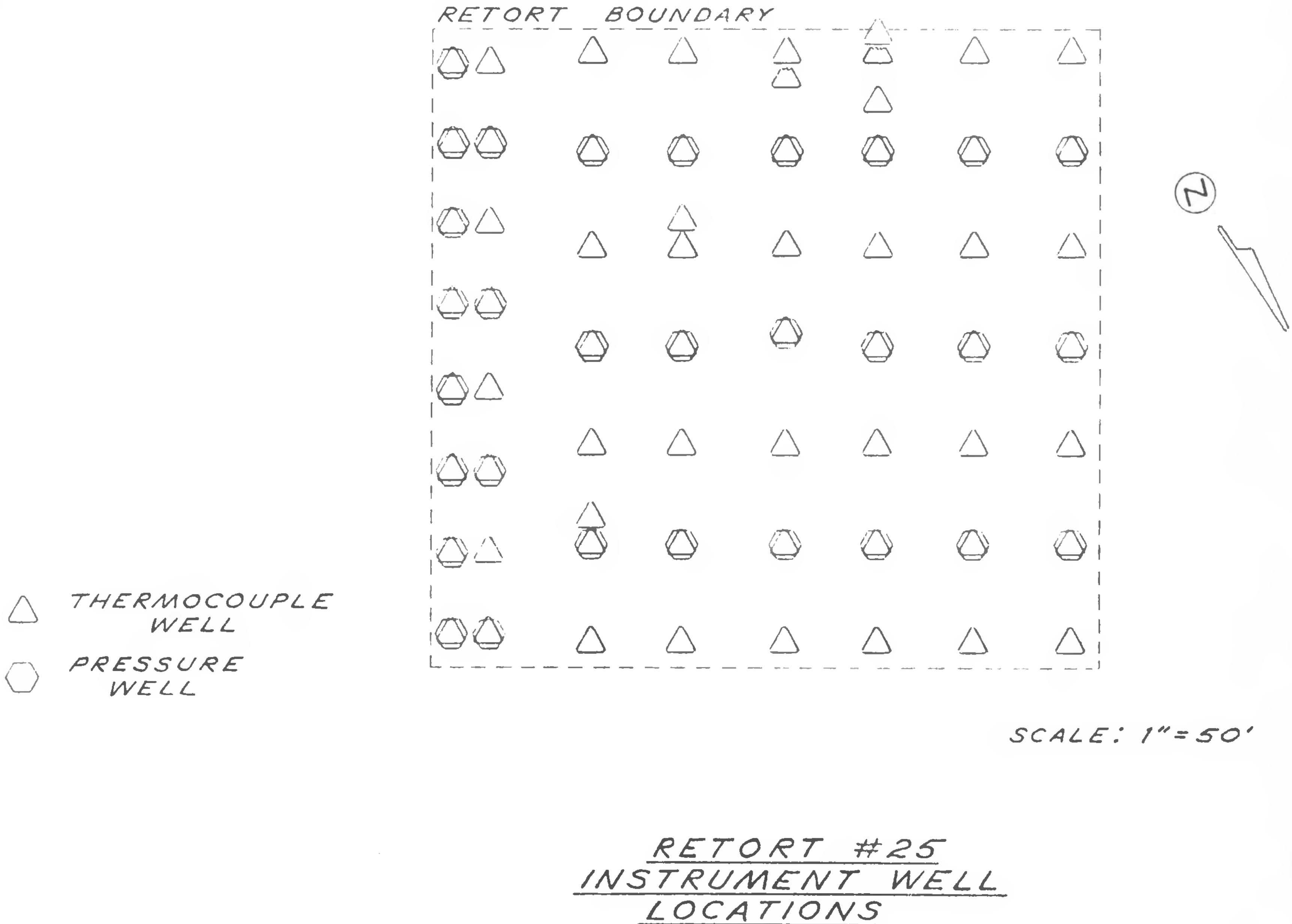



Figure 8. Retort #25 Instrument Well Locations

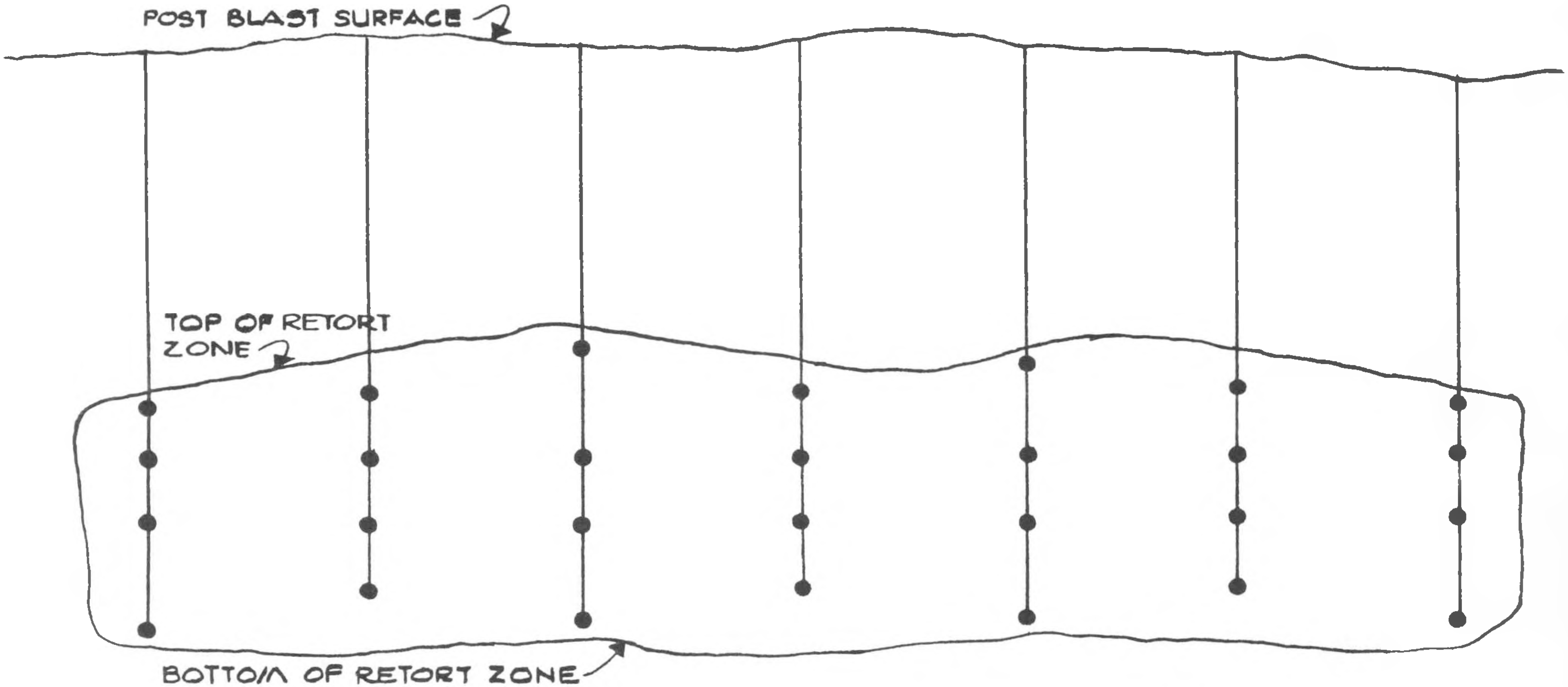



Figure 9. Cross Section Through Thermocouple Row Seven, Showing Locations of 4 Thermocouples in Each Thermowell

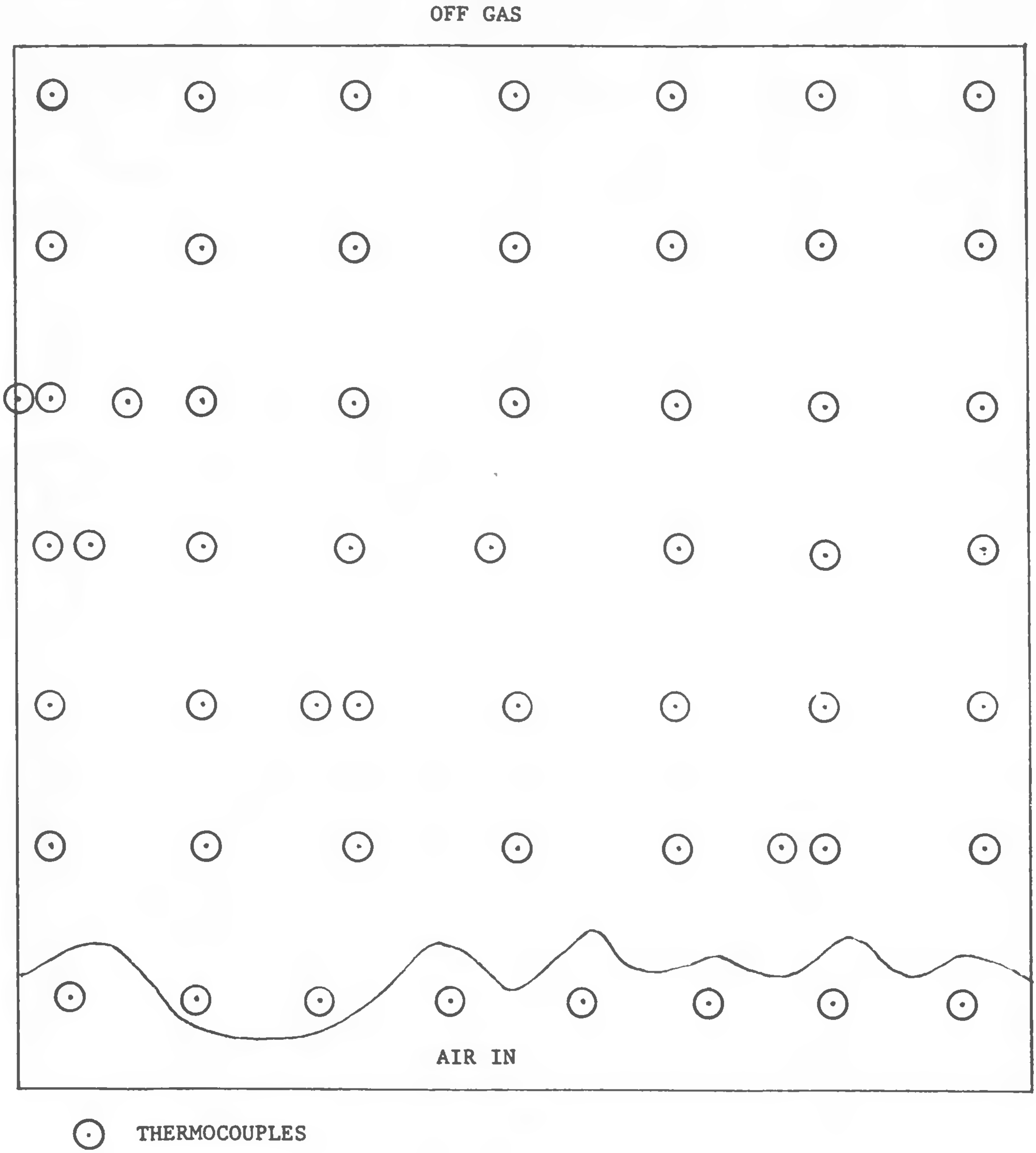



Figure 10. Retort #25 - Fire Front Location
800°F Isotherm - Day 10

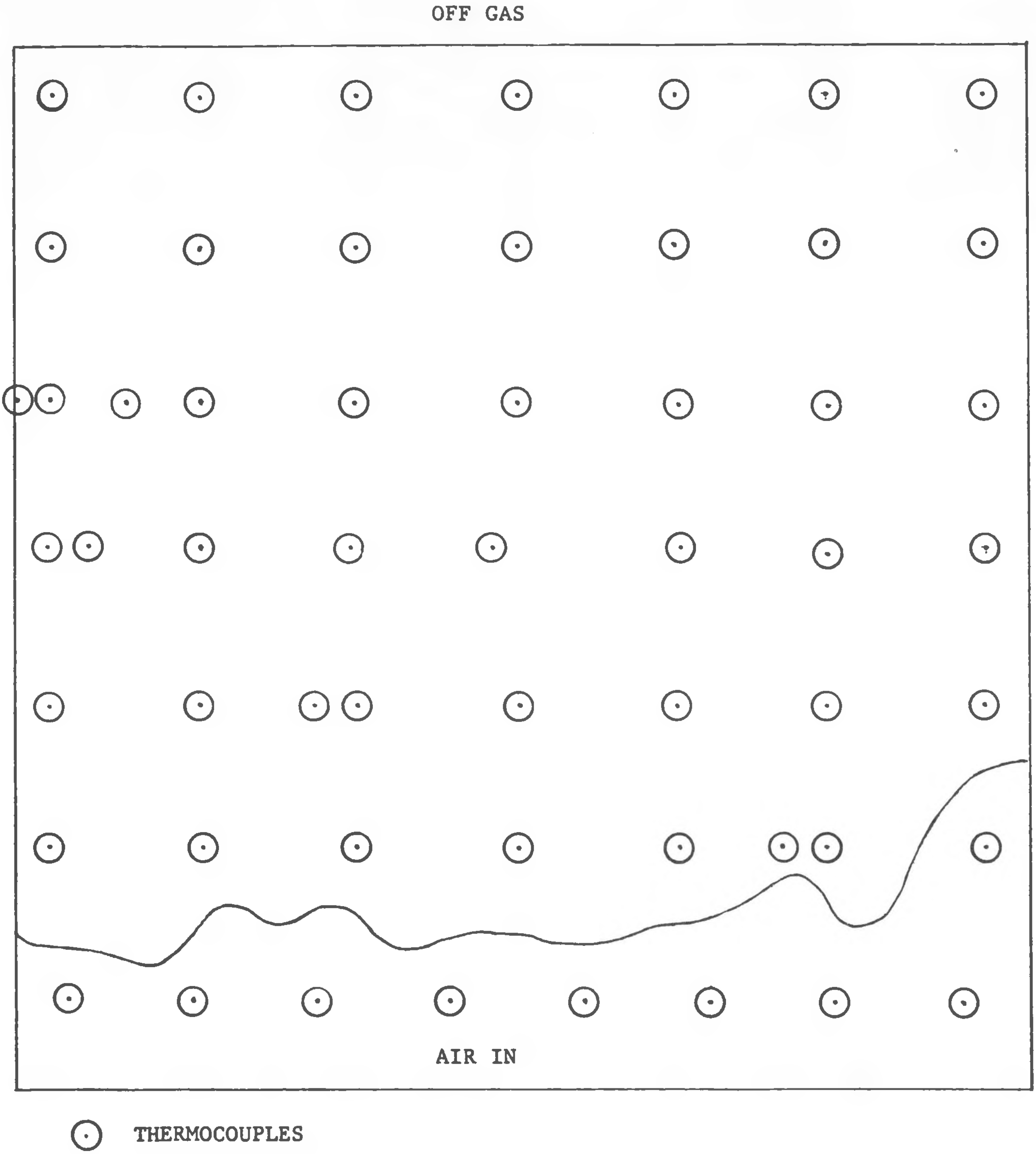



Figure 11. Retort #25 - Fire Front Location
800°F Isotherm - Day 30

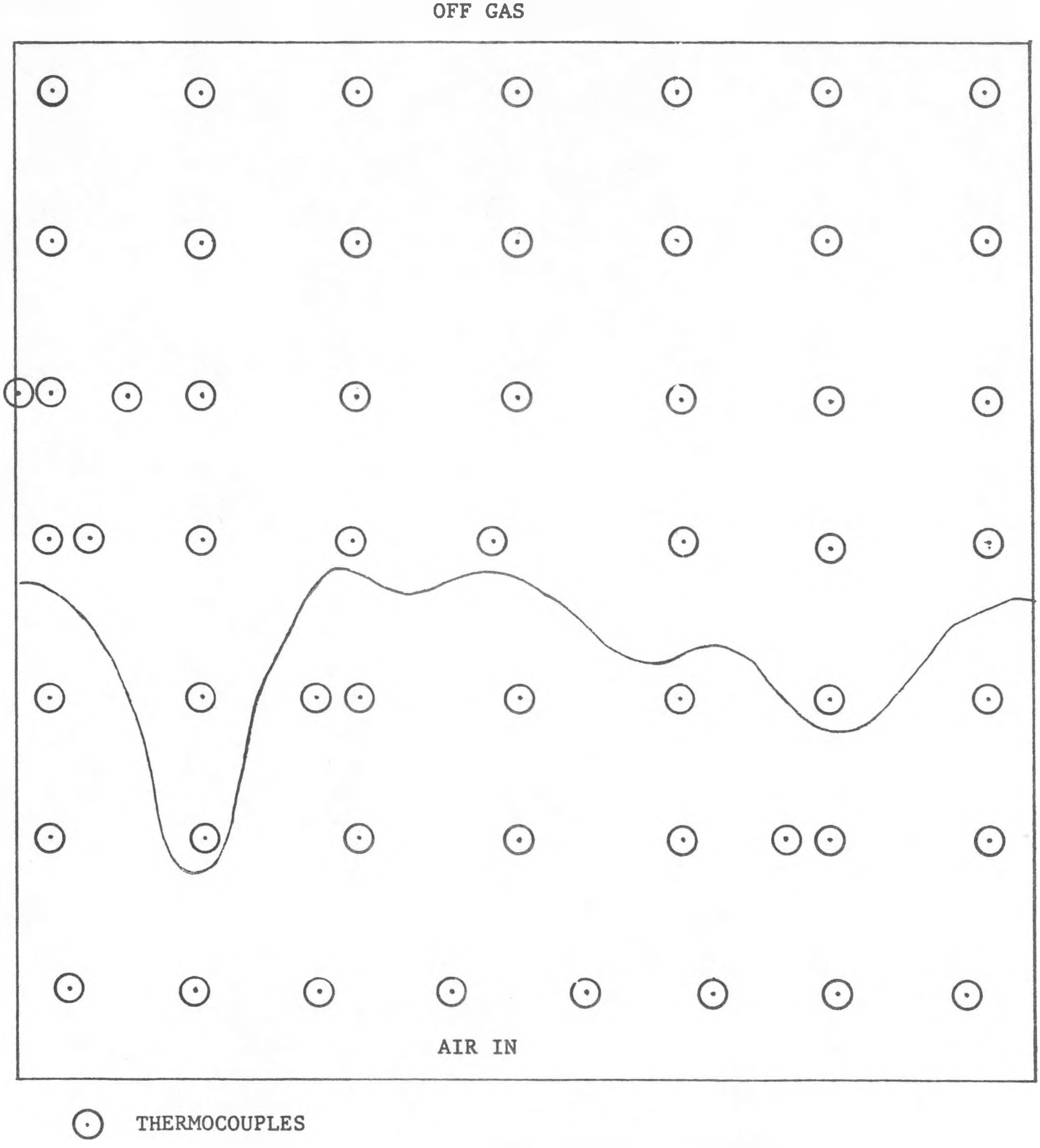



Figure 12. Retort #25 - Fire Front Location
800°F Isotherm - Day 60

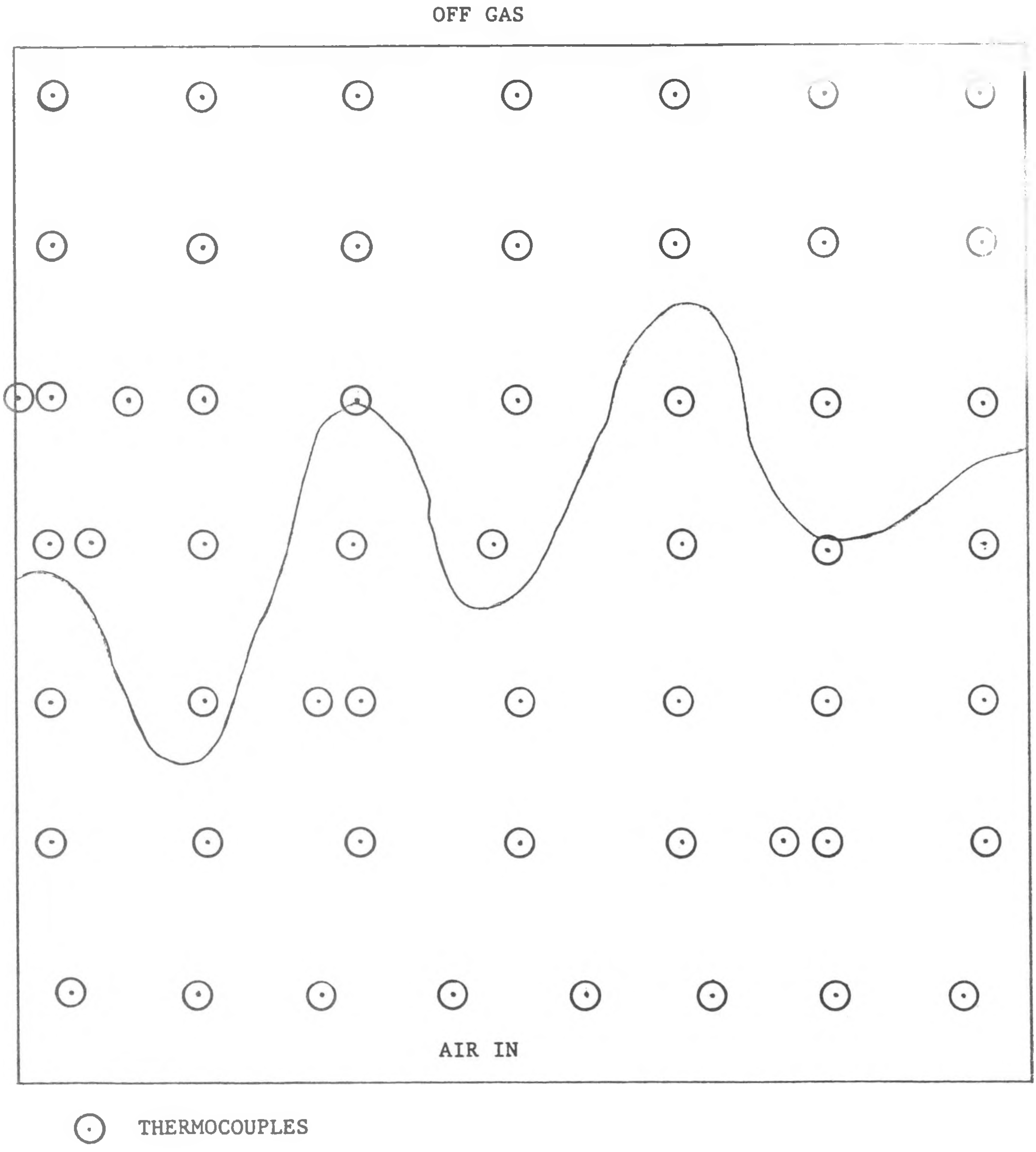



Figure 13. Retort #25 - Fire Front Location
800°F Isotherm - Day 90

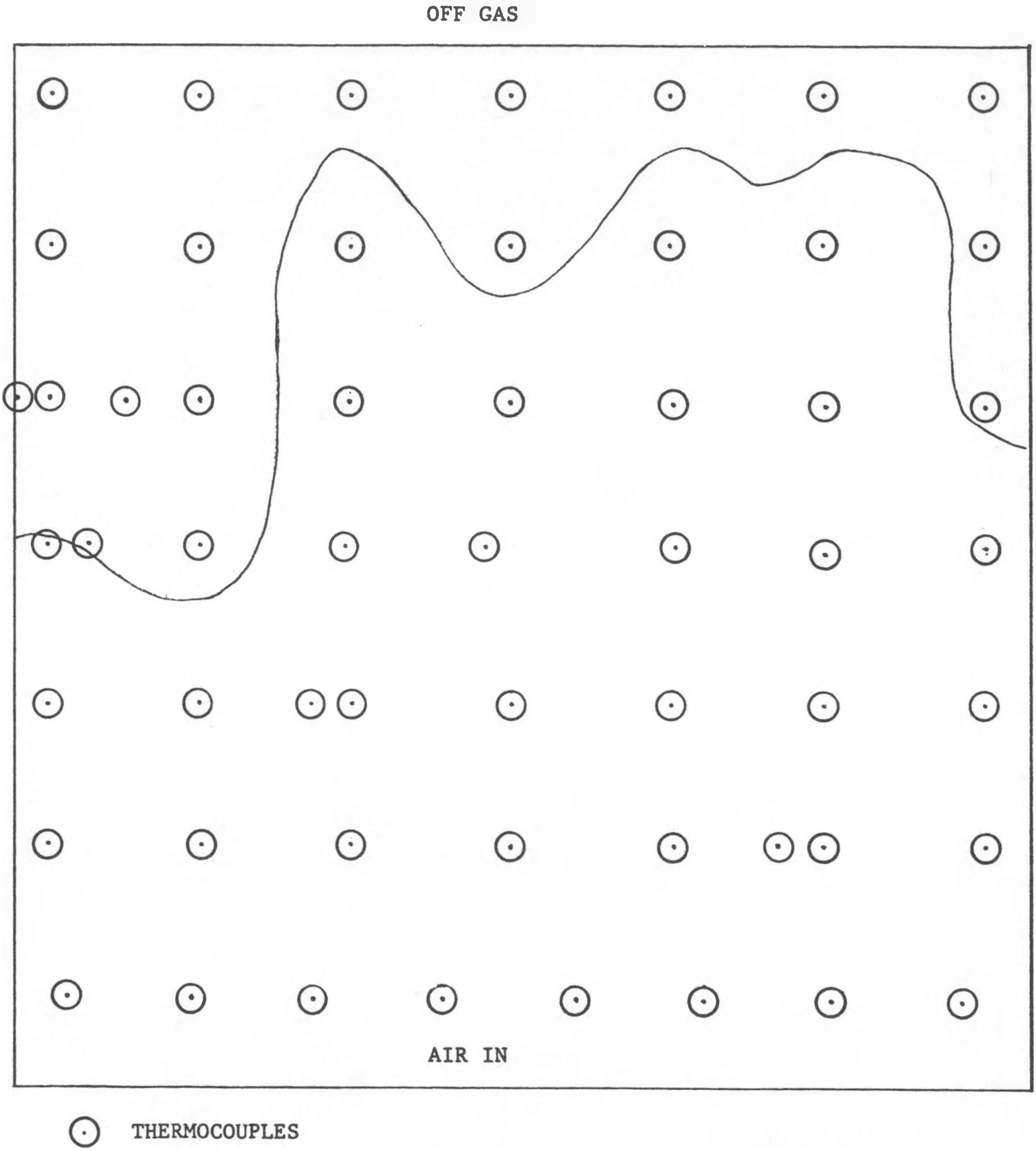



Figure 14. Retort #25 - Fire Front Location
800°F Isotherm - Day 120

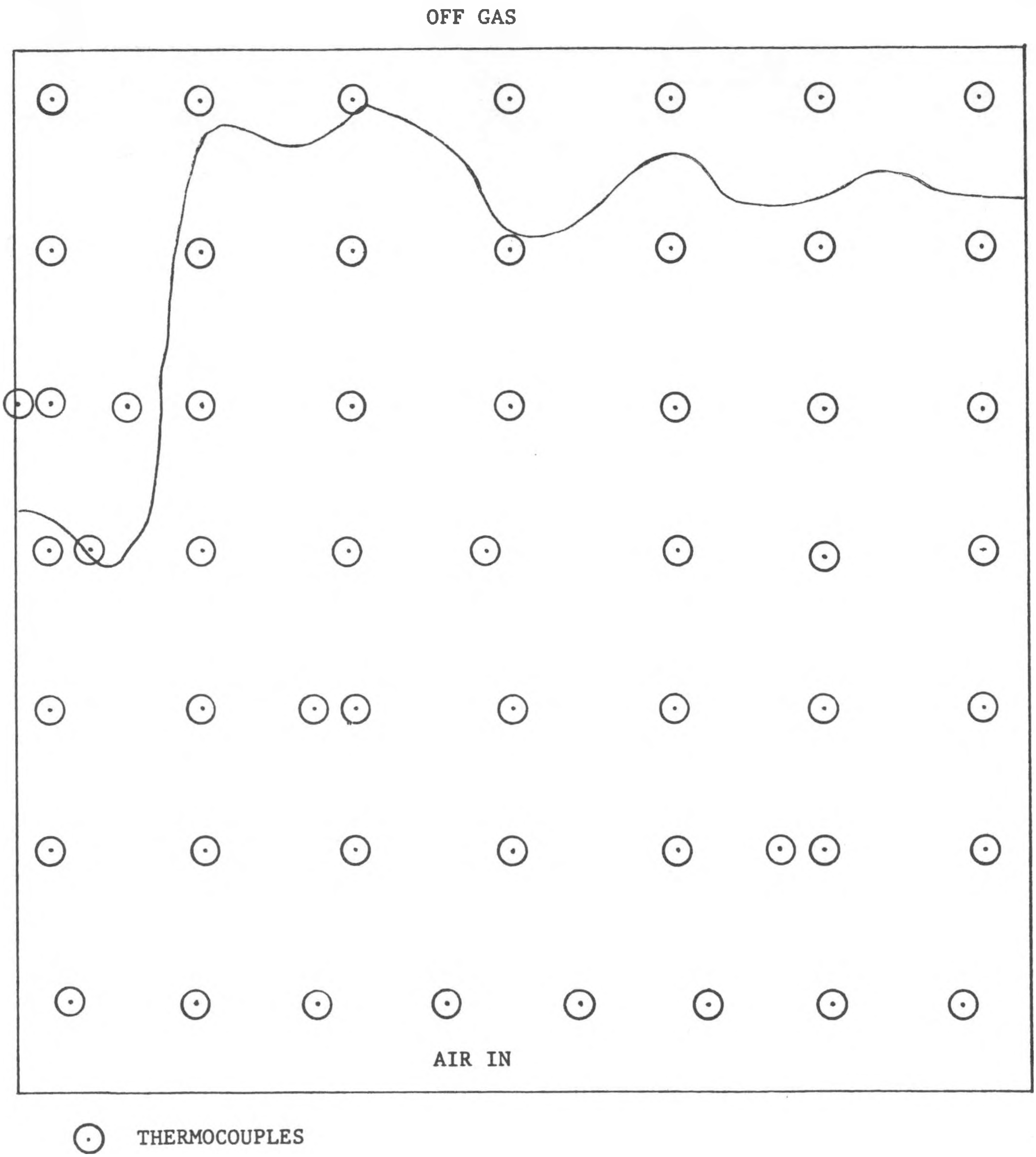



Figure 15. Retort #25 - Fire Front Location
800°F Isotherm - Day 150

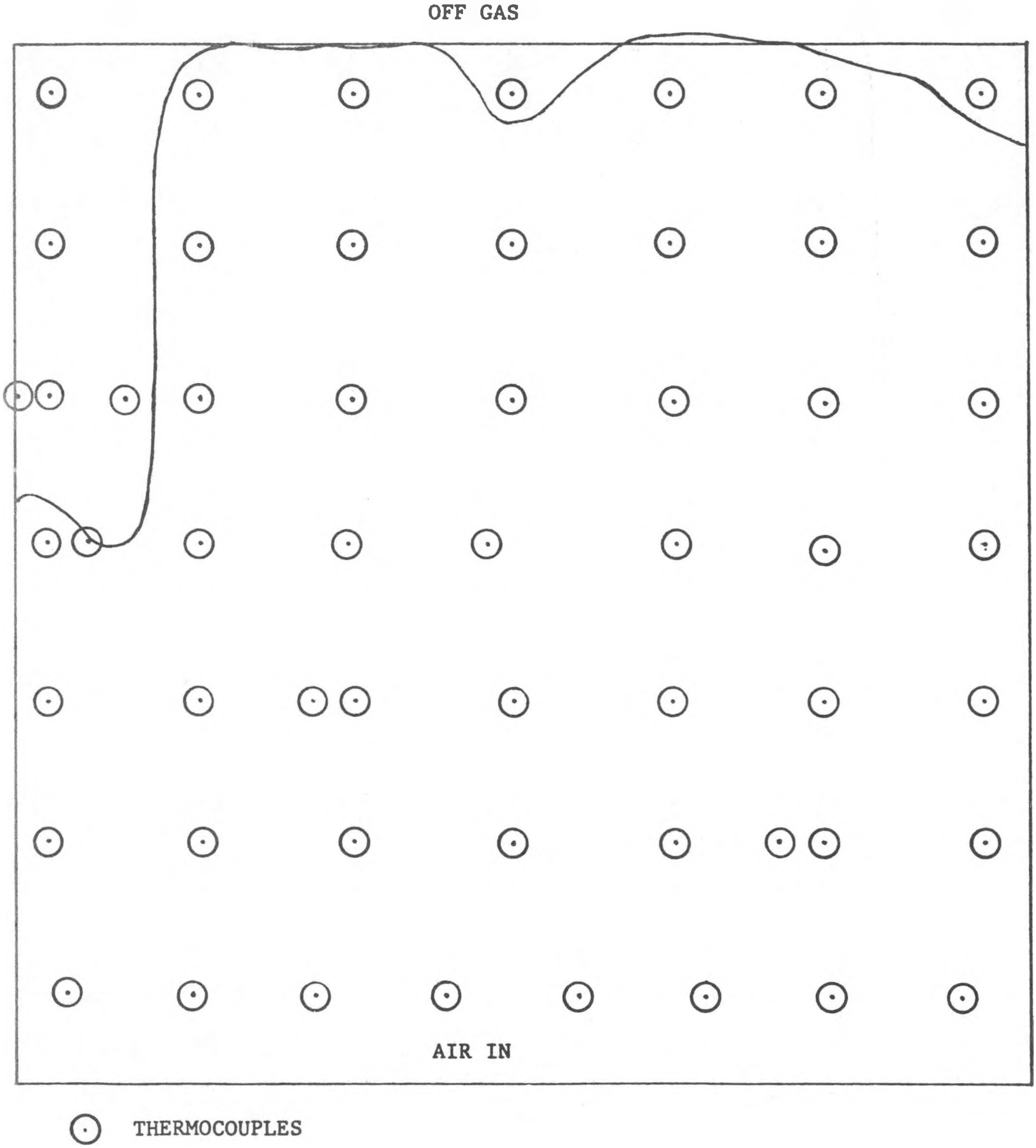



Figure 16. Retort #25 - Fire Front Location
800°F Isotherm - Day <u>180</u>

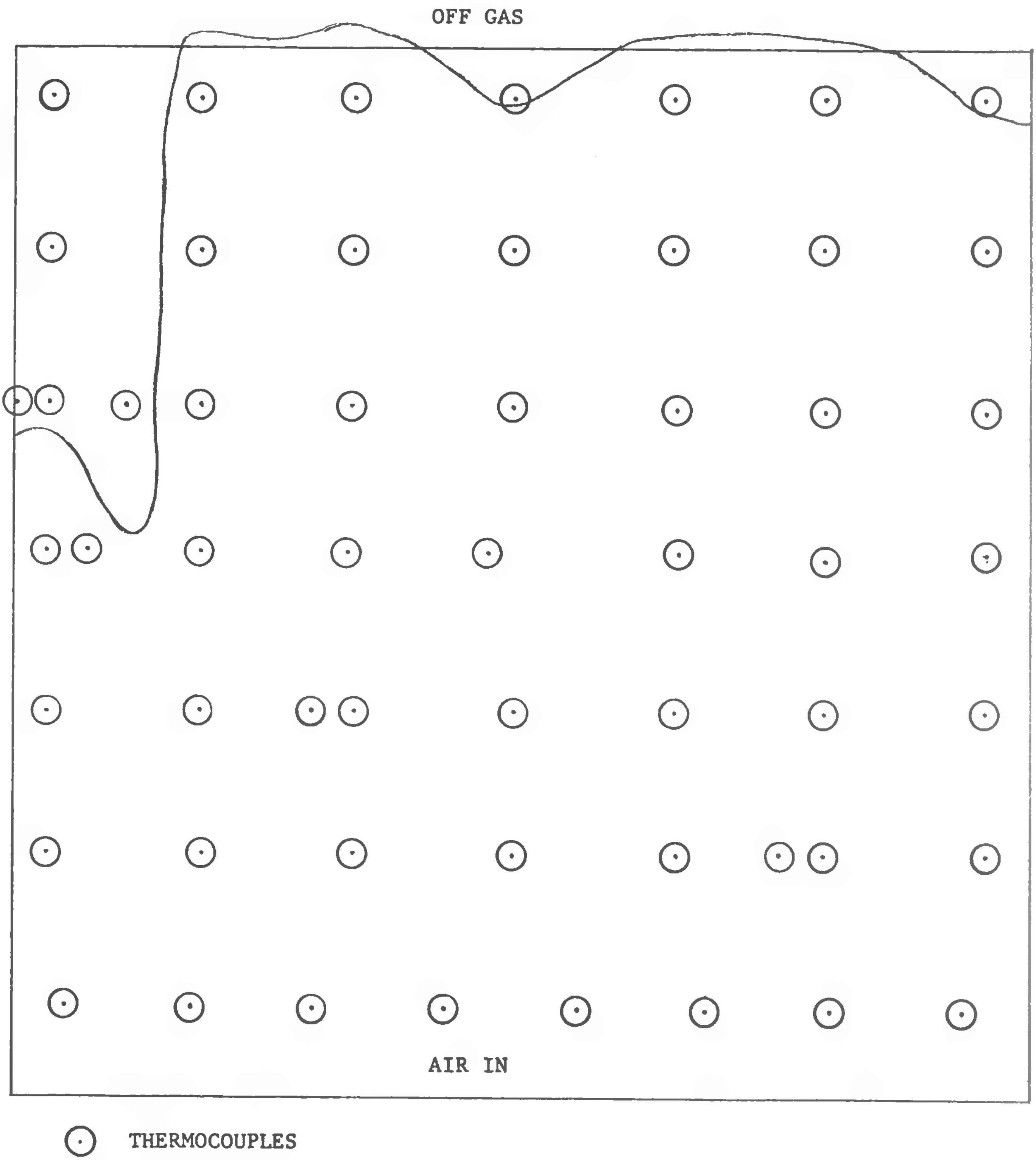



Figure 17. Retort #25 - Fire Front Location
800°F Isotherm - Day 210

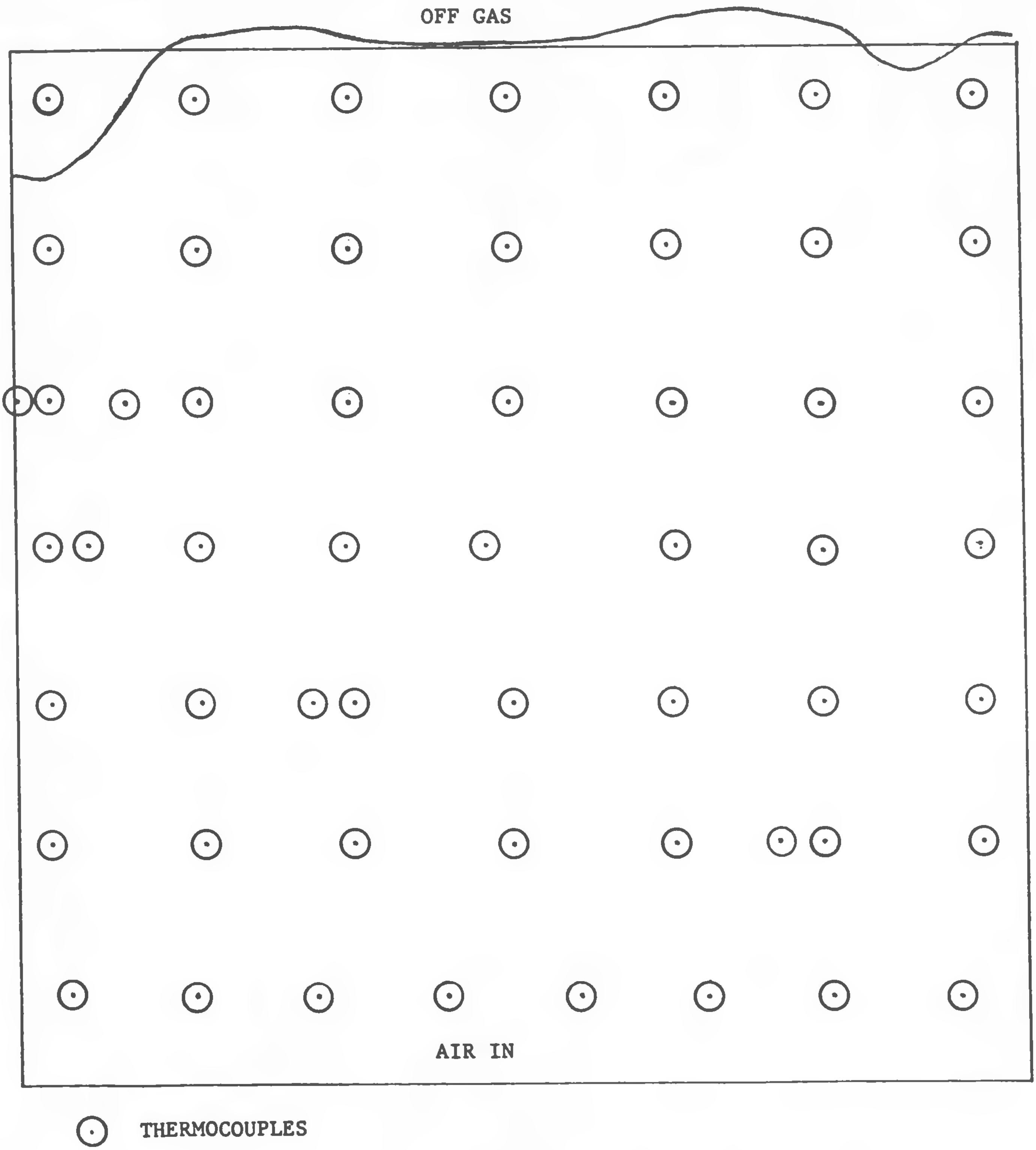



Figure 18. Retort #25 - Fire Front Location
800°F Isotherm - Day 230

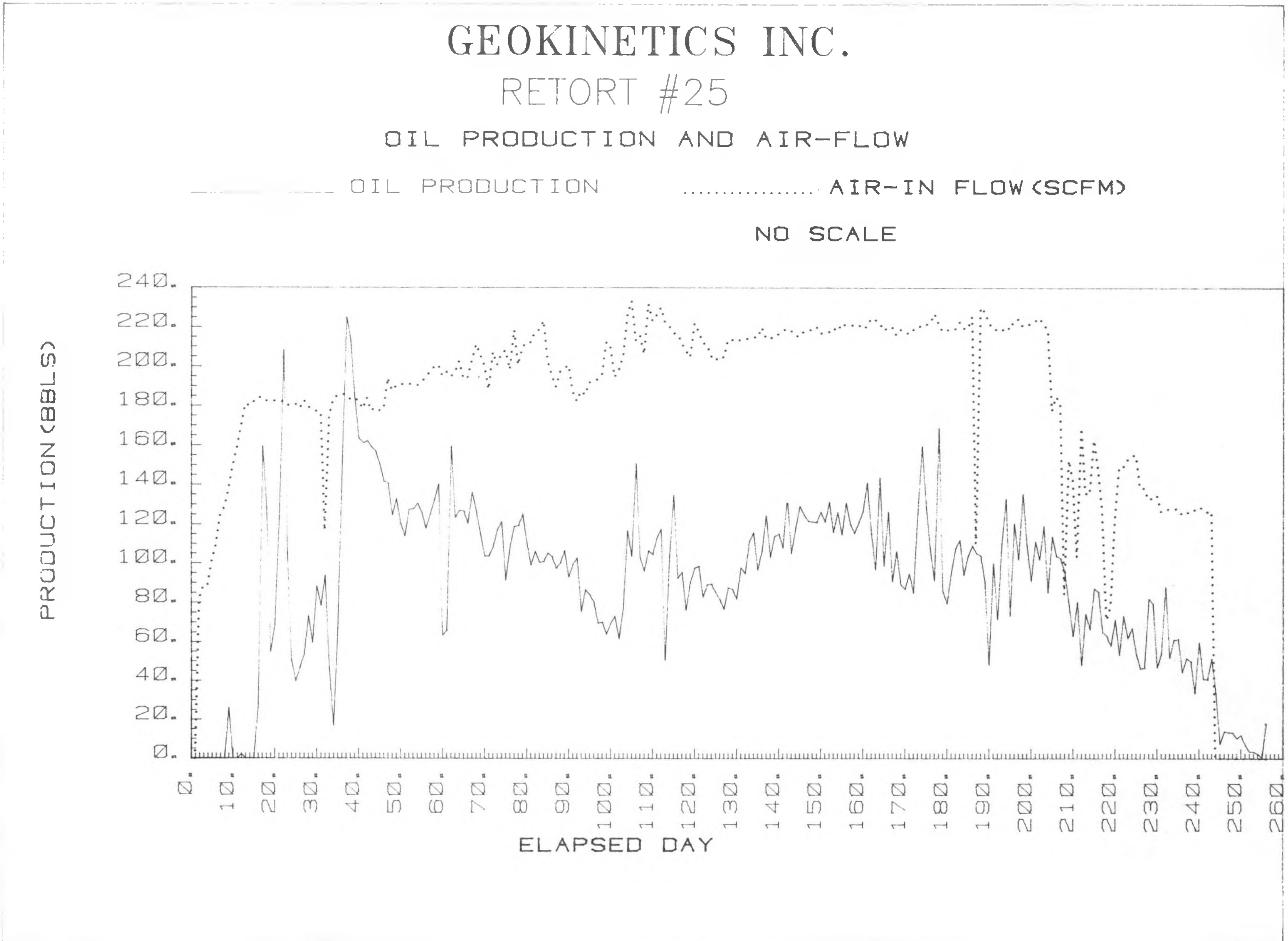



Figure 19. Oil Production and Air Flow Retort #25

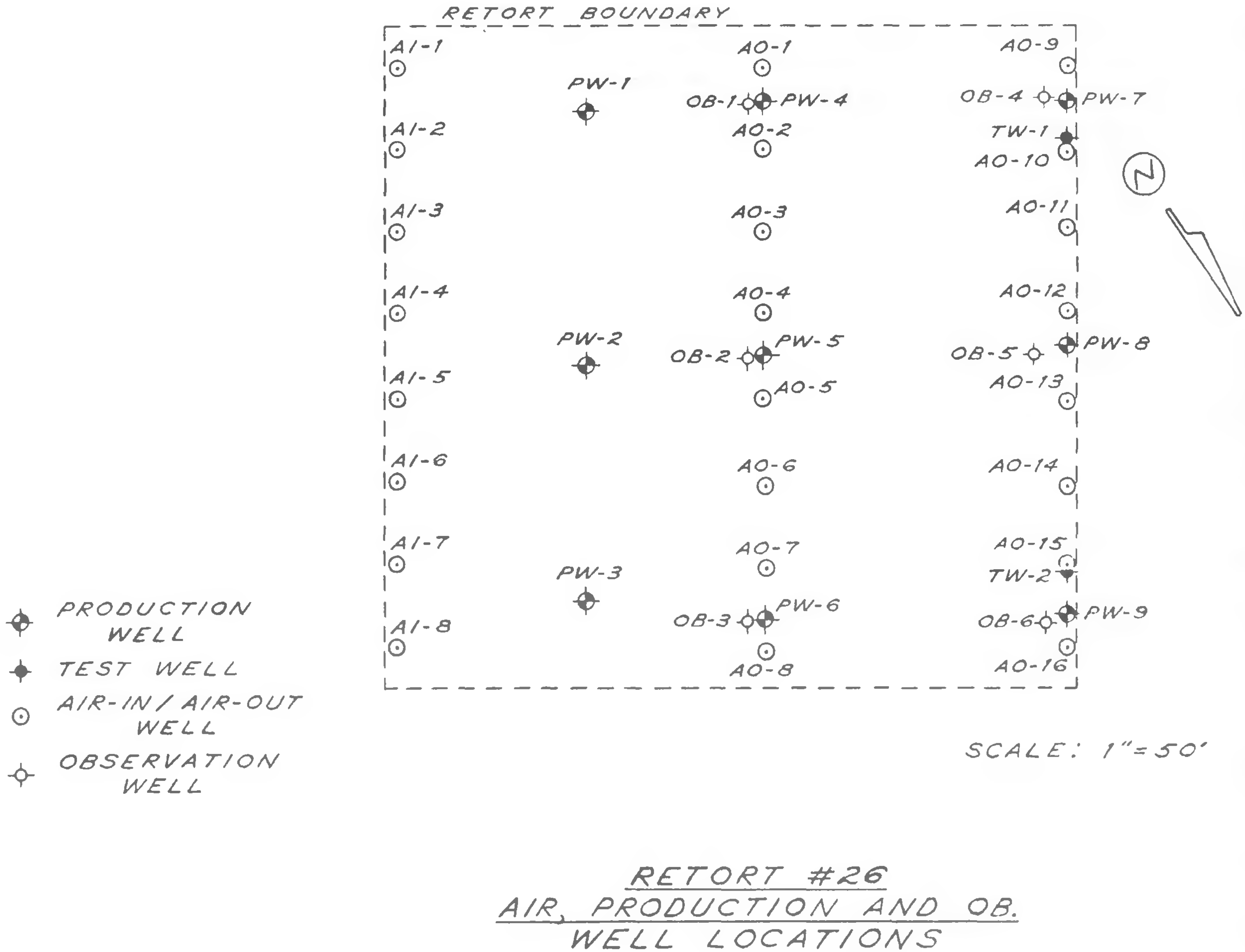
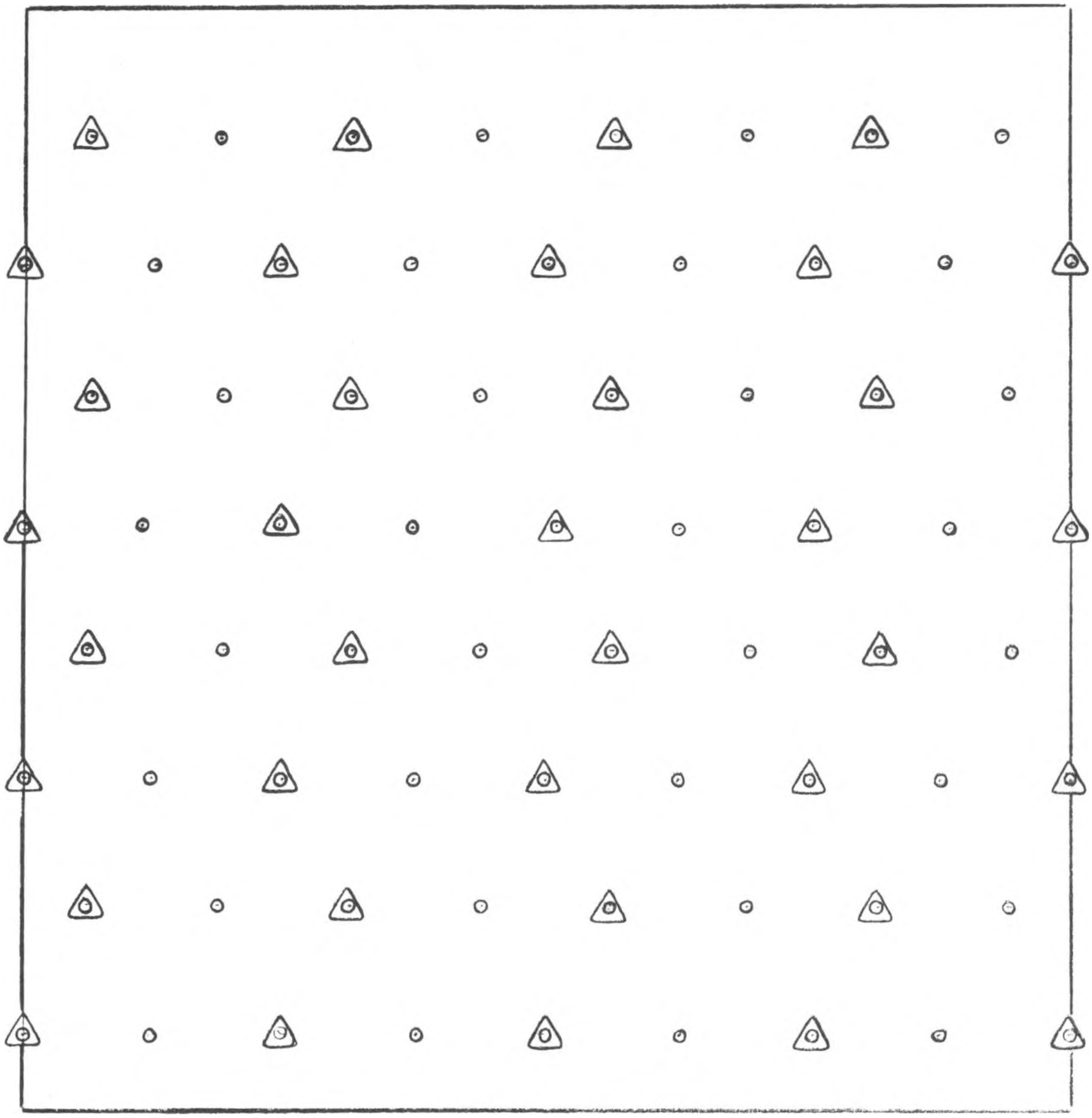



Figure 20. Process Well Locations, Retort #26



o Thermocouple Well

△ Retort Pressure Well

Figure 21. Retort #26
Instrumentation Well Locations

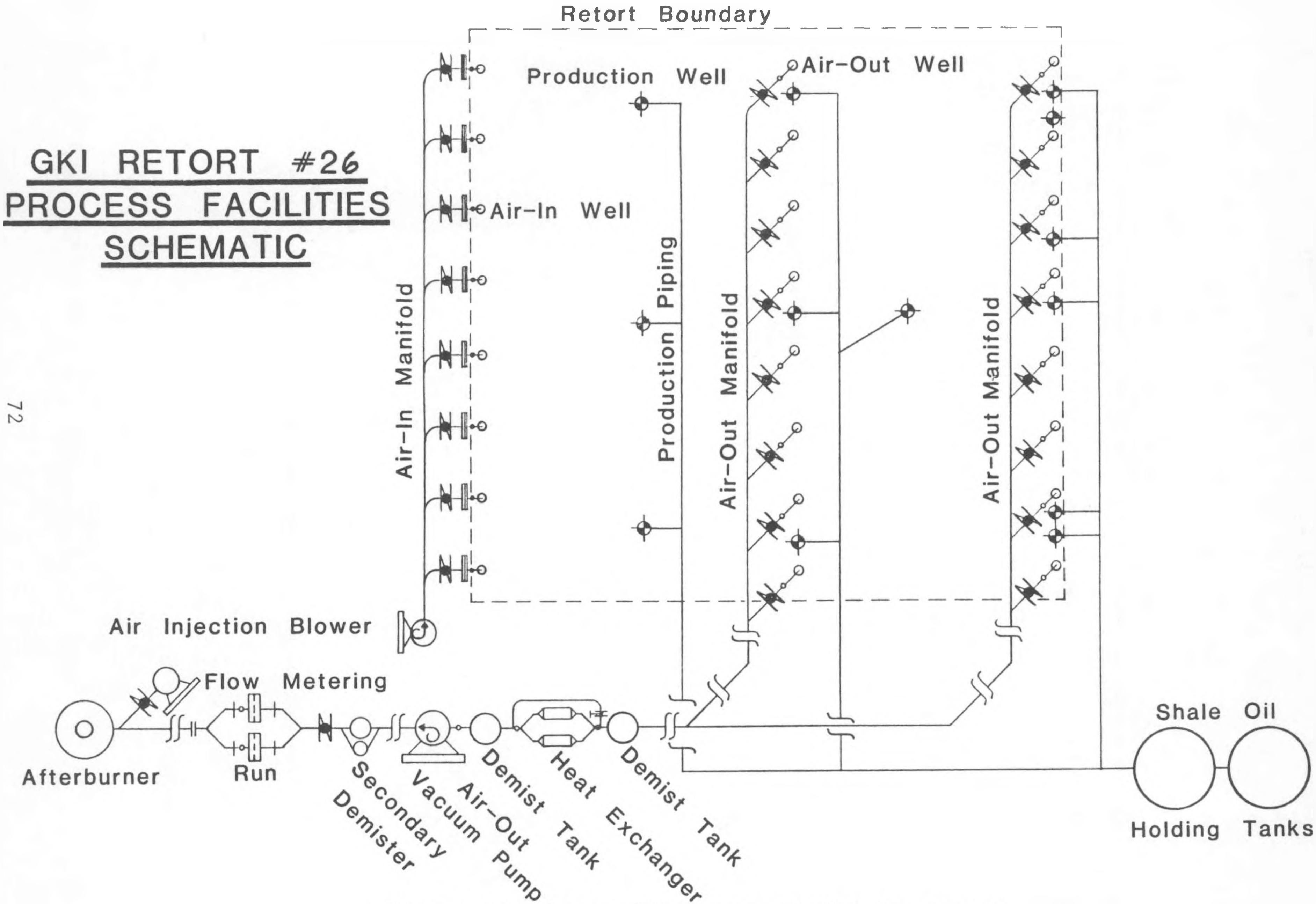



Figure 22. Retort #26 Process Facilities Layout

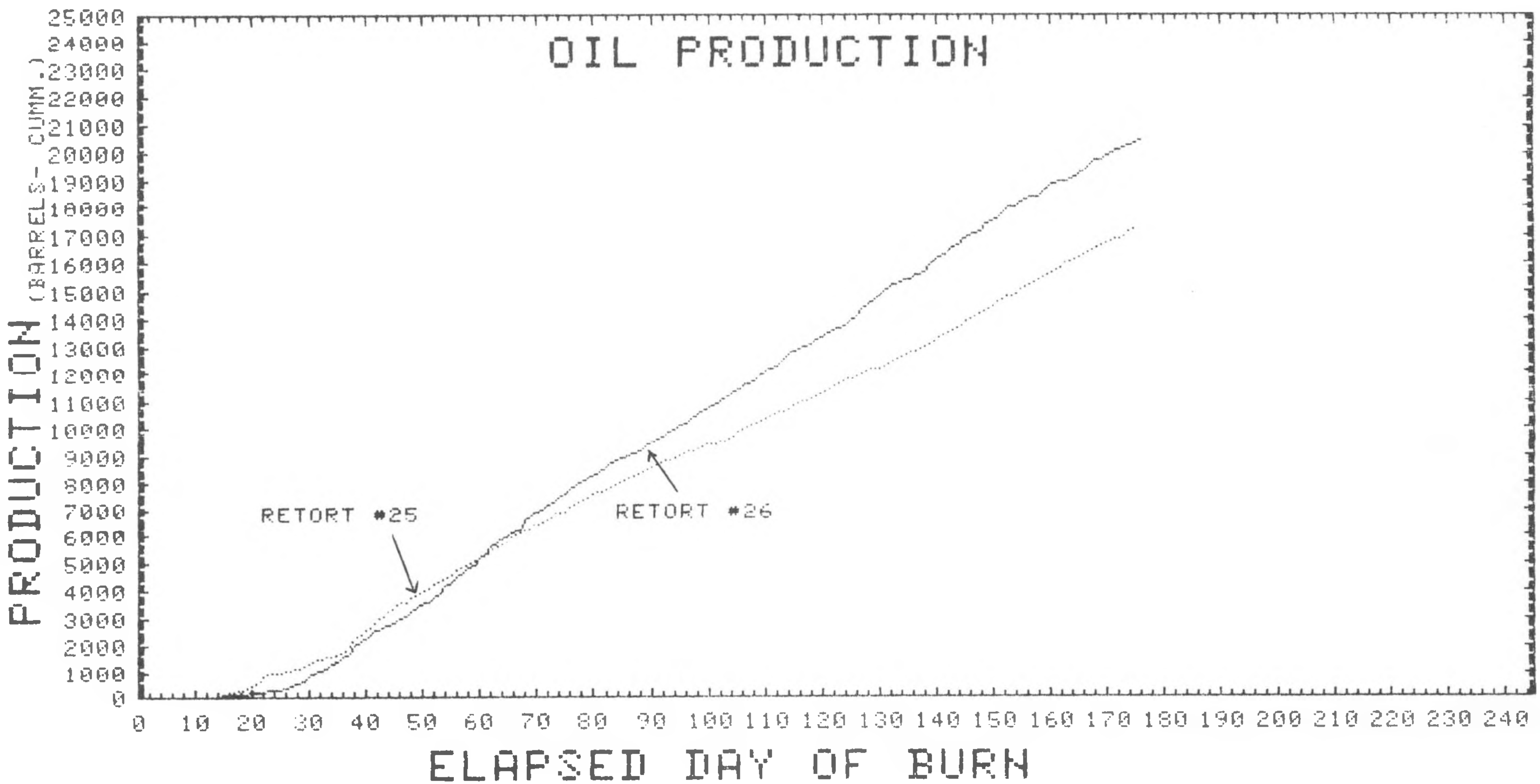



Figure 23. Cumulative Oil Production Comparison Retorts #25 and #26

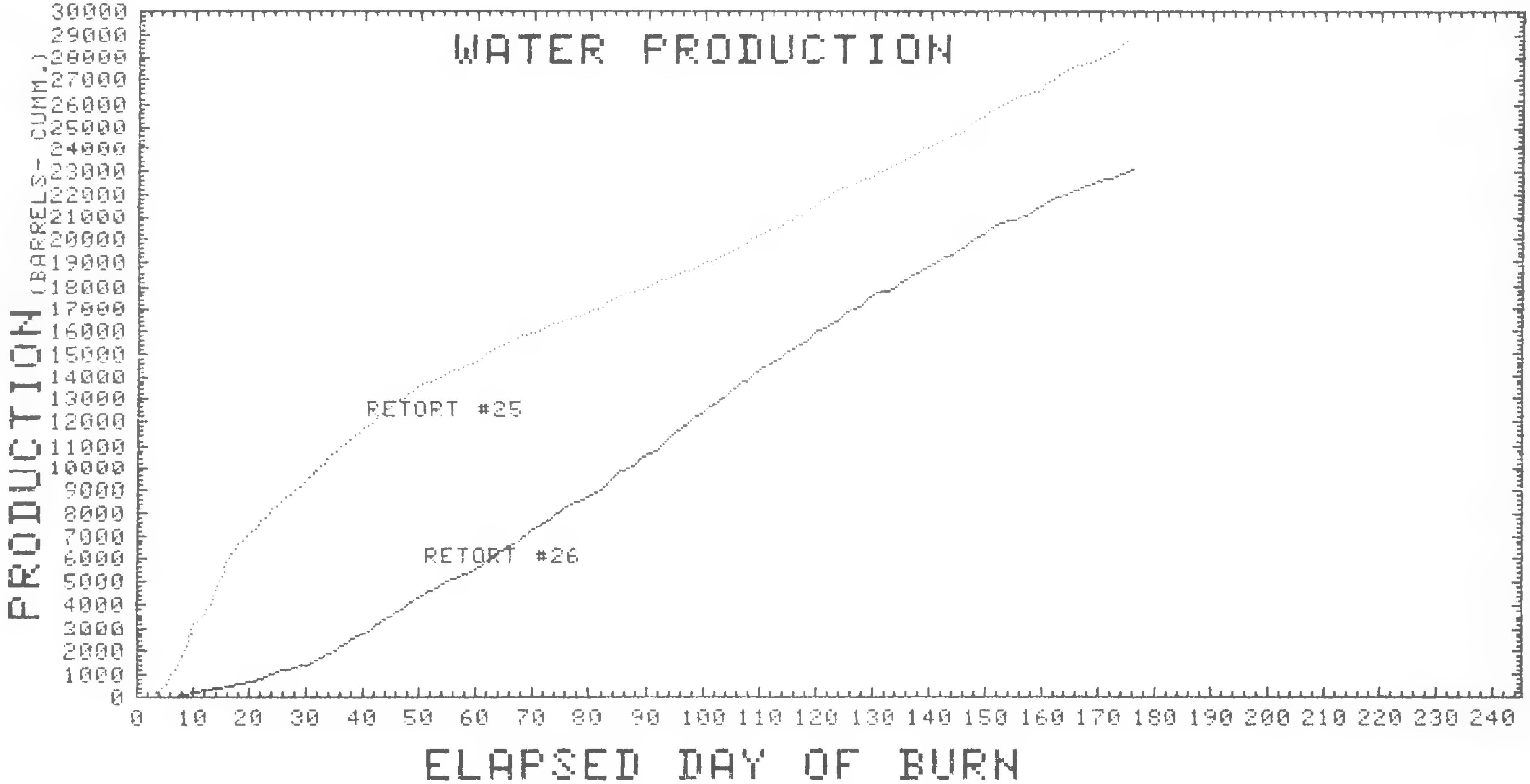



Figure 24. Cumulative Water Production Comparison Retorts #25 and #26

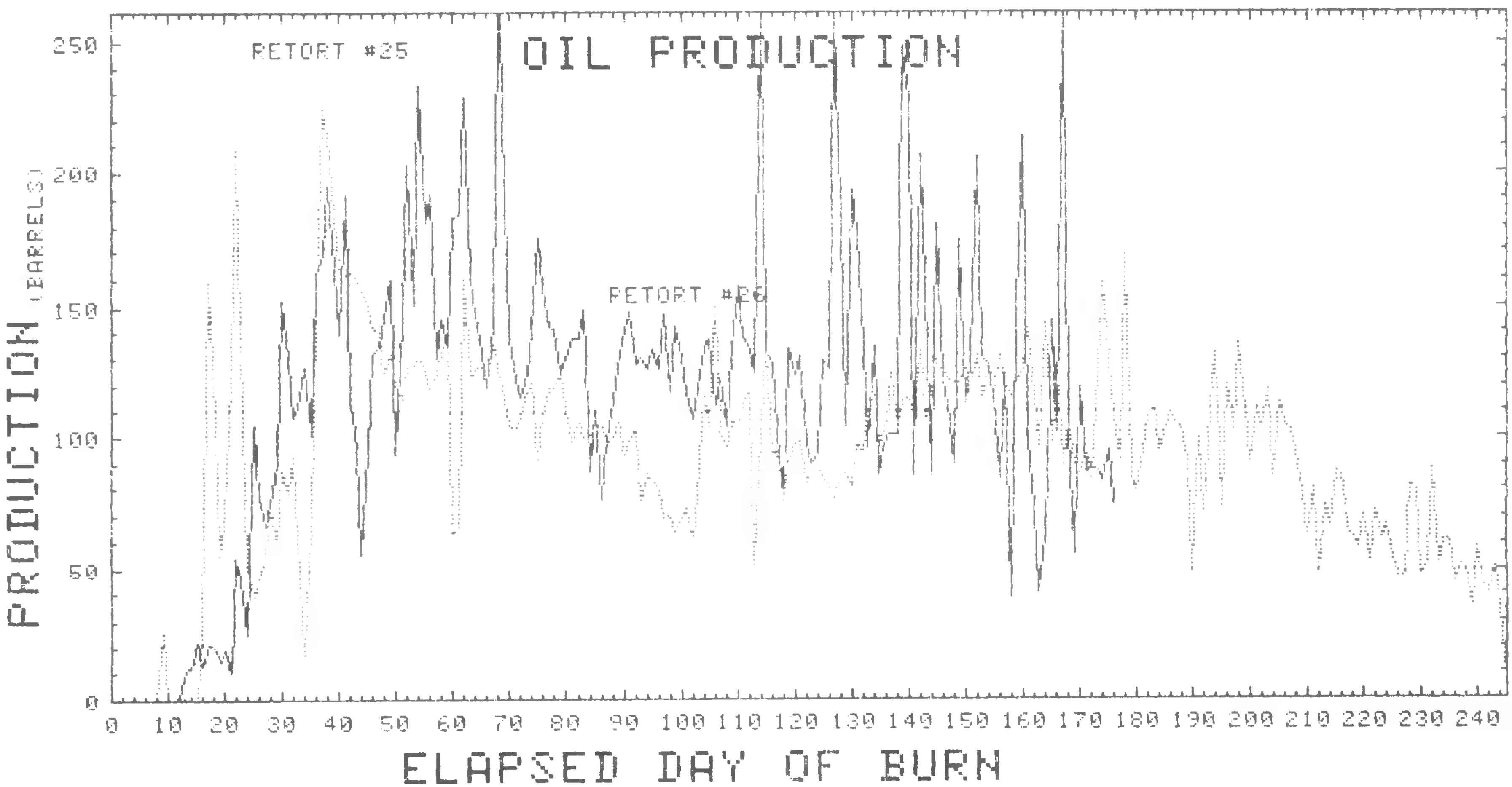



Figure 25. Daily Oil Production Comparison Retorts #25 and #26

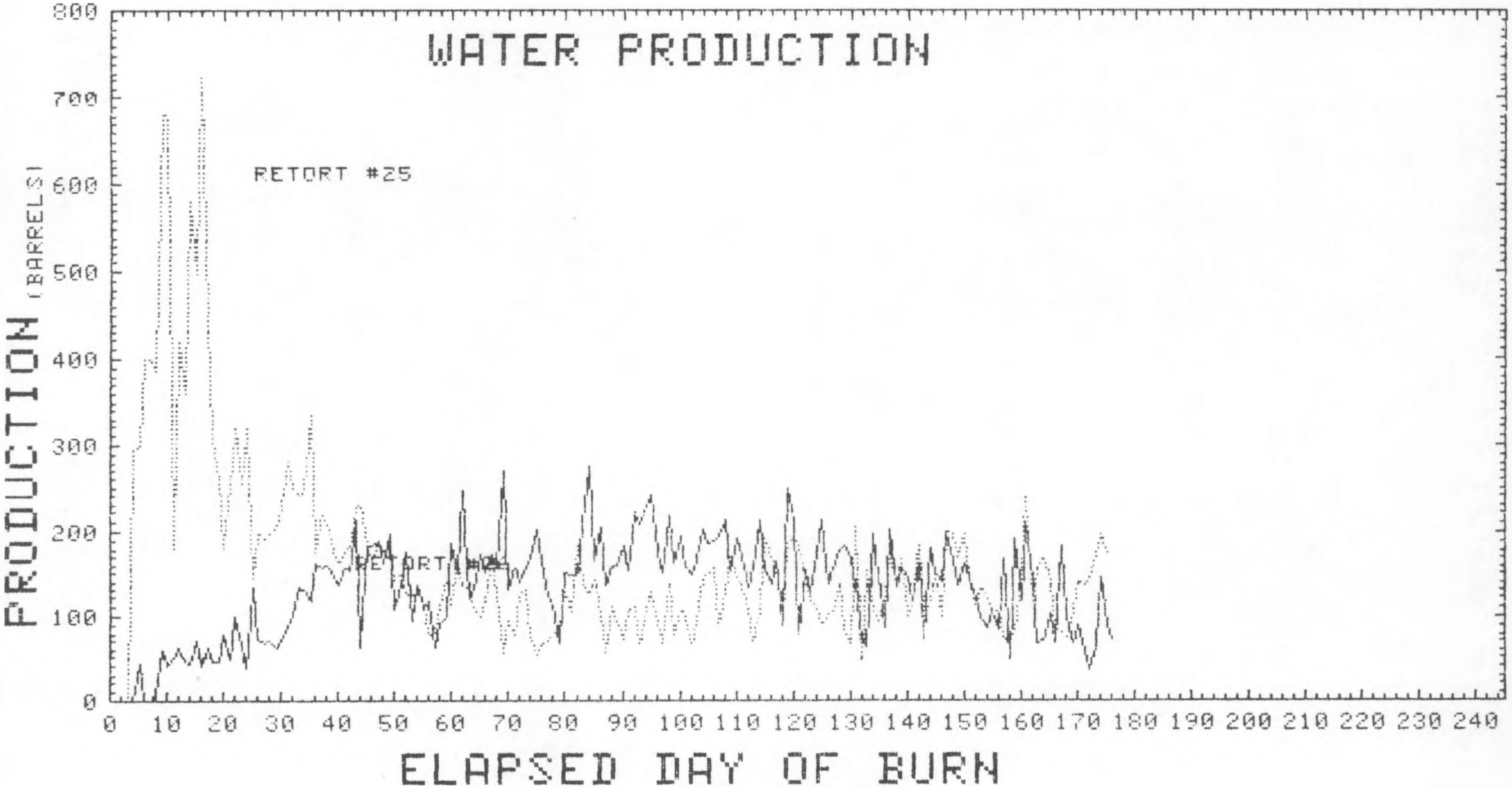



Figure 26. Daily Water Production Comparison Retorts #25 and #26

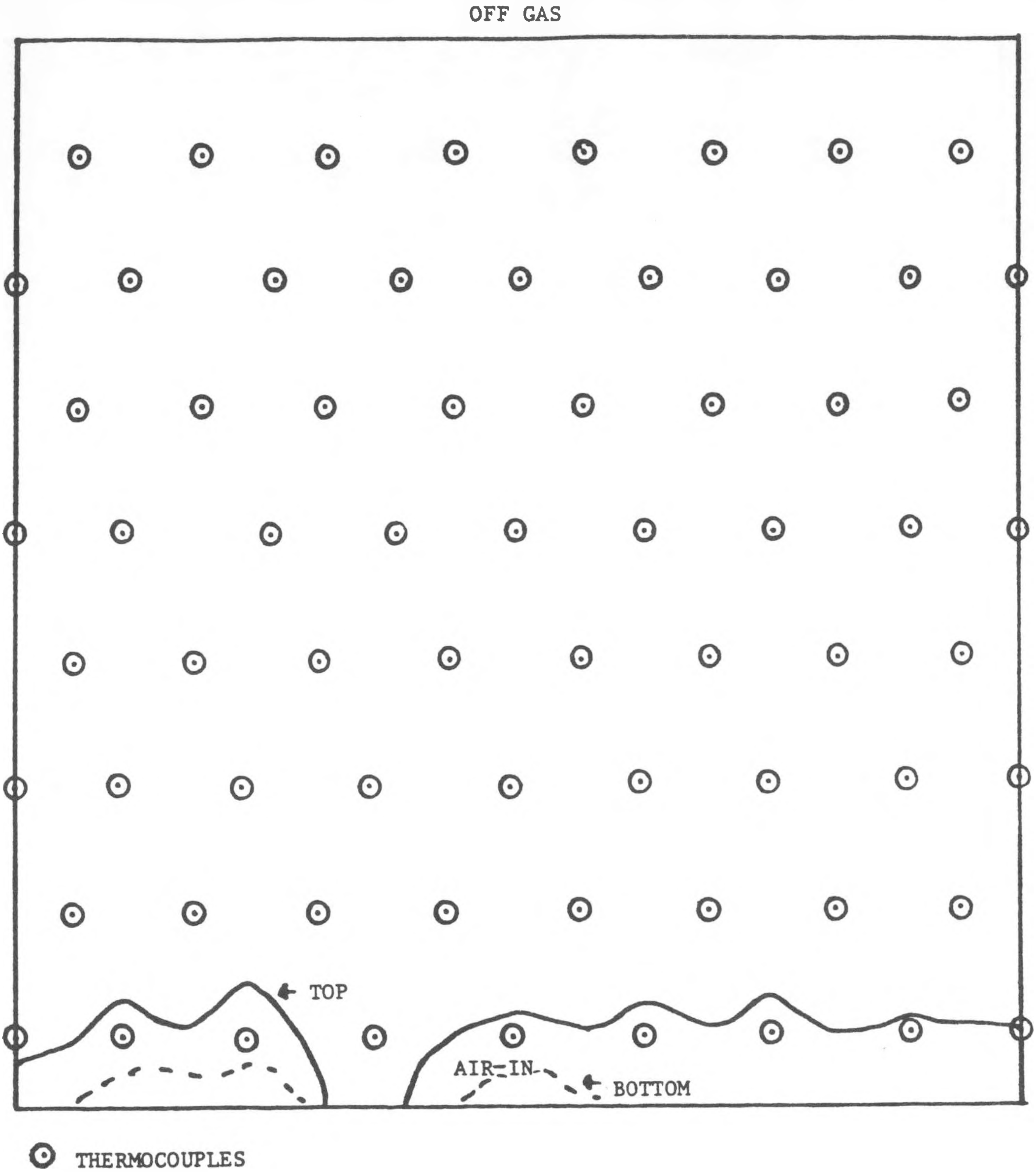



Figure 27. Retort #26 - Fire Front Location
800° Isotherms - End of July, 1982

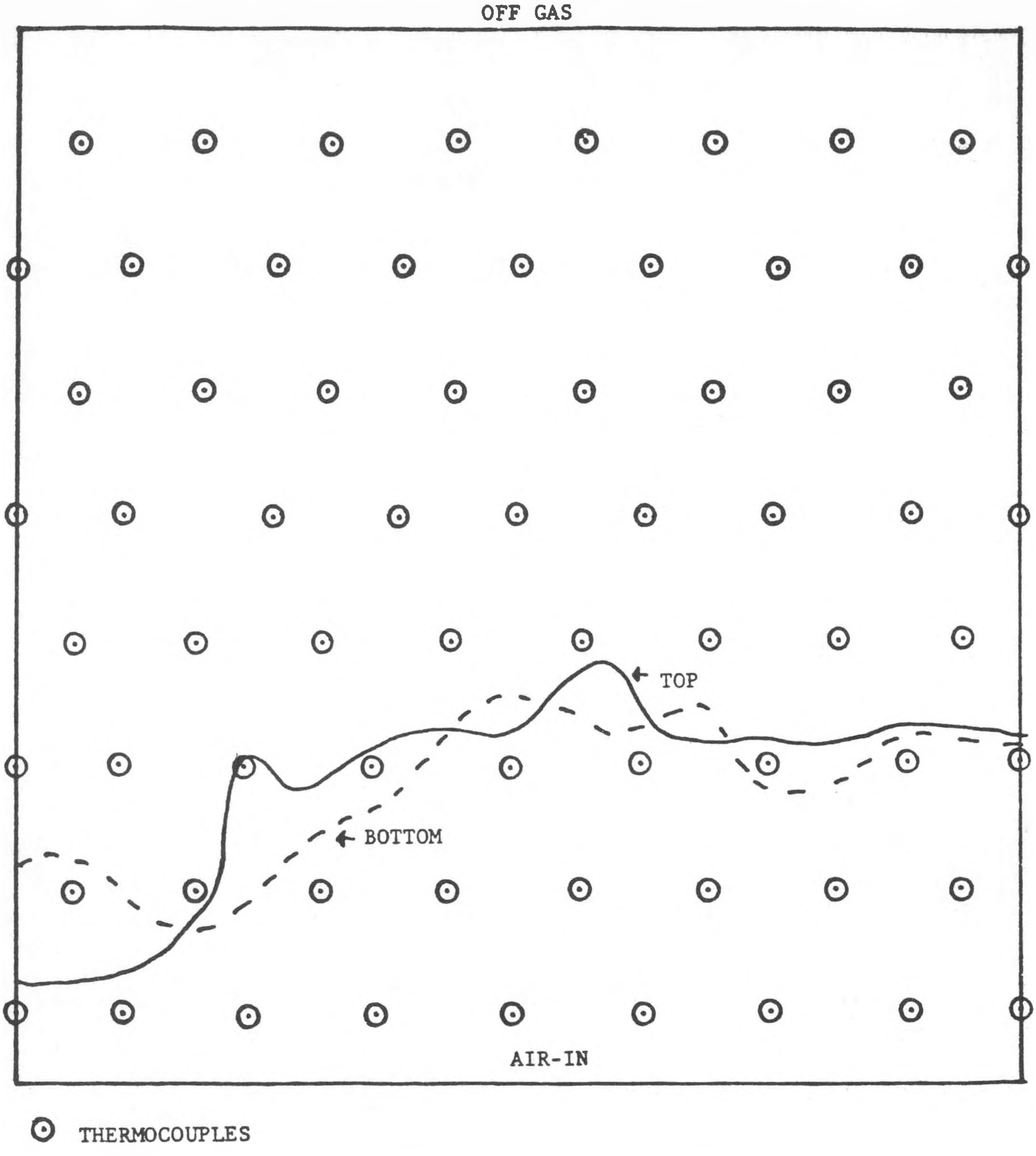



Figure 28. Retort #26 - Fire Front Location
800° Isotherms - End of August, 1982

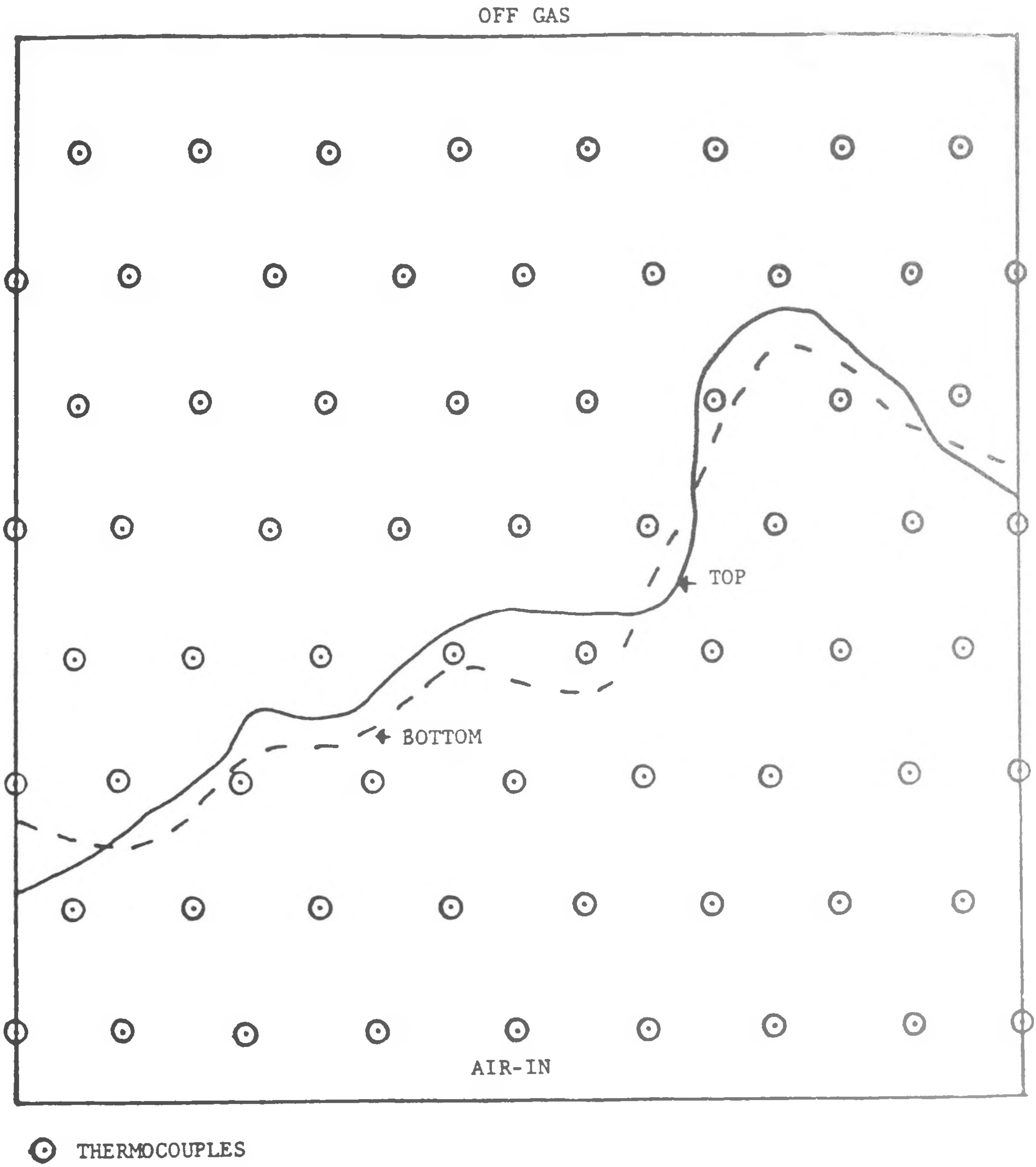



Figure 29. Retort #26 - Fire Front Location
800° Isotherms - End of September 1982

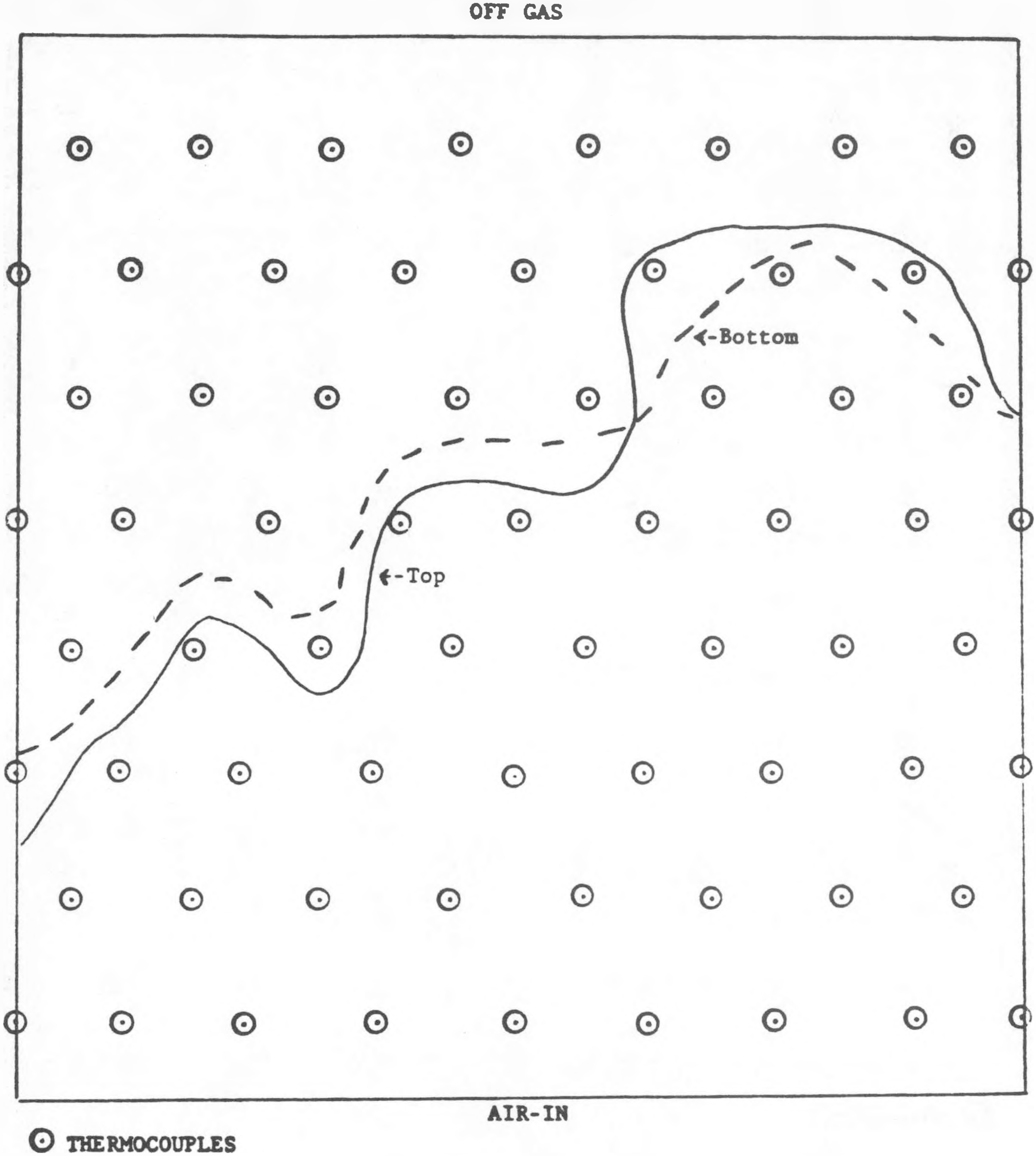



Figure 30. Retort #26 - Fire Front Advance
800° Isotherms -End of October 1982

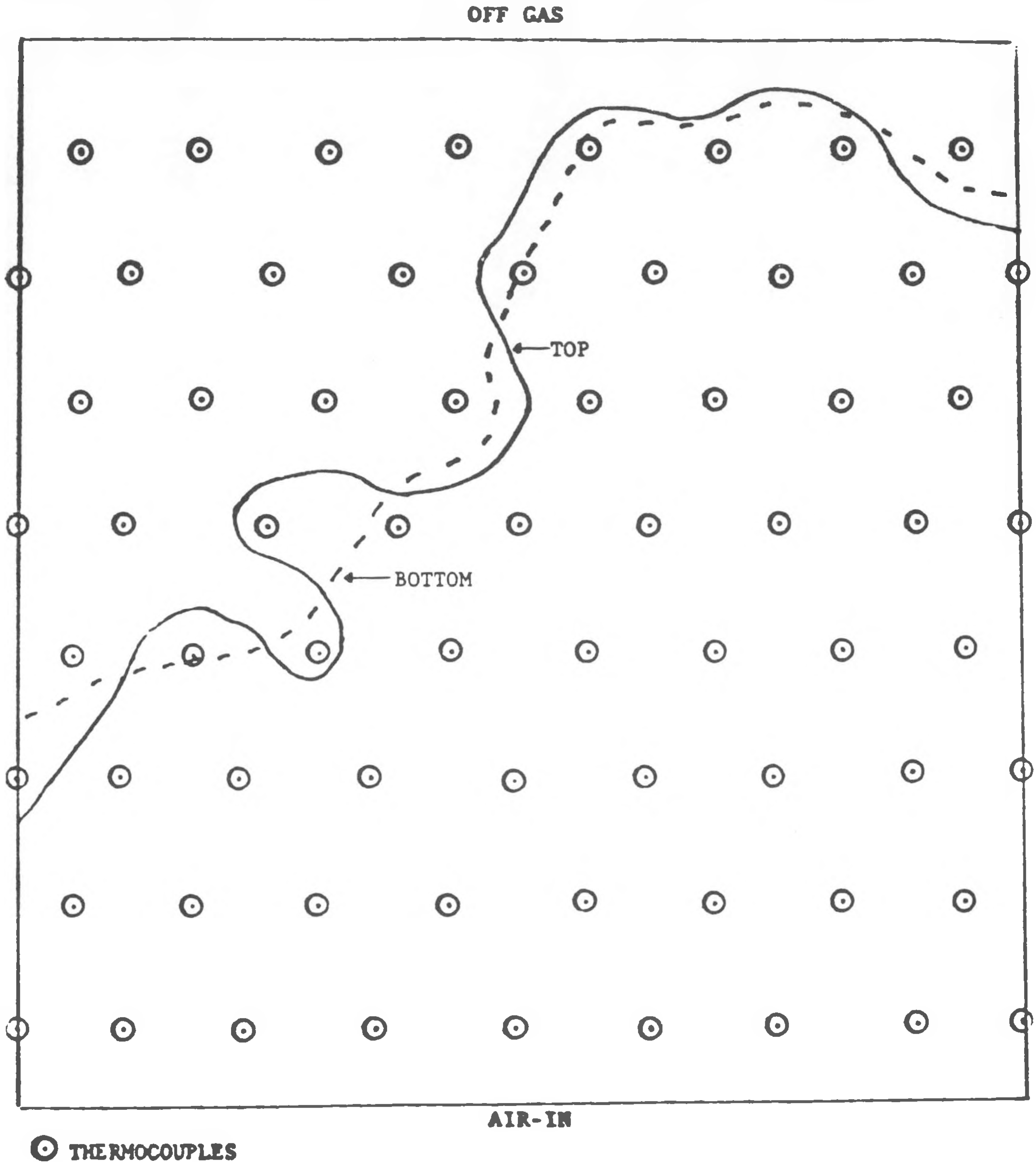



Figure 31. Retort #26 - Fire Front Advance
800° Isotherms
End of November

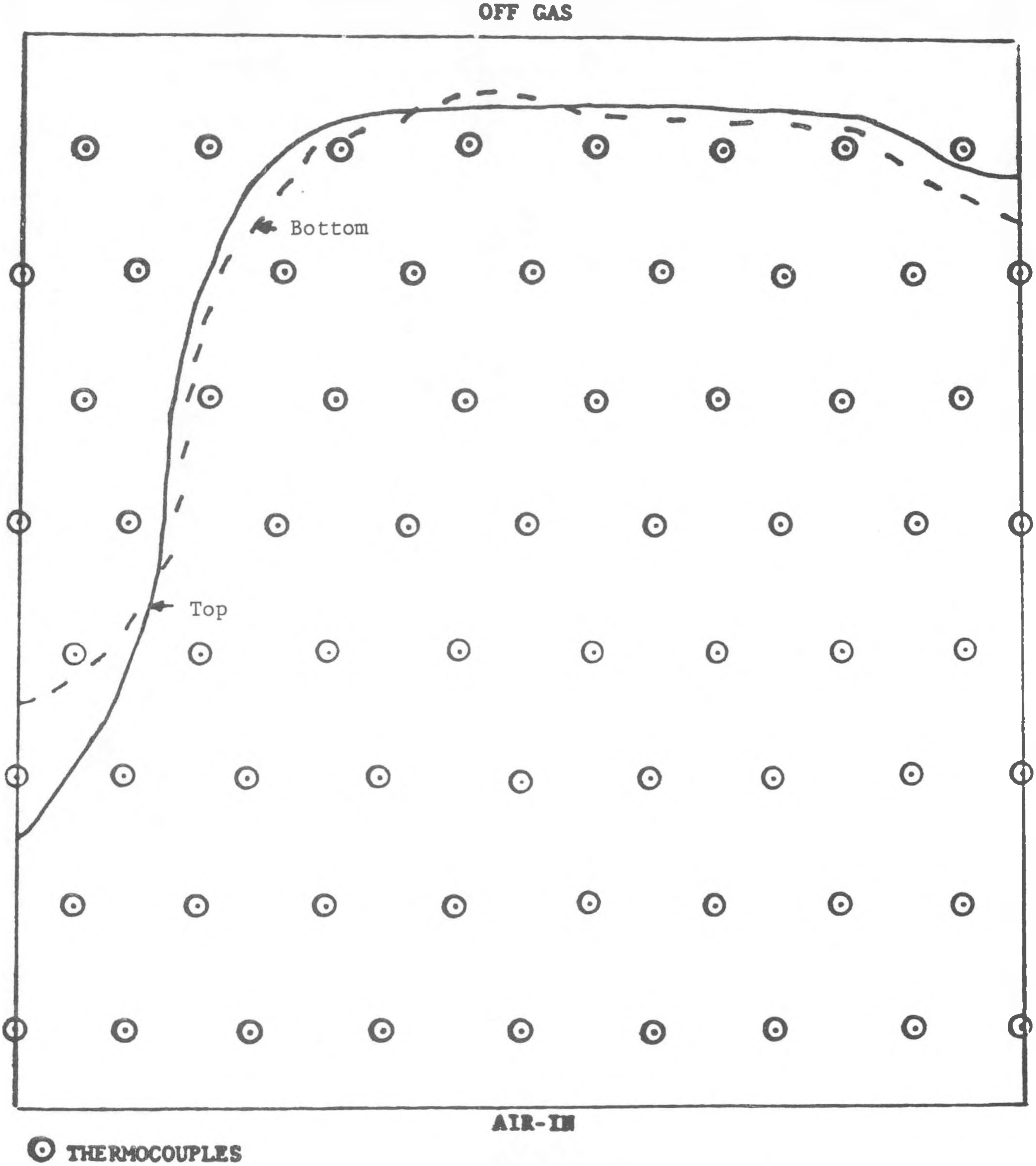



Figure 32. Retort #26 - Fire Front Advance
800° Isotherms
E.D. 176
End of December

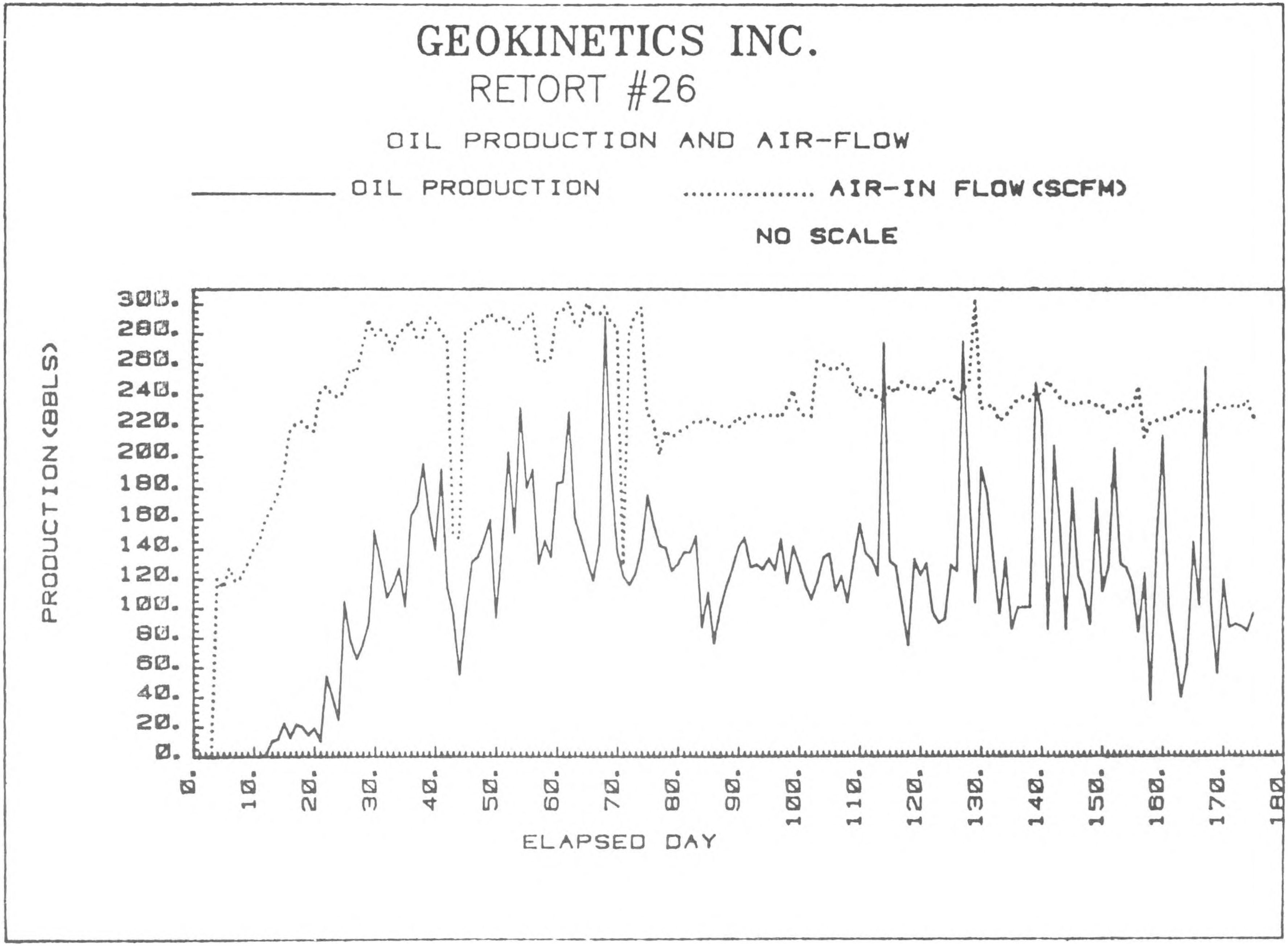



Figure 33. Oil Production and Air Flow

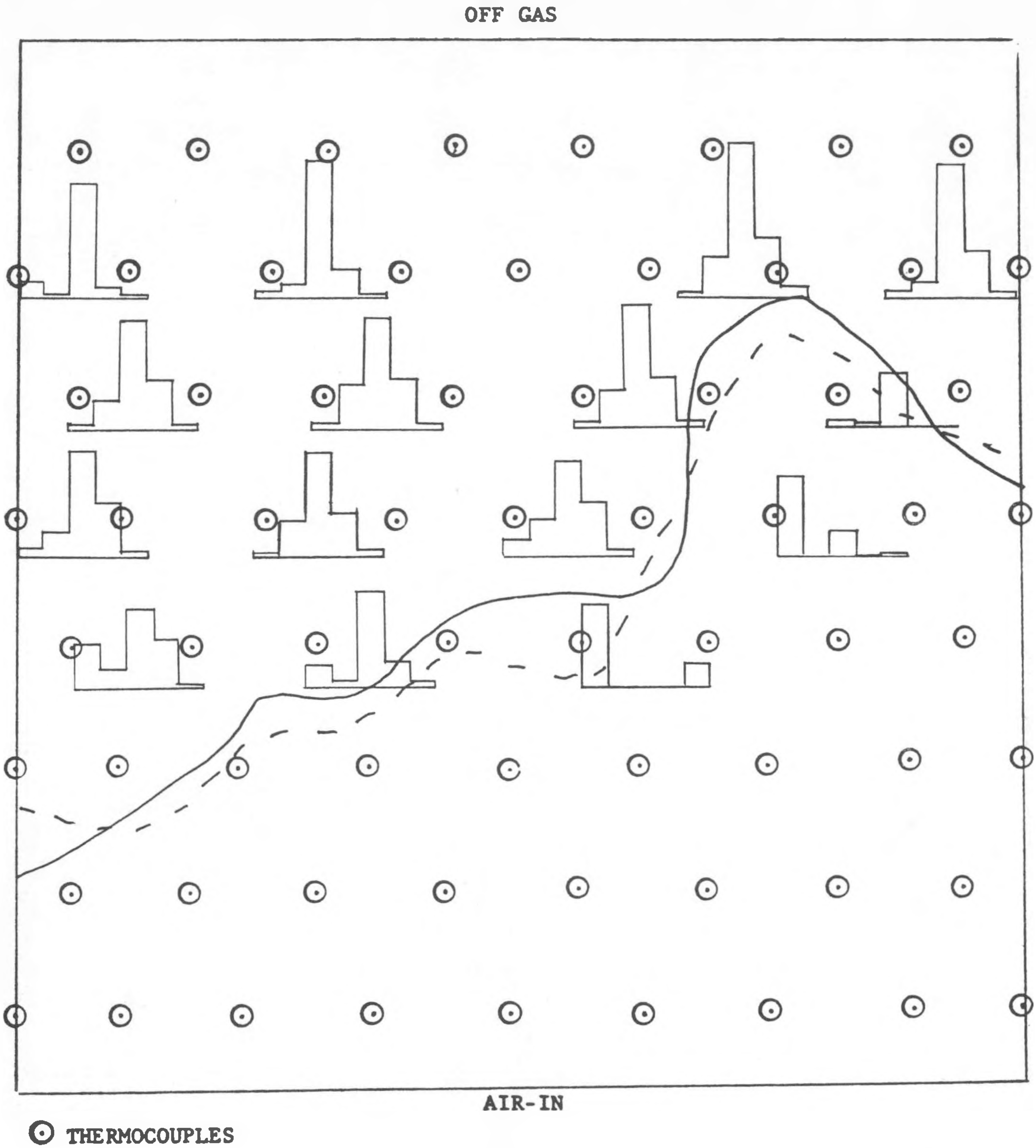
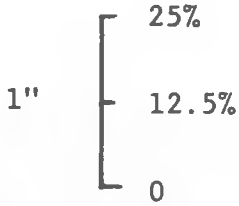
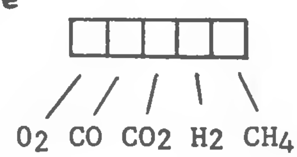



Figure 34. **Retort # 26 - Fire Front Advance 800° Isotherms**
R.P. Gas Sample Analysis
Elapsed Day 85



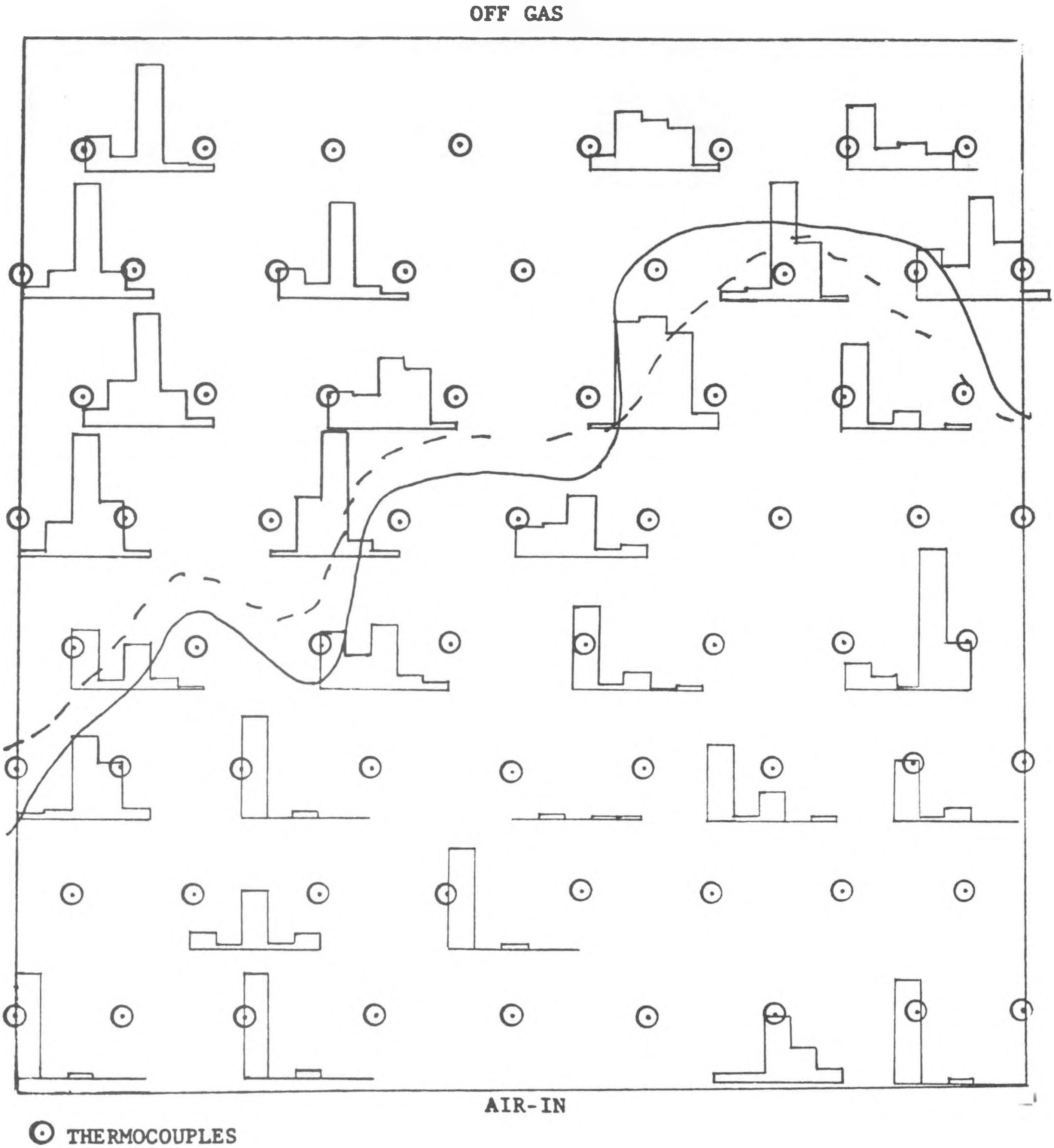
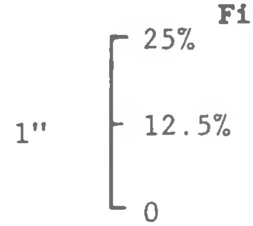
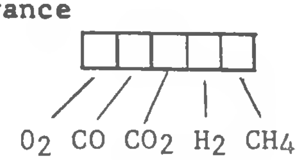



**Figure** 35. **Retort # 26 - Fire Front Advance**
**800° Isotherms**
R.P. Gas Sample Analysis
Elapsed Day 125



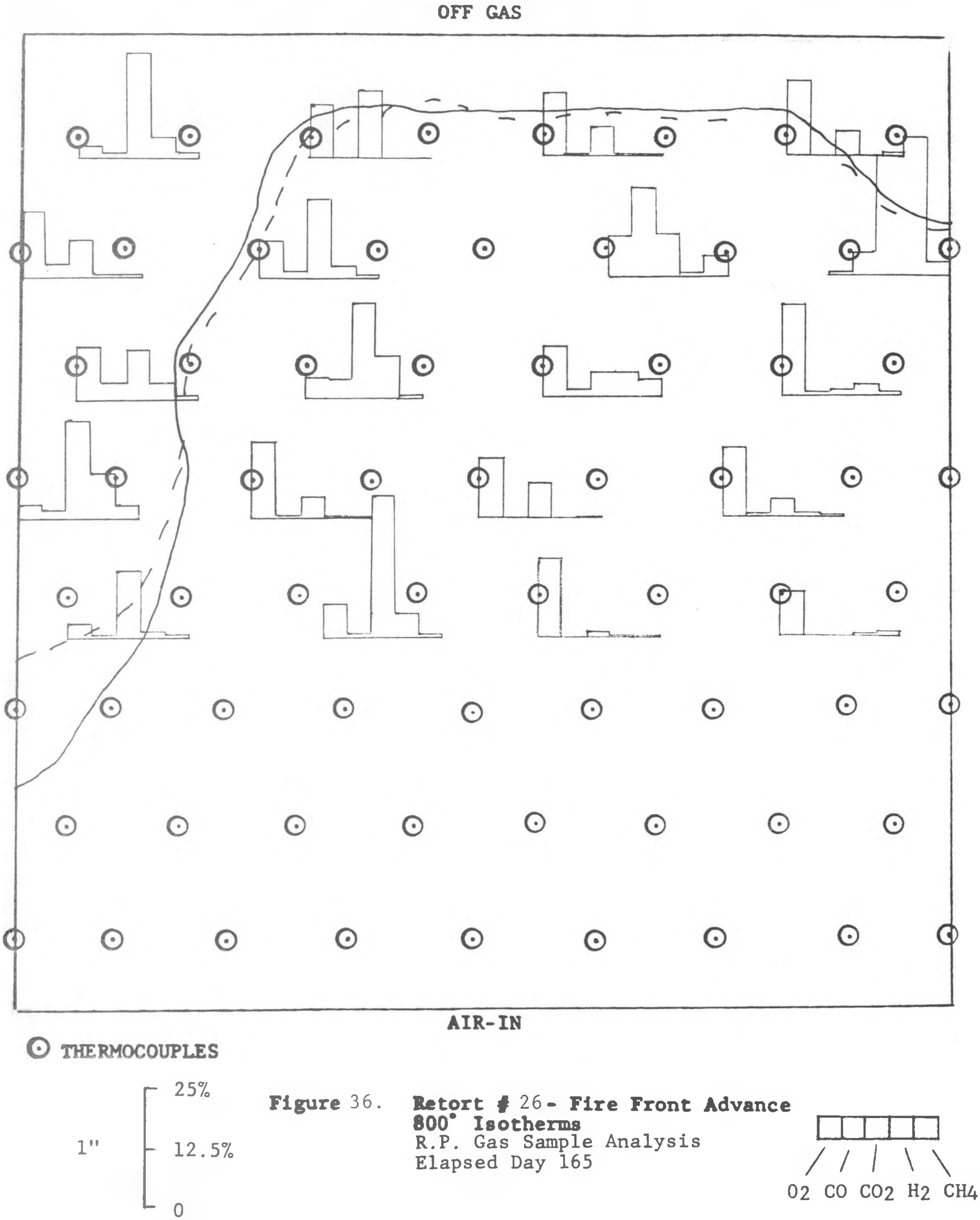



**Figure** 36. **Retort # 26 - Fire Front Advance**
**800° Isotherms**
R.P. Gas Sample Analysis
Elapsed Day 165

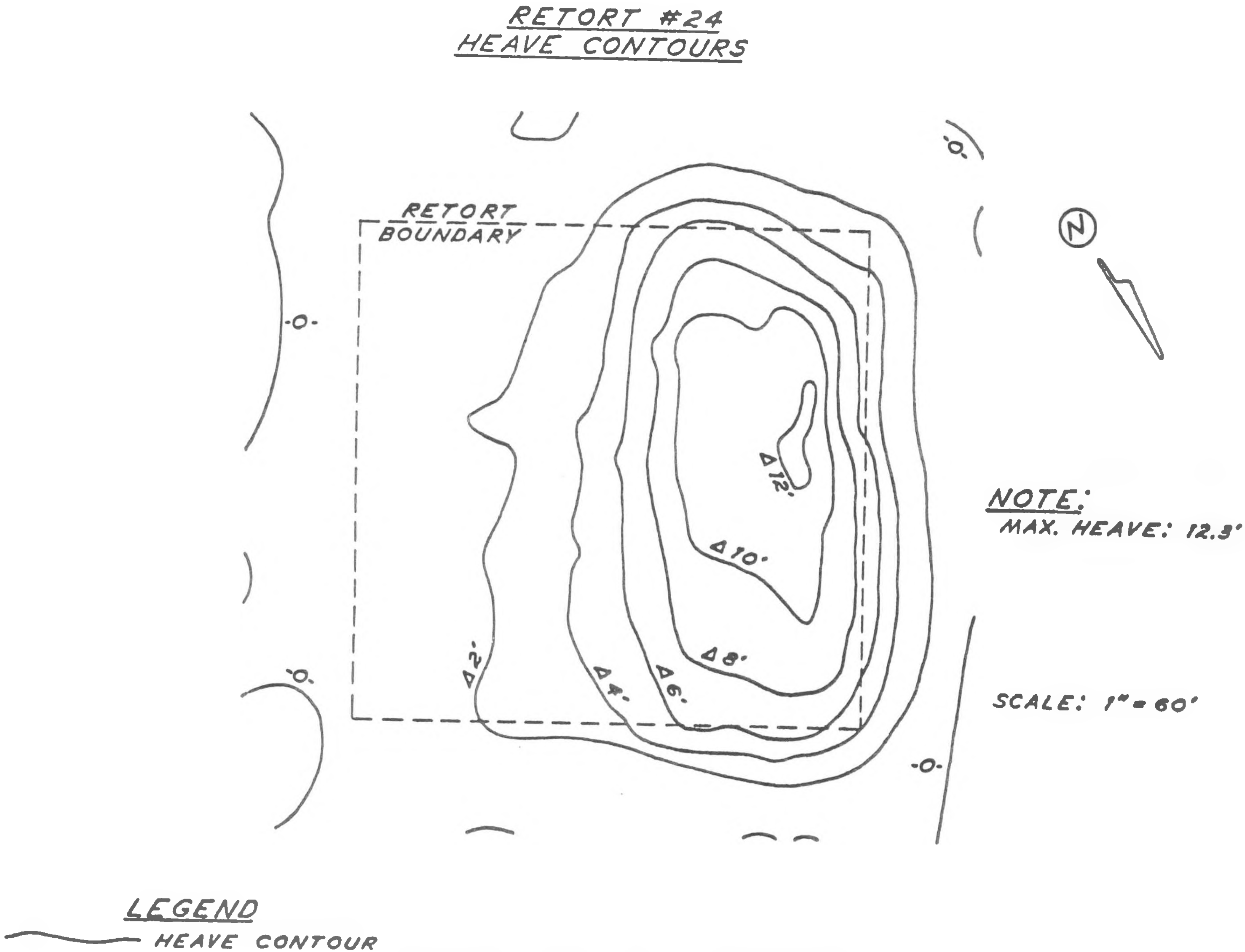



Figure 37. Retort #24 - Heave Contours

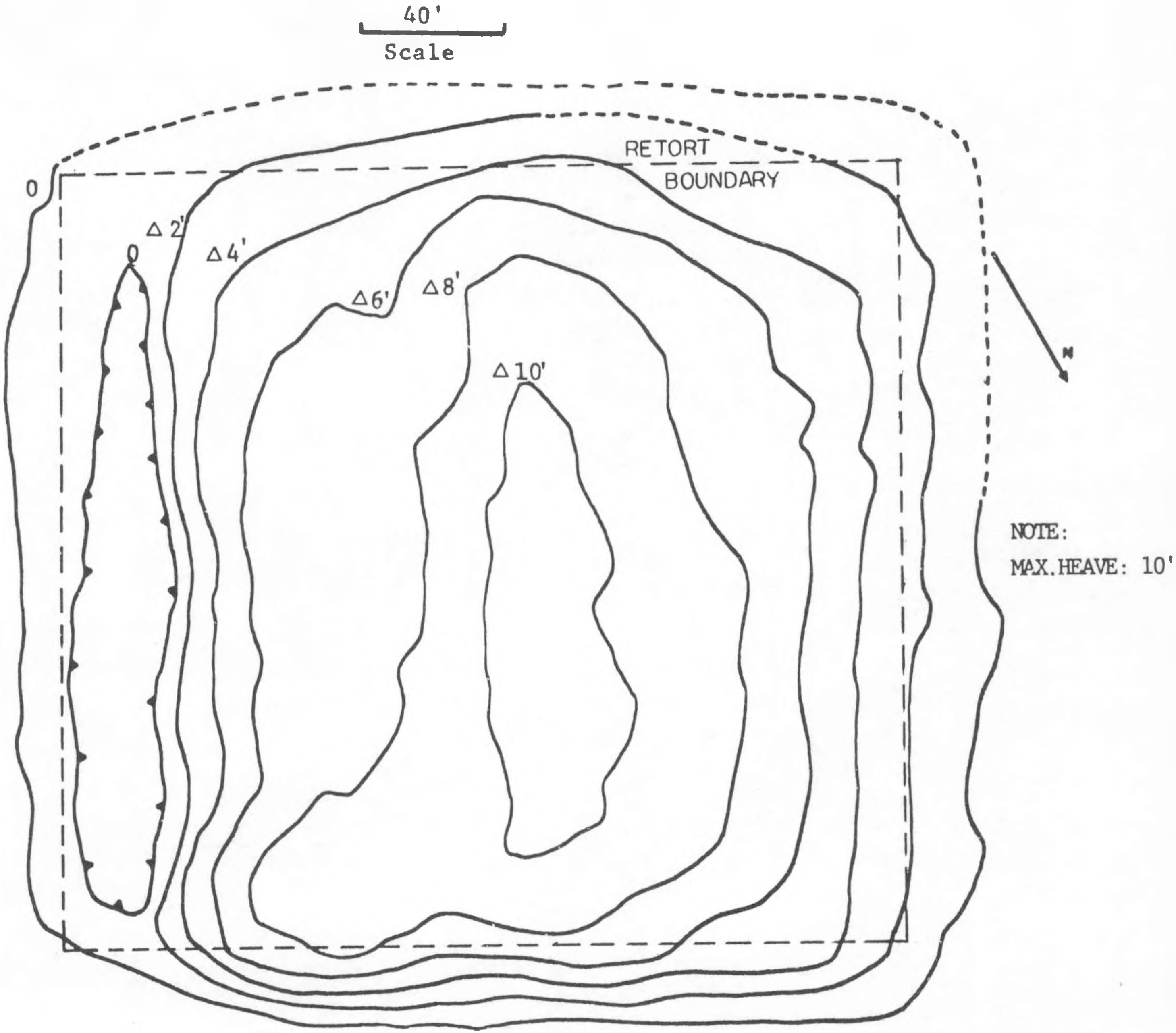



Figure 38-a. Retort #27 - Heave Contours

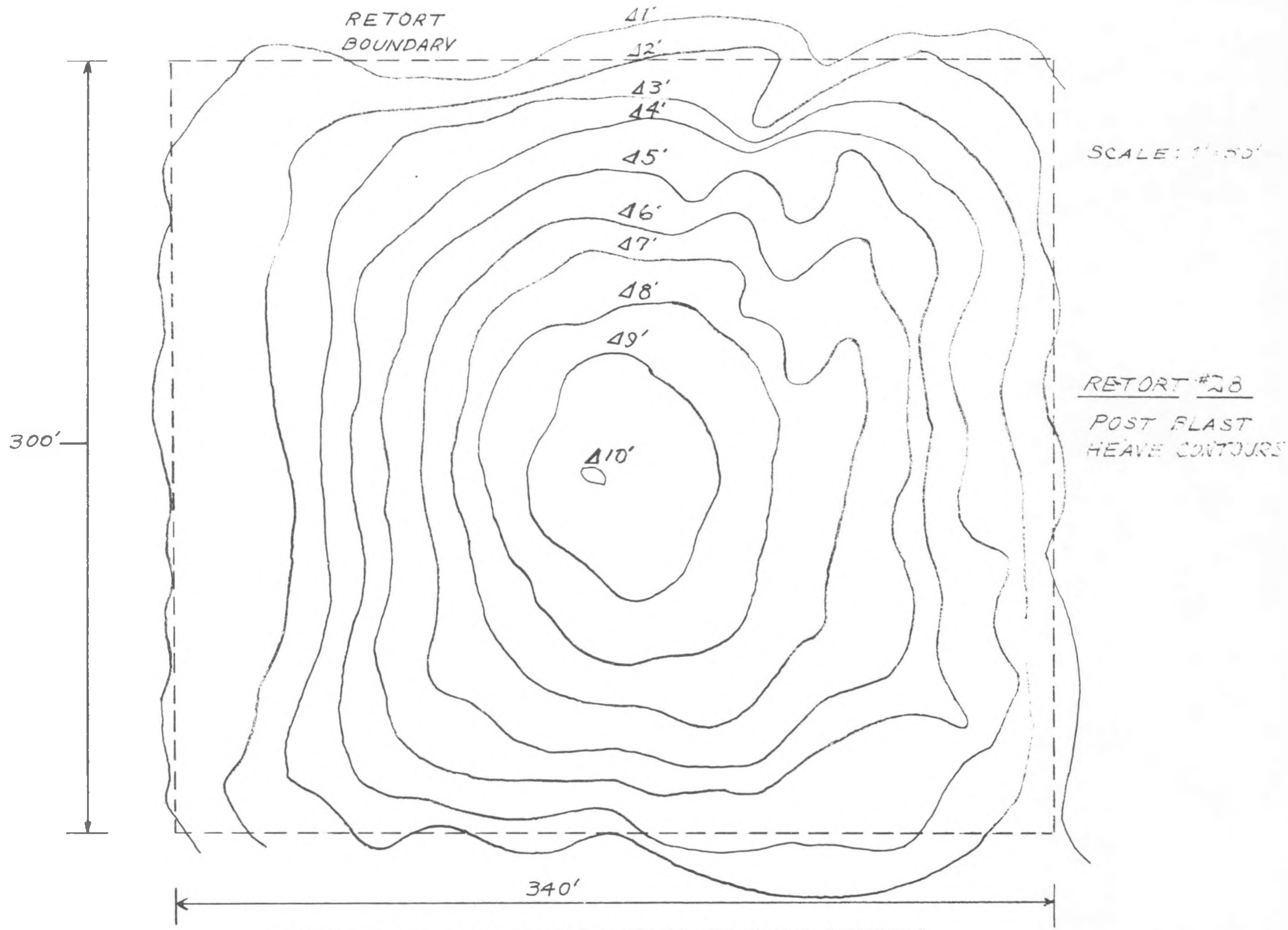



FIGURE 38-b. RETORT #28 POST-BLAST HEAVE CONTOURS

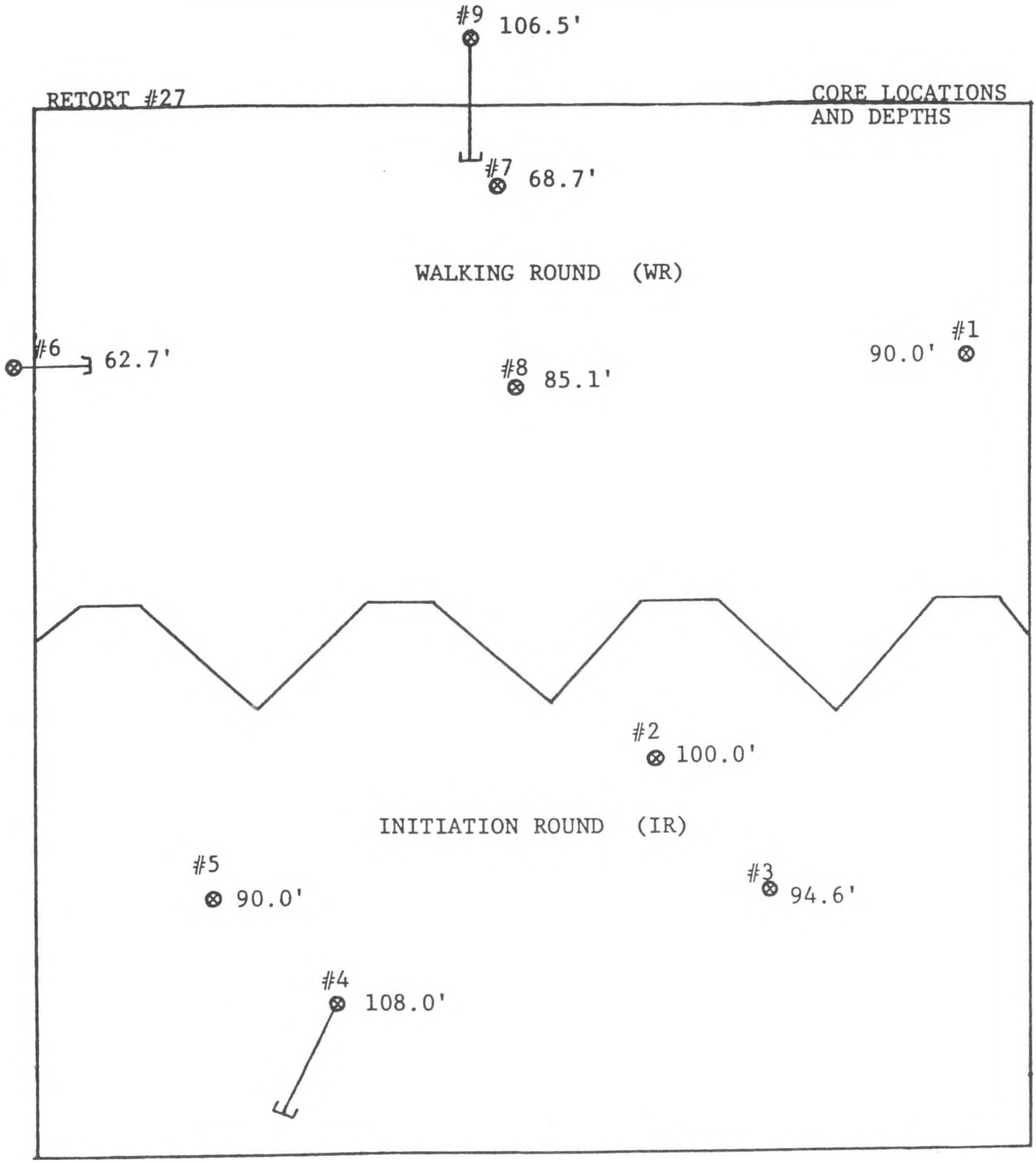



Figure 39. Retort #27 - Core Hole Locations

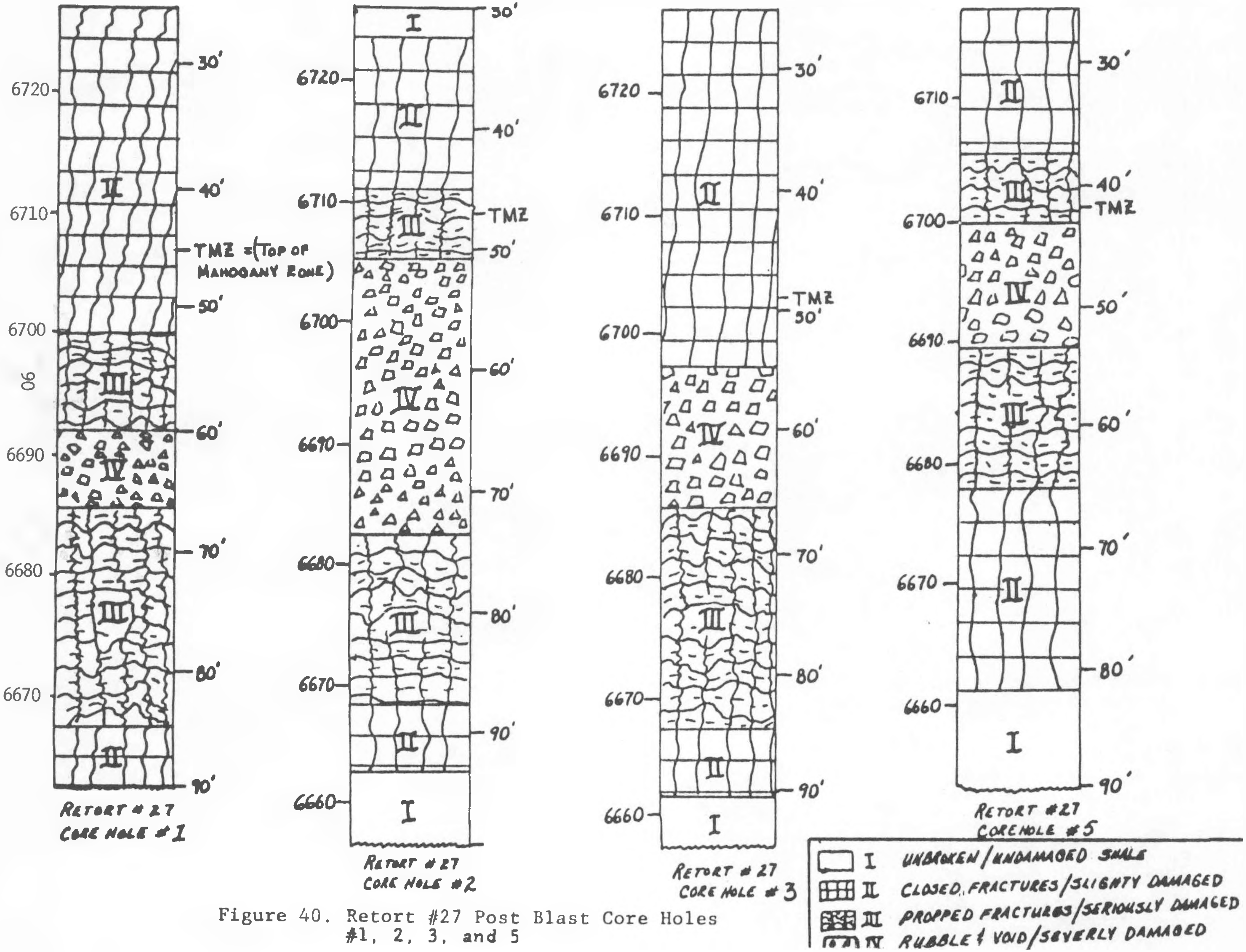



Figure 40. Retort #27 Post Blast Core Holes #1, 2, 3, and 5

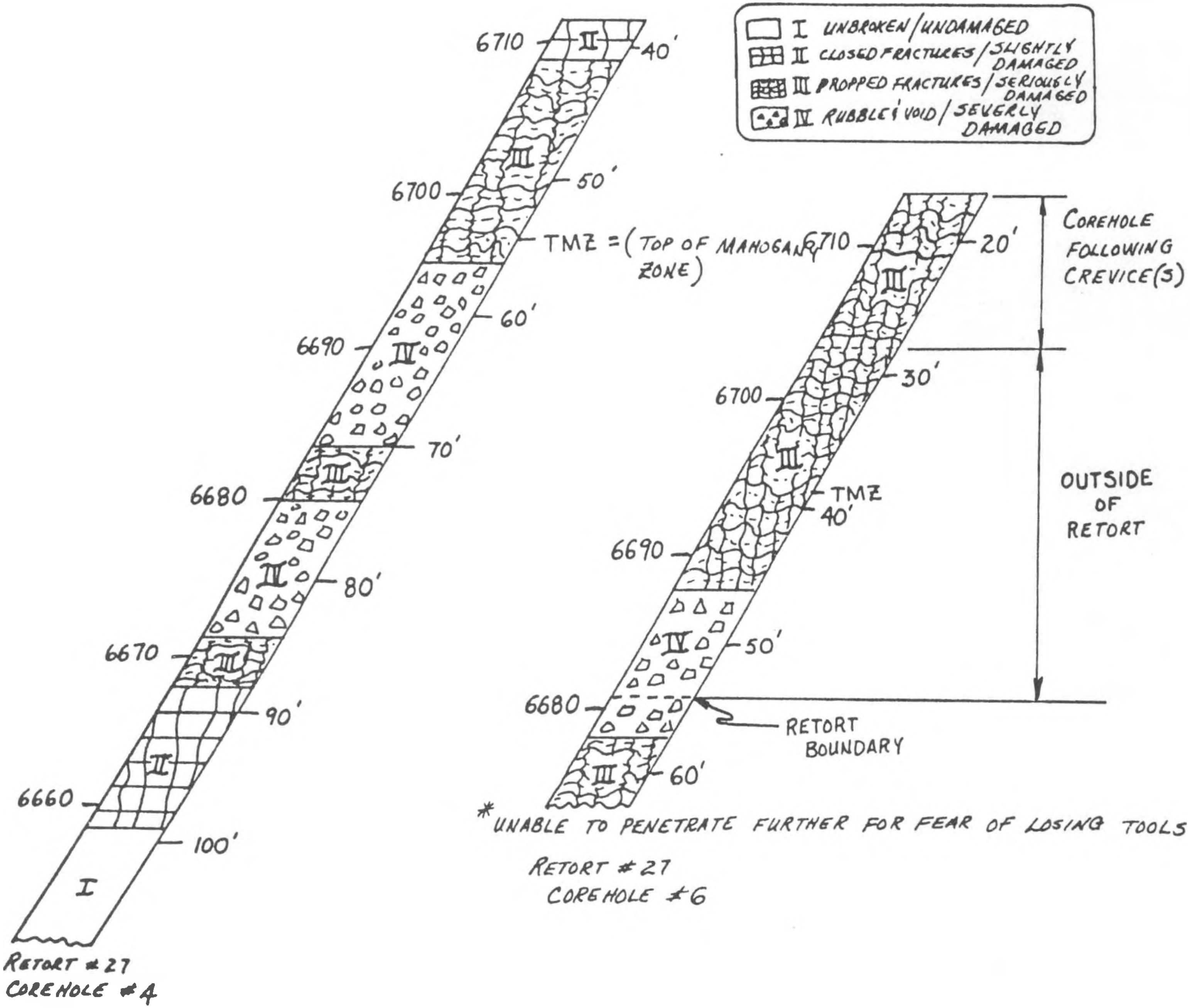



Figure 41. Retort #27 Post Blast Core Holes #4 and 6

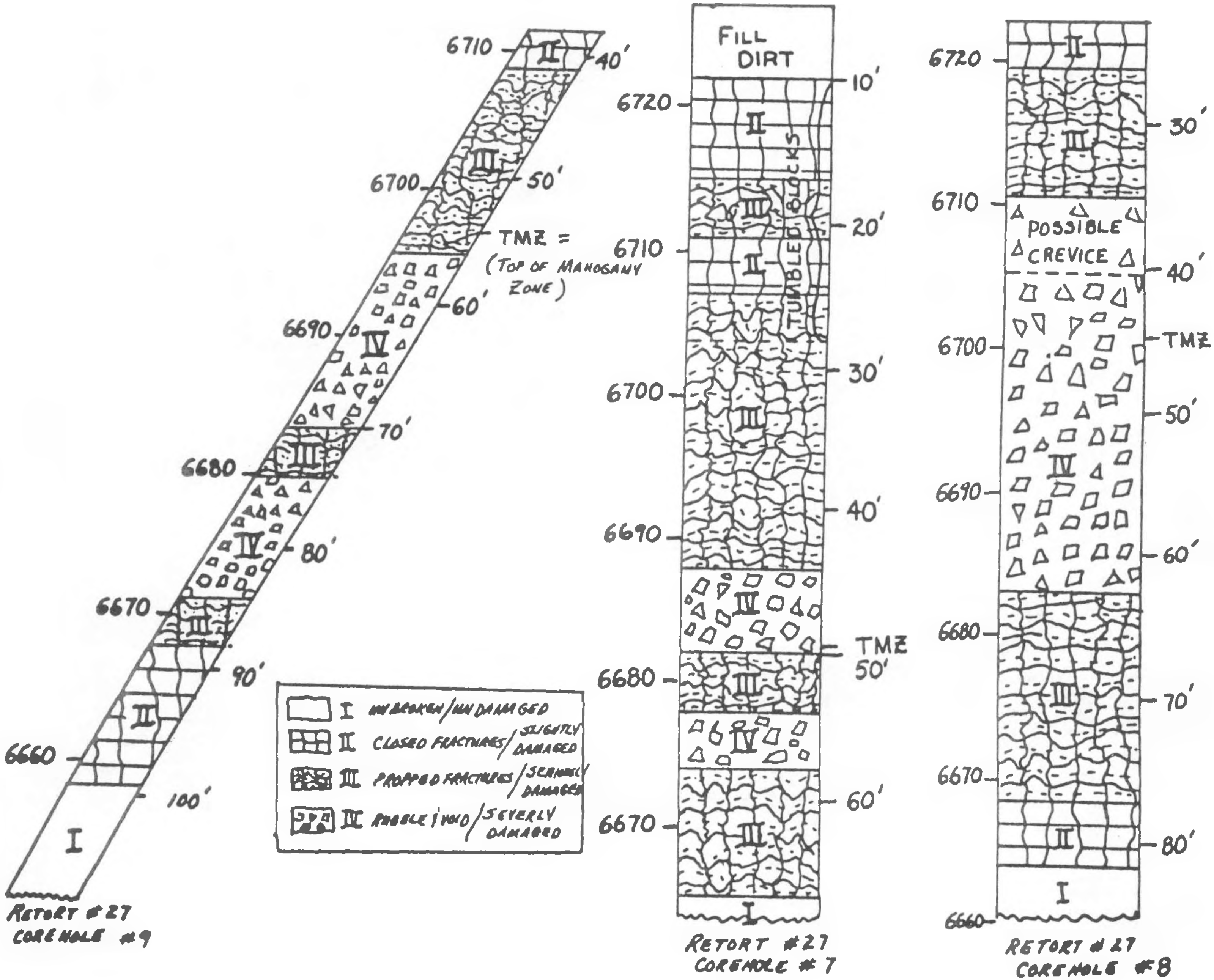



Figure 42. Retort #27 Post Blast Core Holes #7, 8, and 9

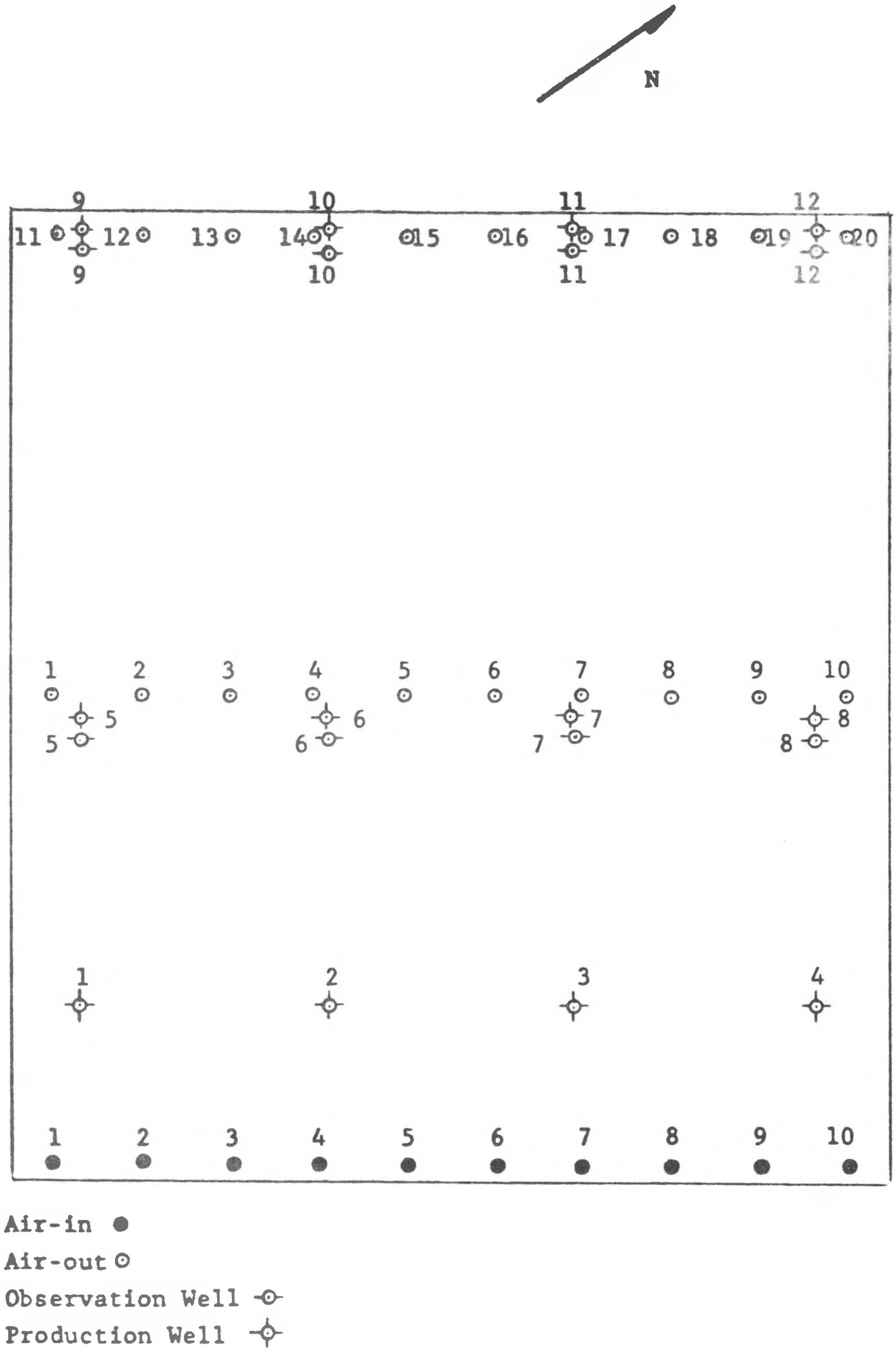



Figure 43. Retort #27 - Process Wells

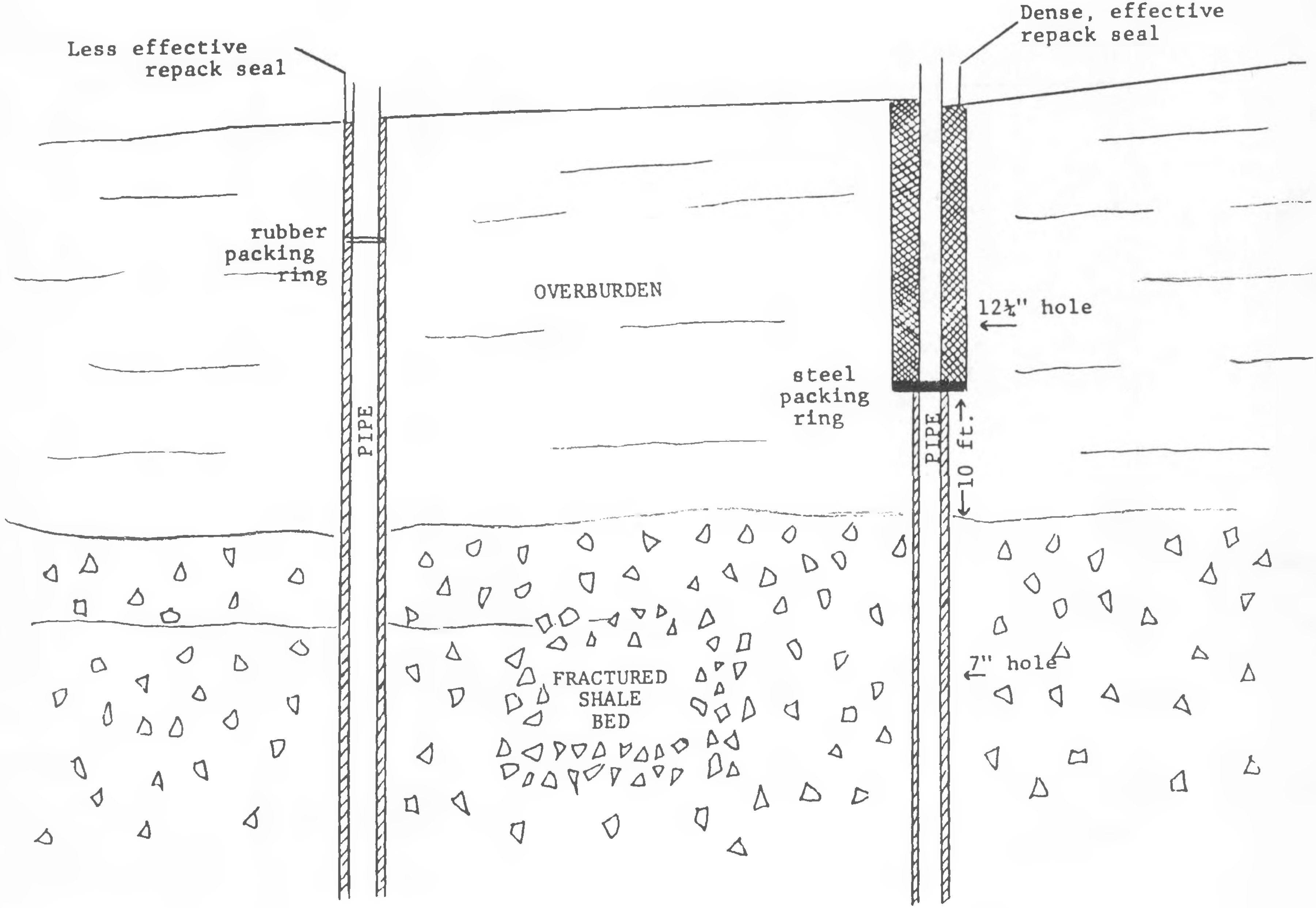



Figure 44. Representation of New Stemming Procedure for Retort Process Wells.
Retorts #27 and #28

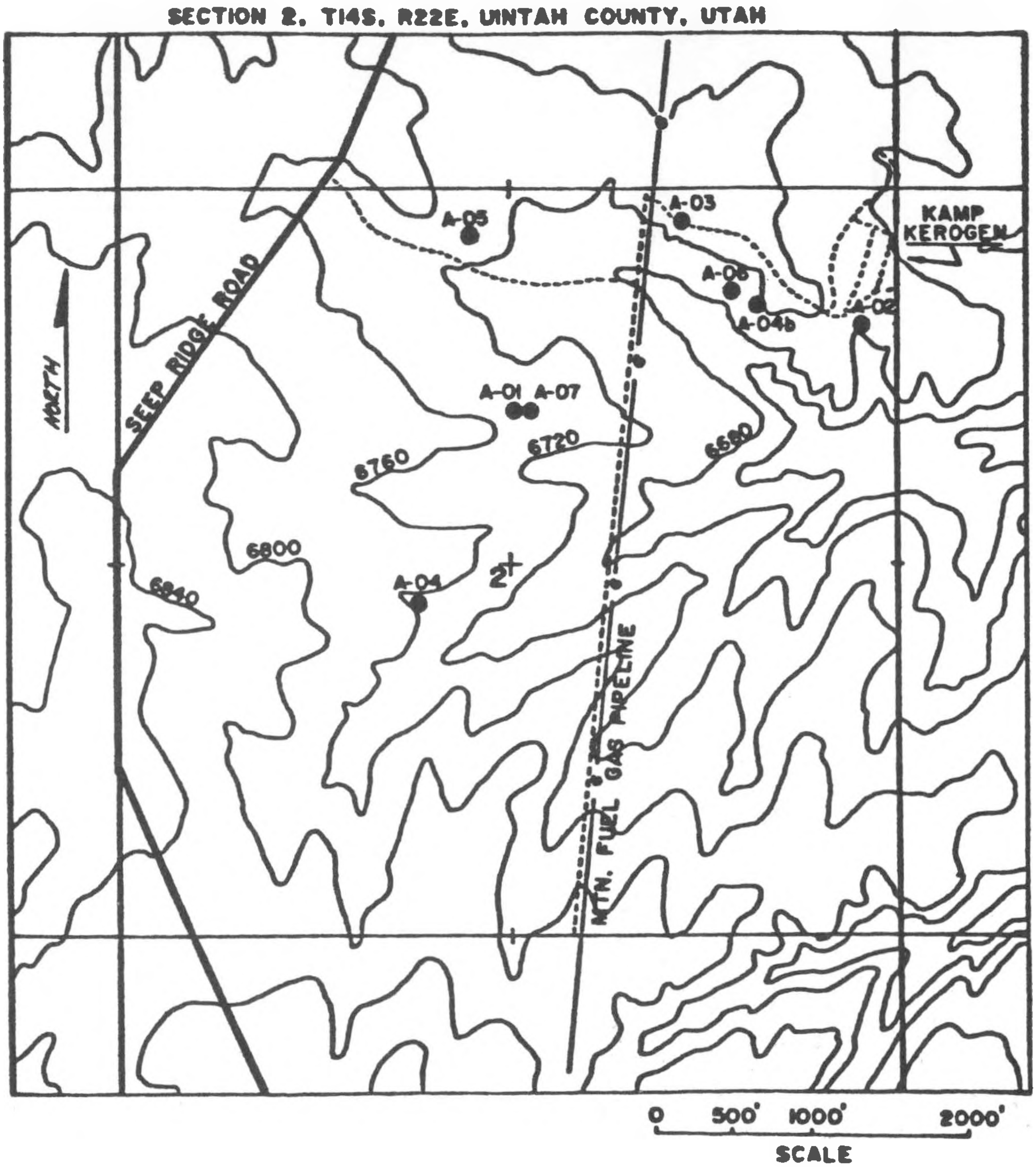
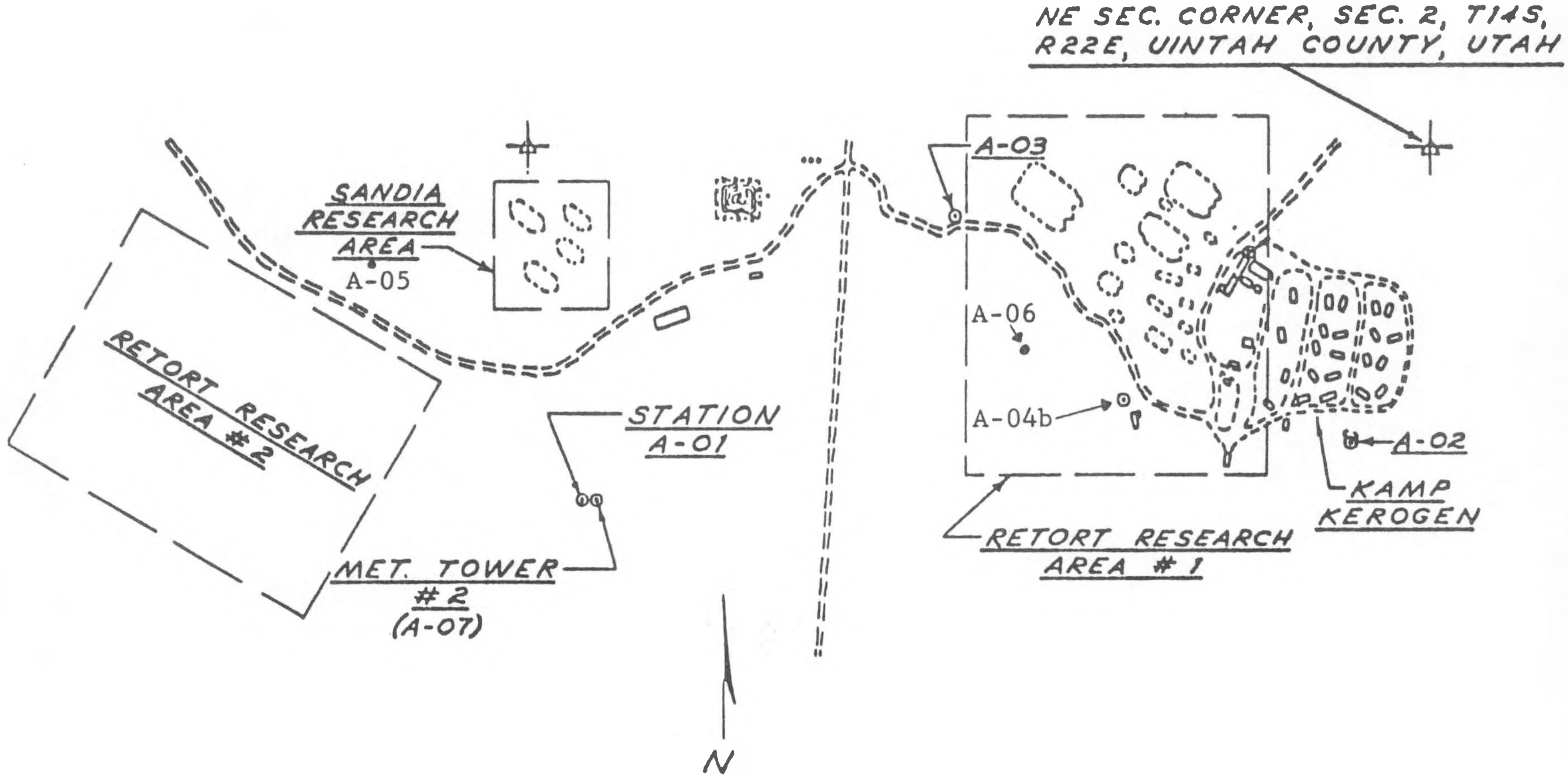



Figure 45. Generalized Meteorological Stations




0 500' 1000'
SCALE

Figure 46. Meteorological Stations in Relationship to Retort Research Areas

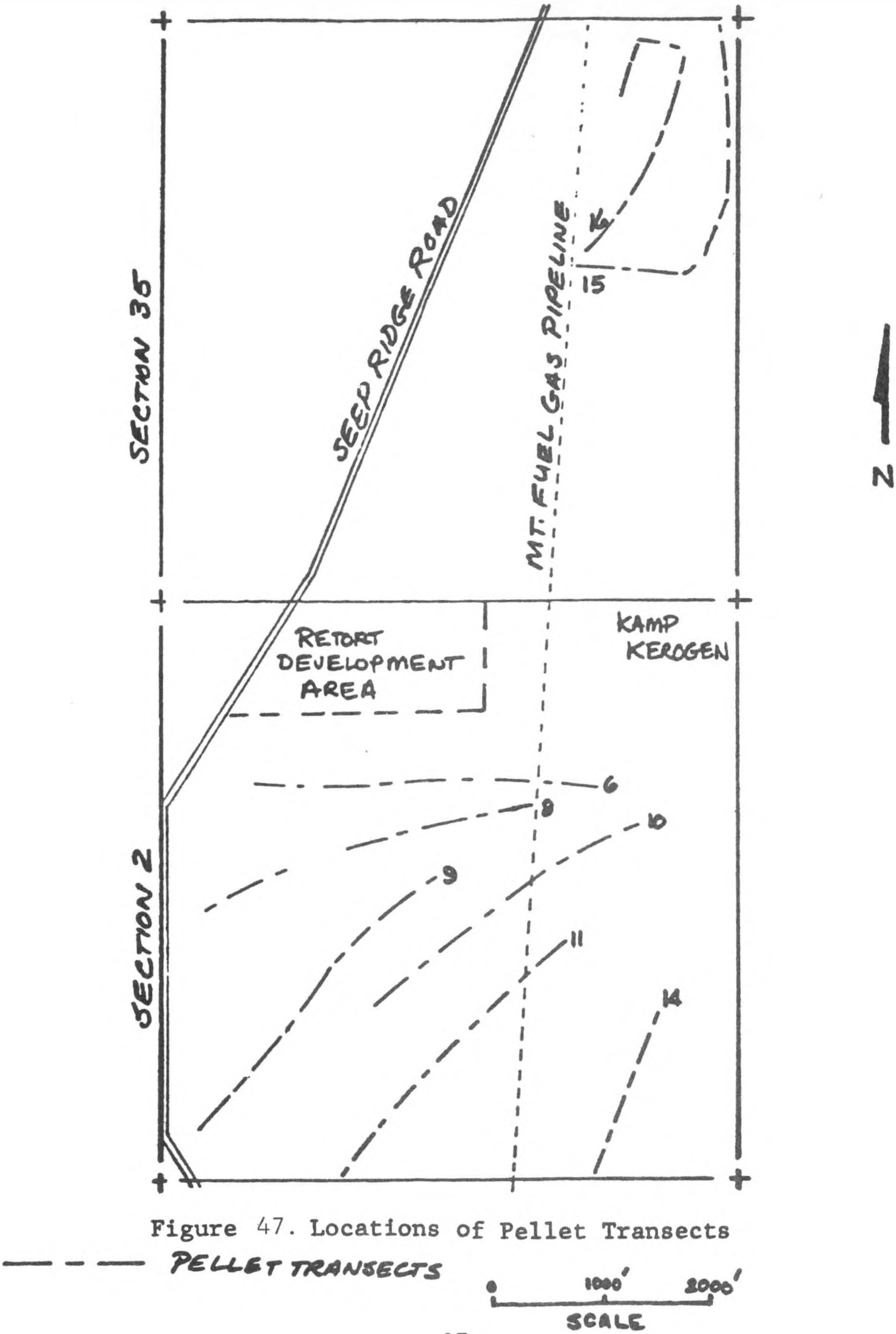



Figure 47. Locations of Pellet Transects

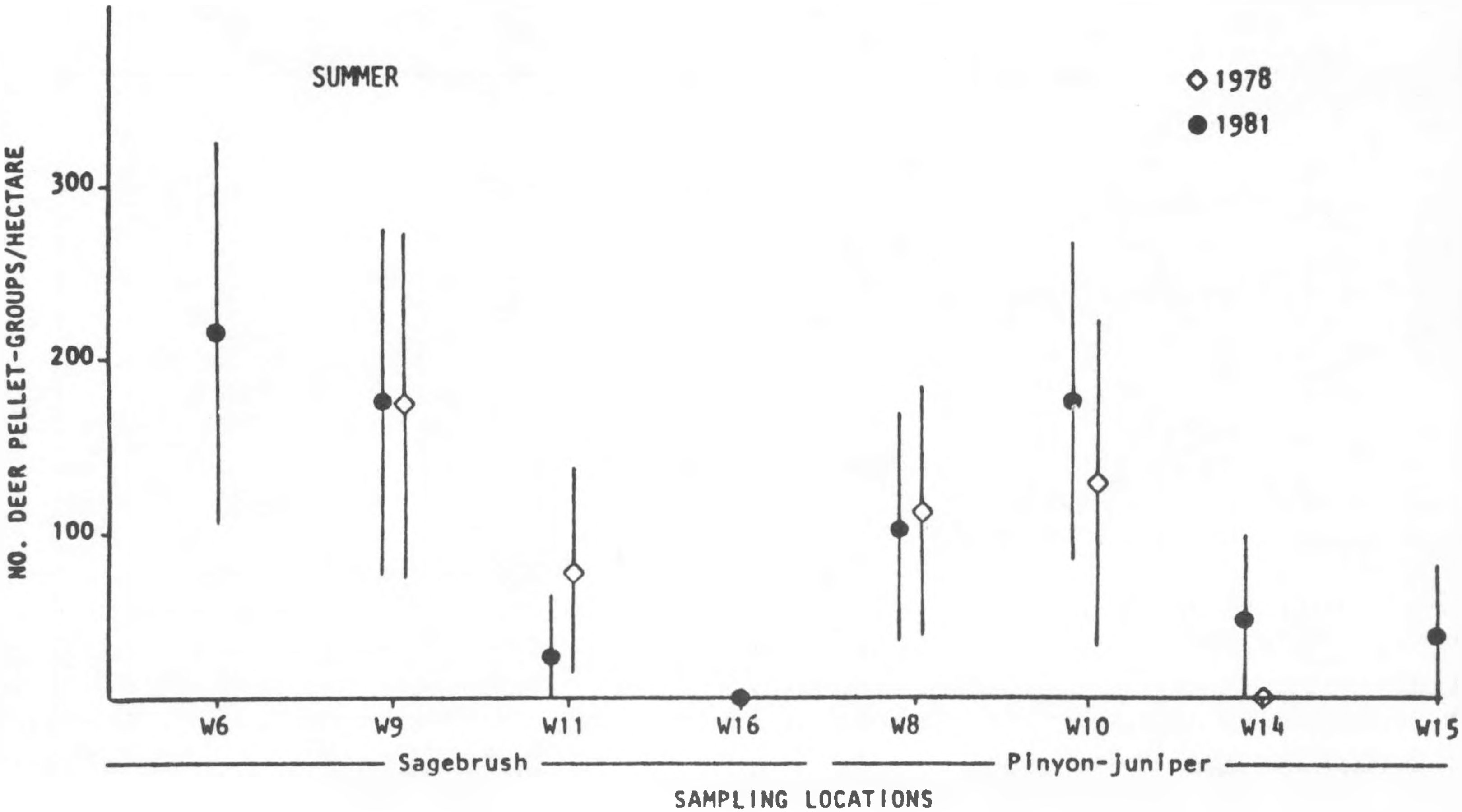



Figure 48. Mule deer pellet-group densities for two summer periods. Data are means ± 95 percent confidence intervals.

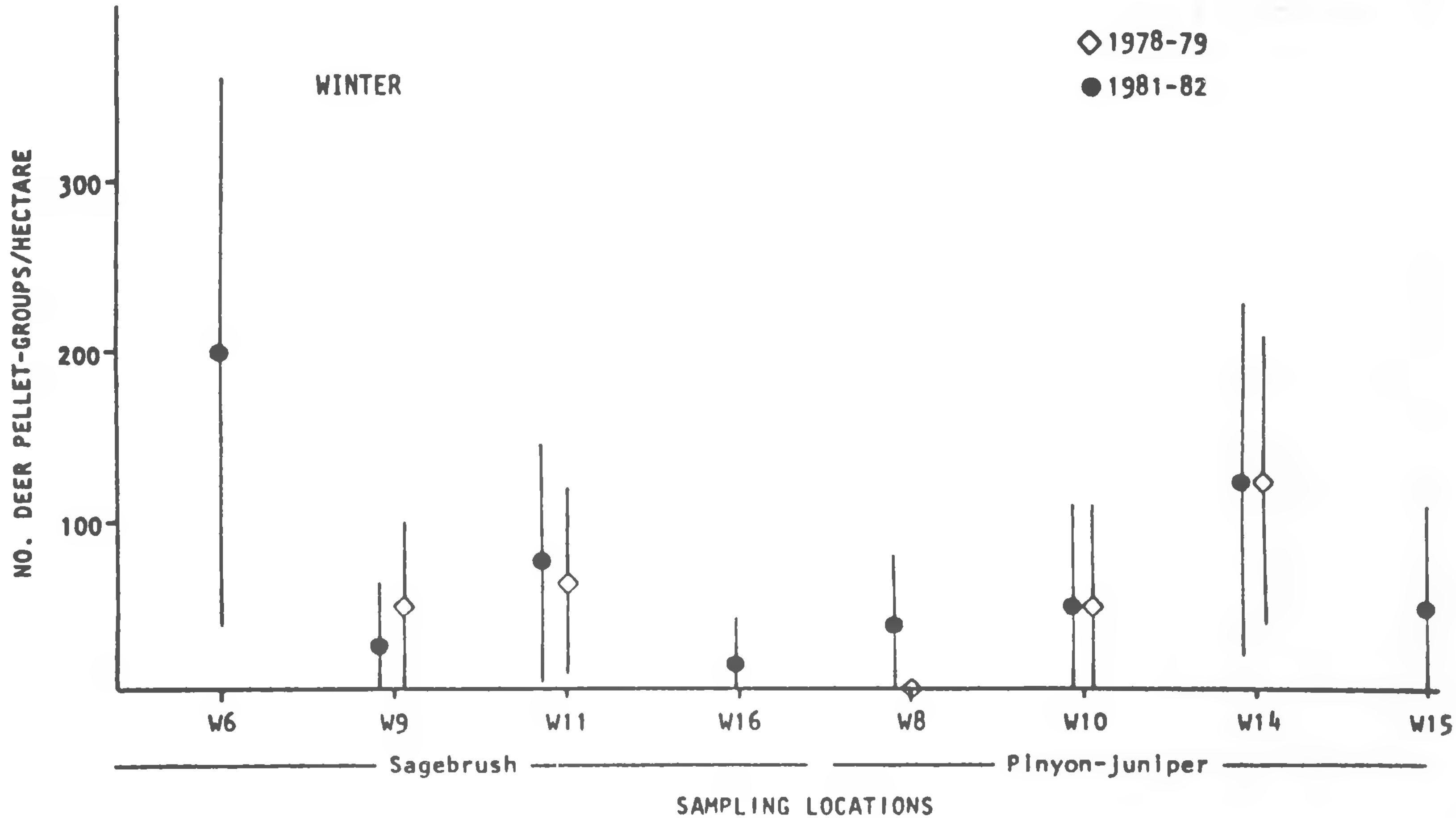



Figure 49. Mule deer pellet-group densities for two winter periods. Data are means ± 95 percent confidence intervals.

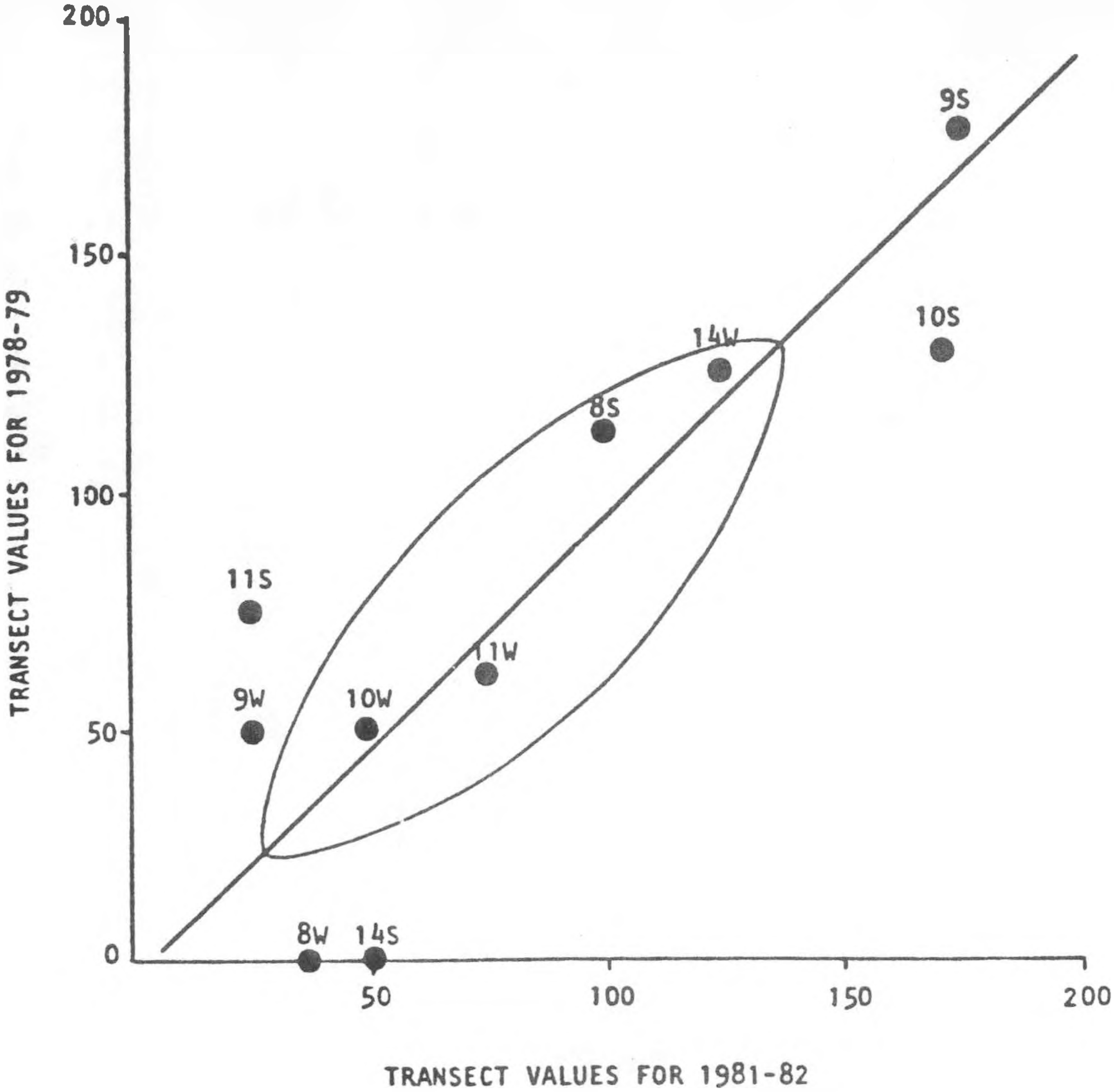



Figure 50. Between-year correlation of mule deer pellet-group counts. The points plotted are transect values—the number of pellet-groups per hectare for the same transect for the 2-year period. Transect location and season (S=summer; W=winter) is shown alongside the dots. The graph demonstrates a significant correlation ($r=0.84$; $df=8$; $P<0.002$) in pellet-group counts for the ten transect locations, suggesting similar habitat usage for both years. The ellipse is the 95% confidence region.

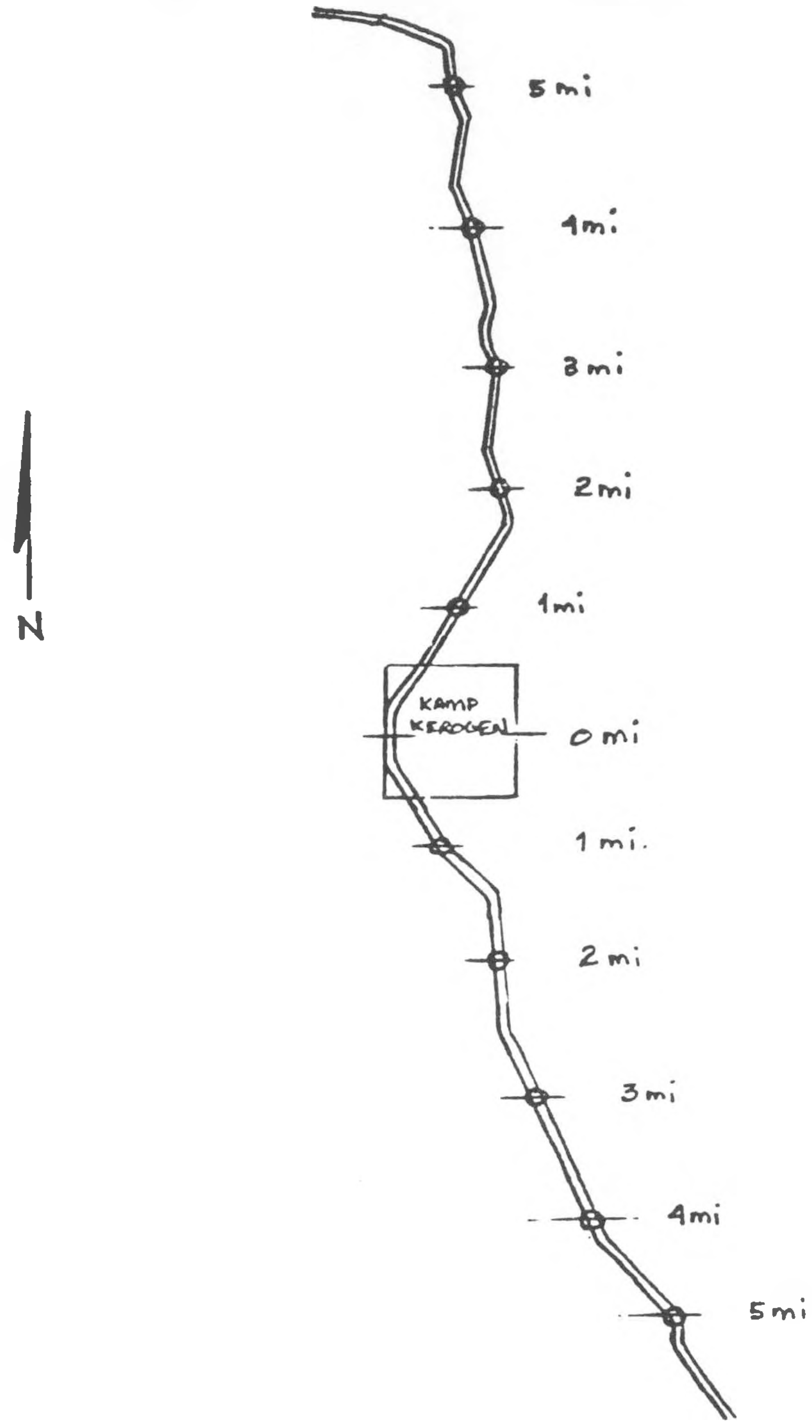



Figure 51. Road Count Route

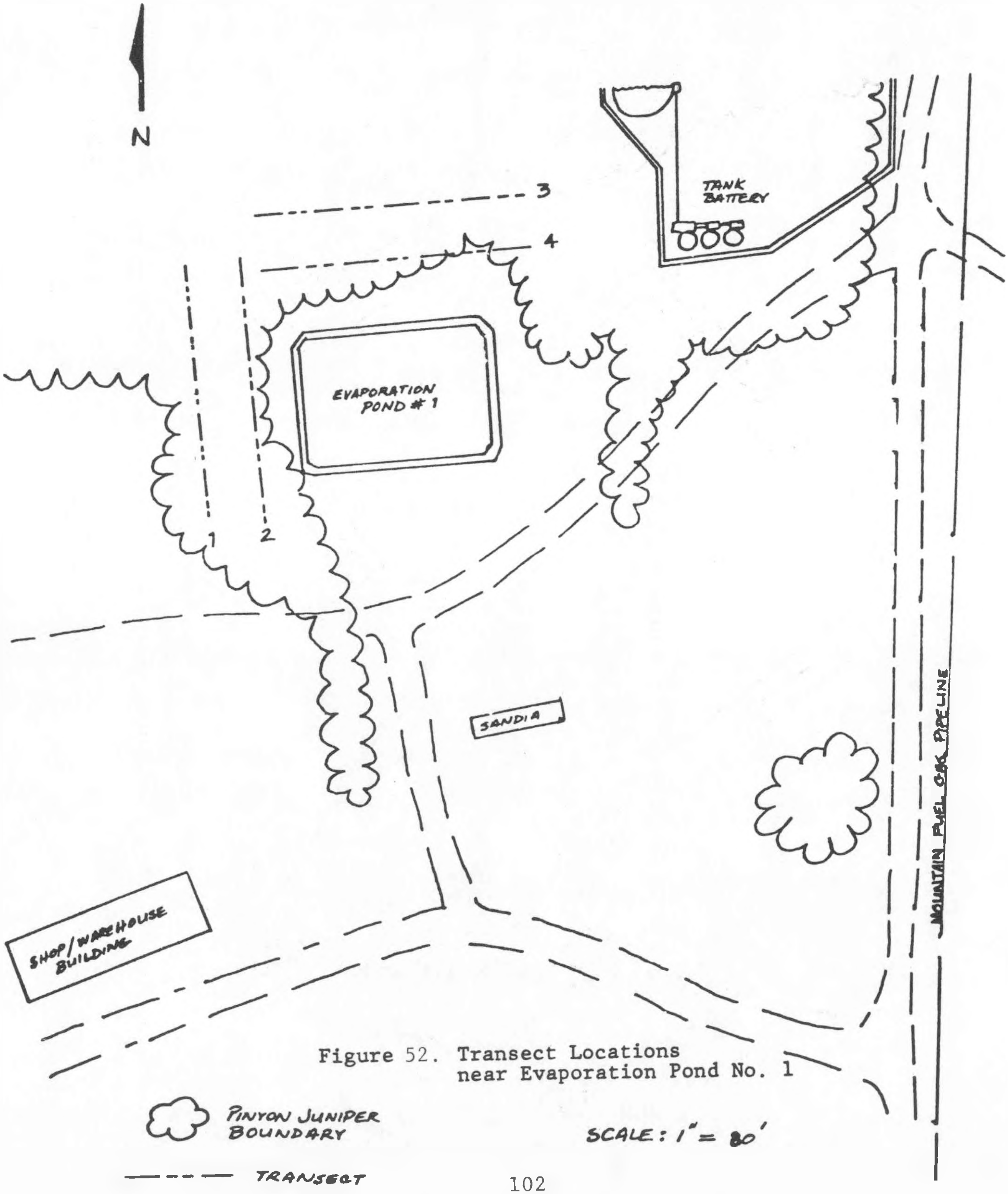



Figure 52. Transect Locations near Evaporation Pond No. 1

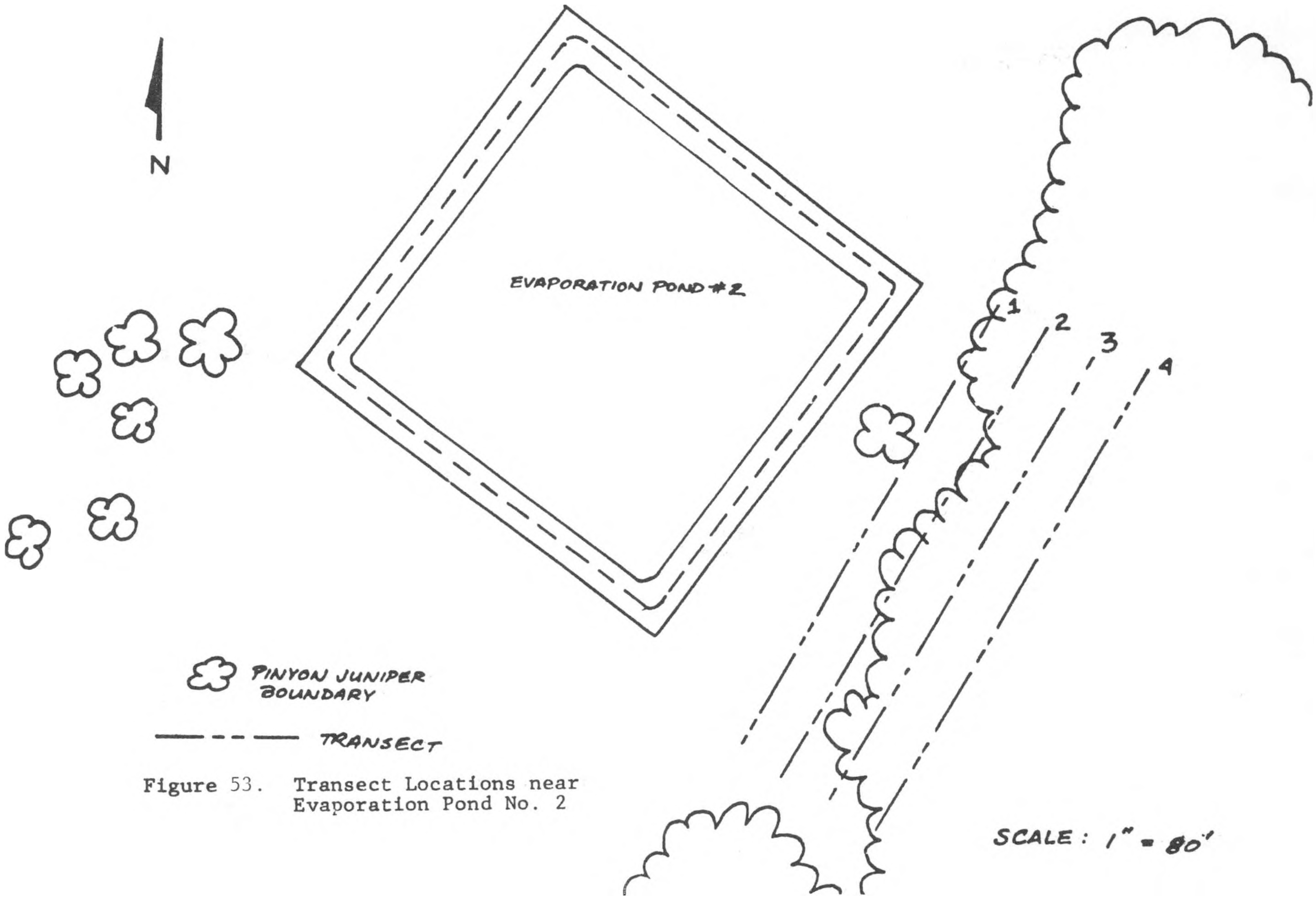



Figure 53. Transect Locations near Evaporation Pond No. 2

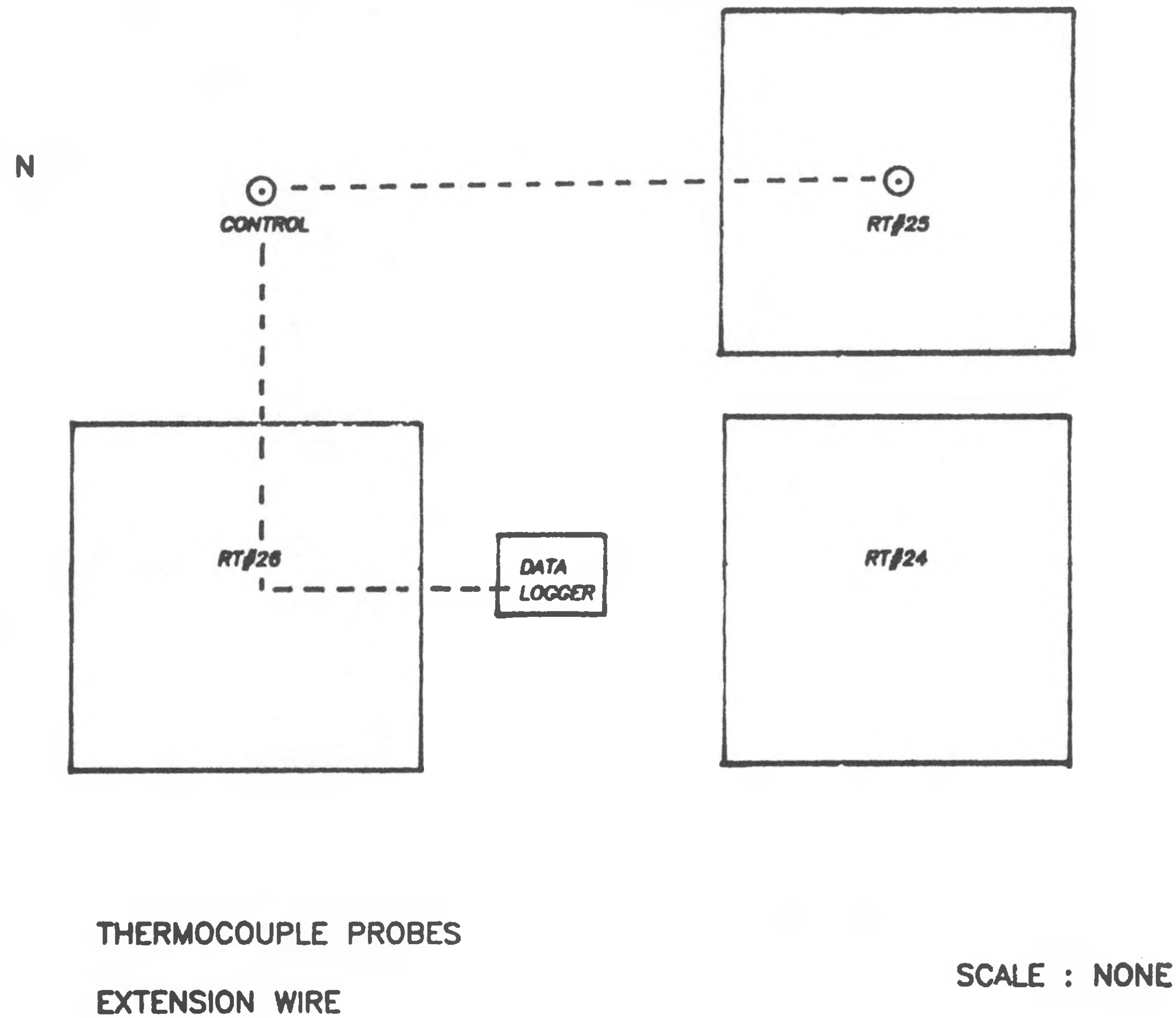



**Figure** 54. **Location of Temperature Sensors**
Retort #25 Soil Temperature Study

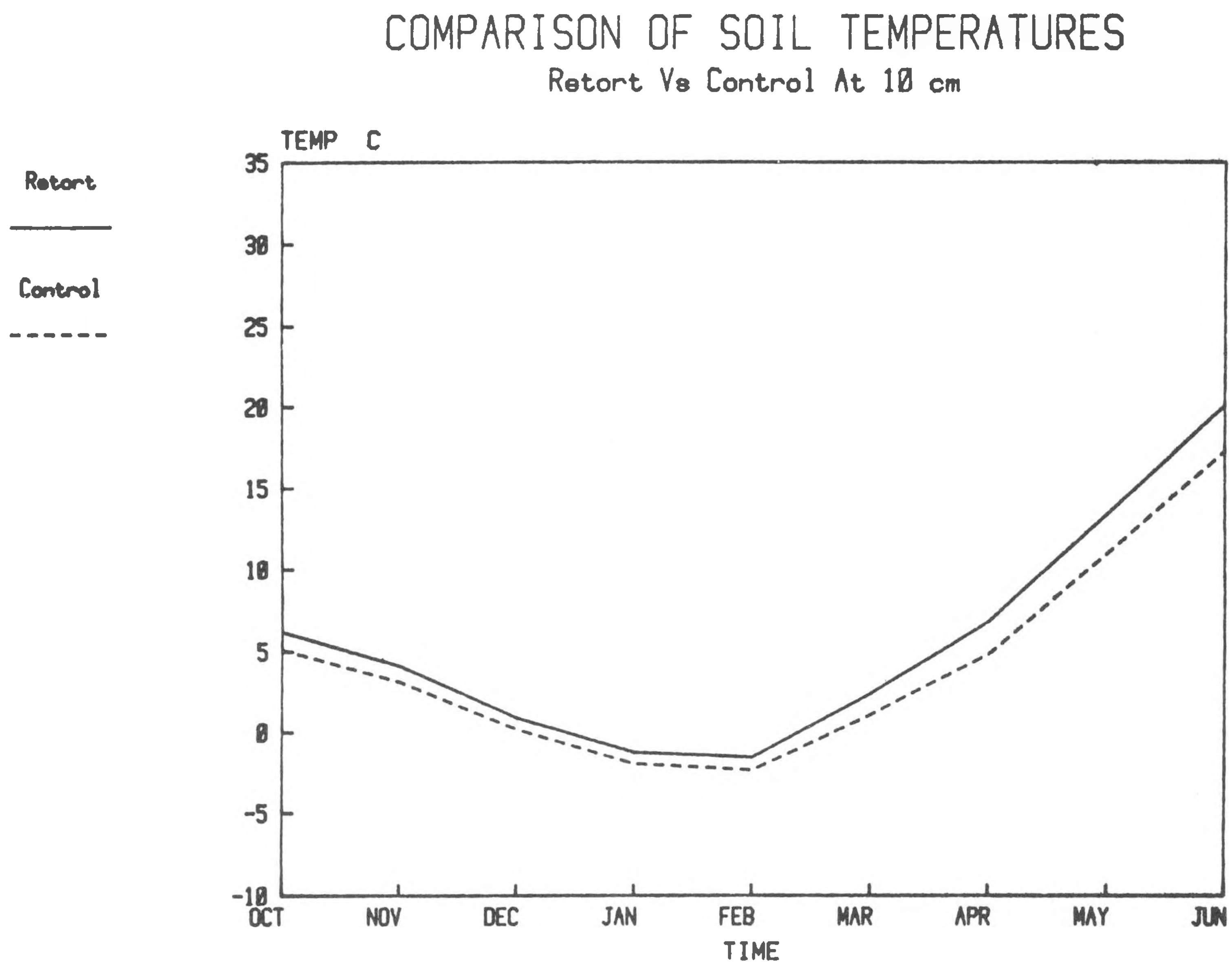



Figure 55. Comparison of Retort #25 and Control Soil Temperatures at Recorded Depths Overtime

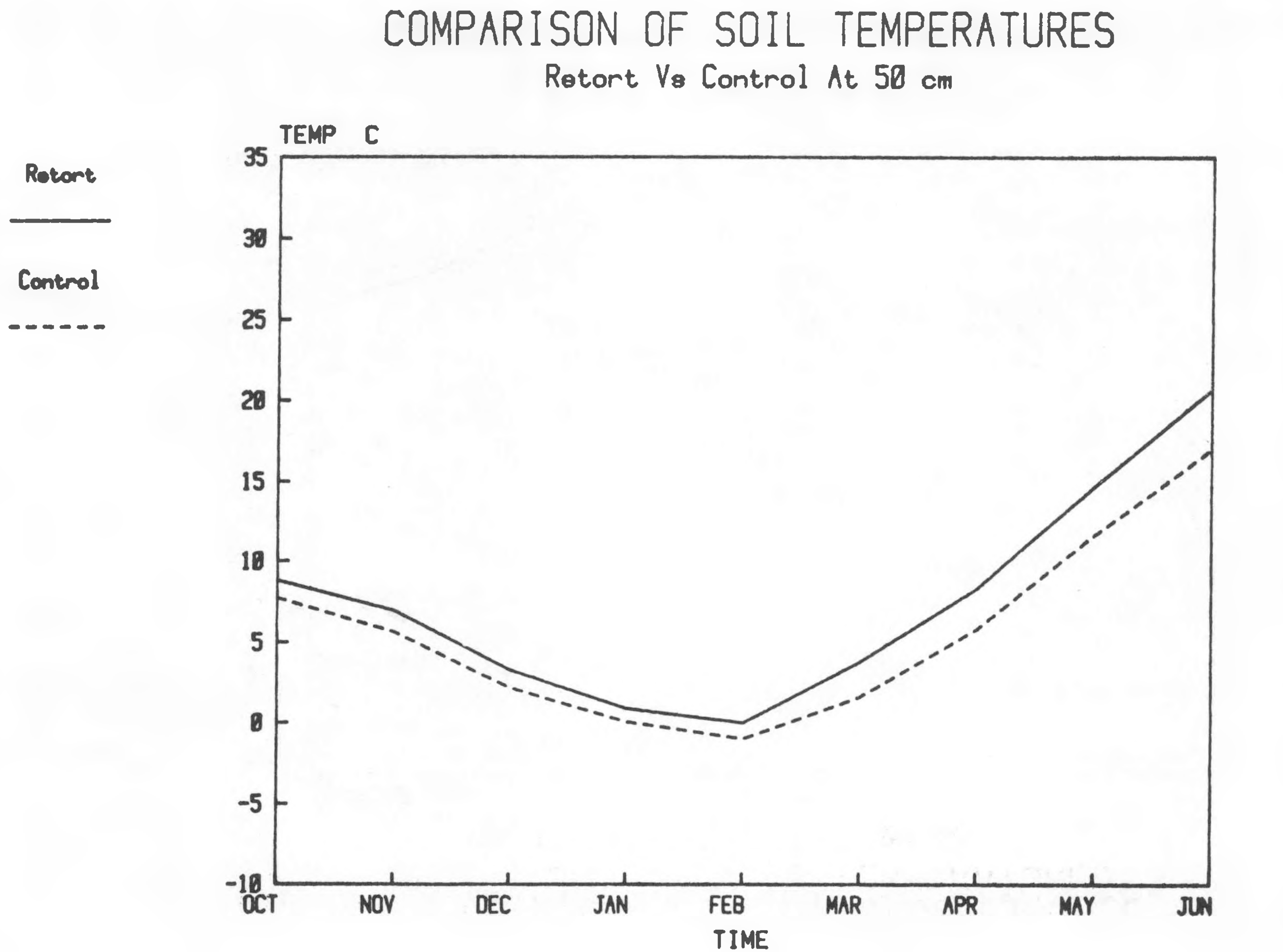

COMPARISON OF SOIL TEMPERATURES
Retort Vs Control At 50 cm
TEMP C
Retort
Control
35
30
25
20
15
10
5
0
-5
-10
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
TIME

Figure 55.

# COMPARISON OF SOIL TEMPERATURES

## Retort Vs Control At 100 cm

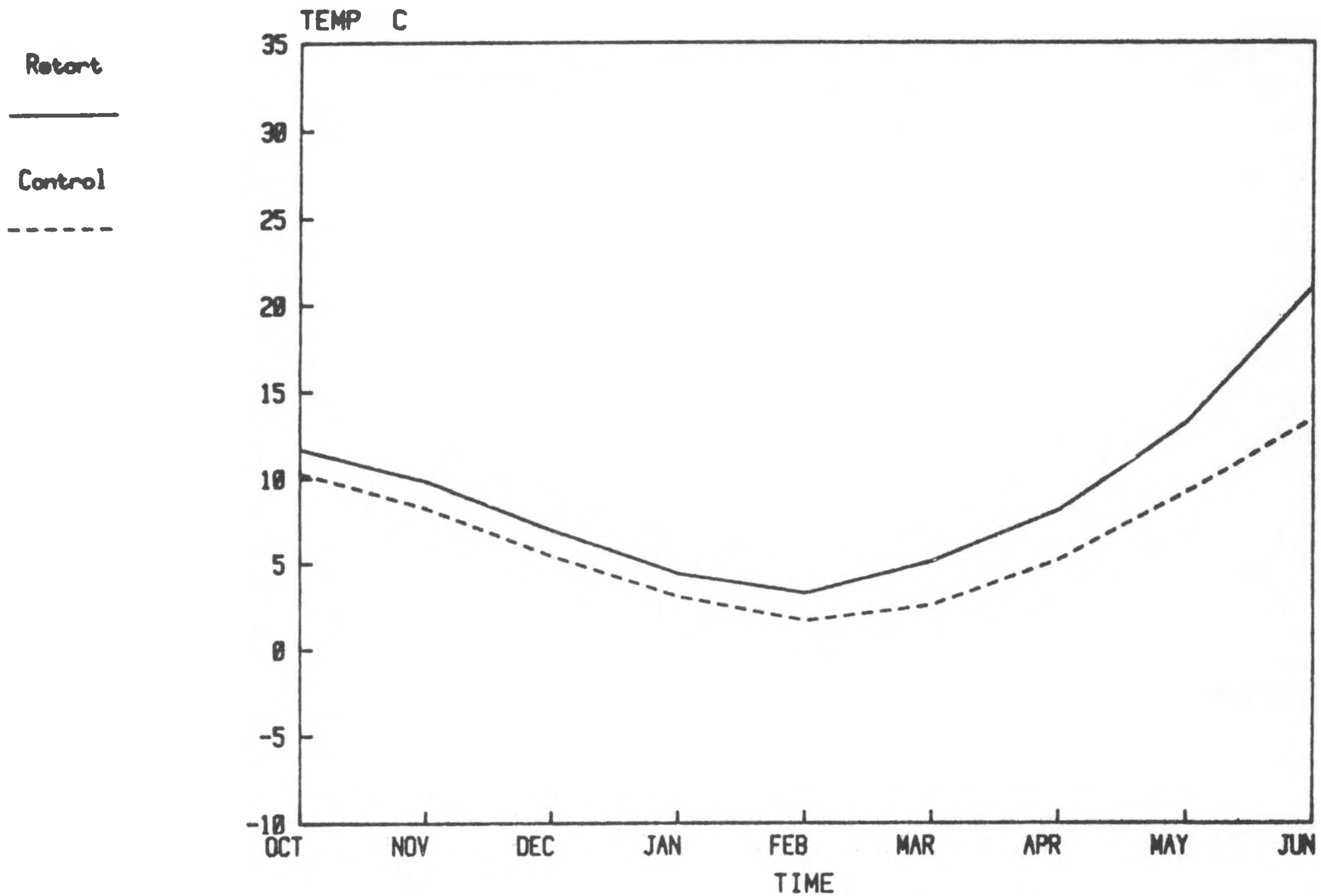



Figure 55.

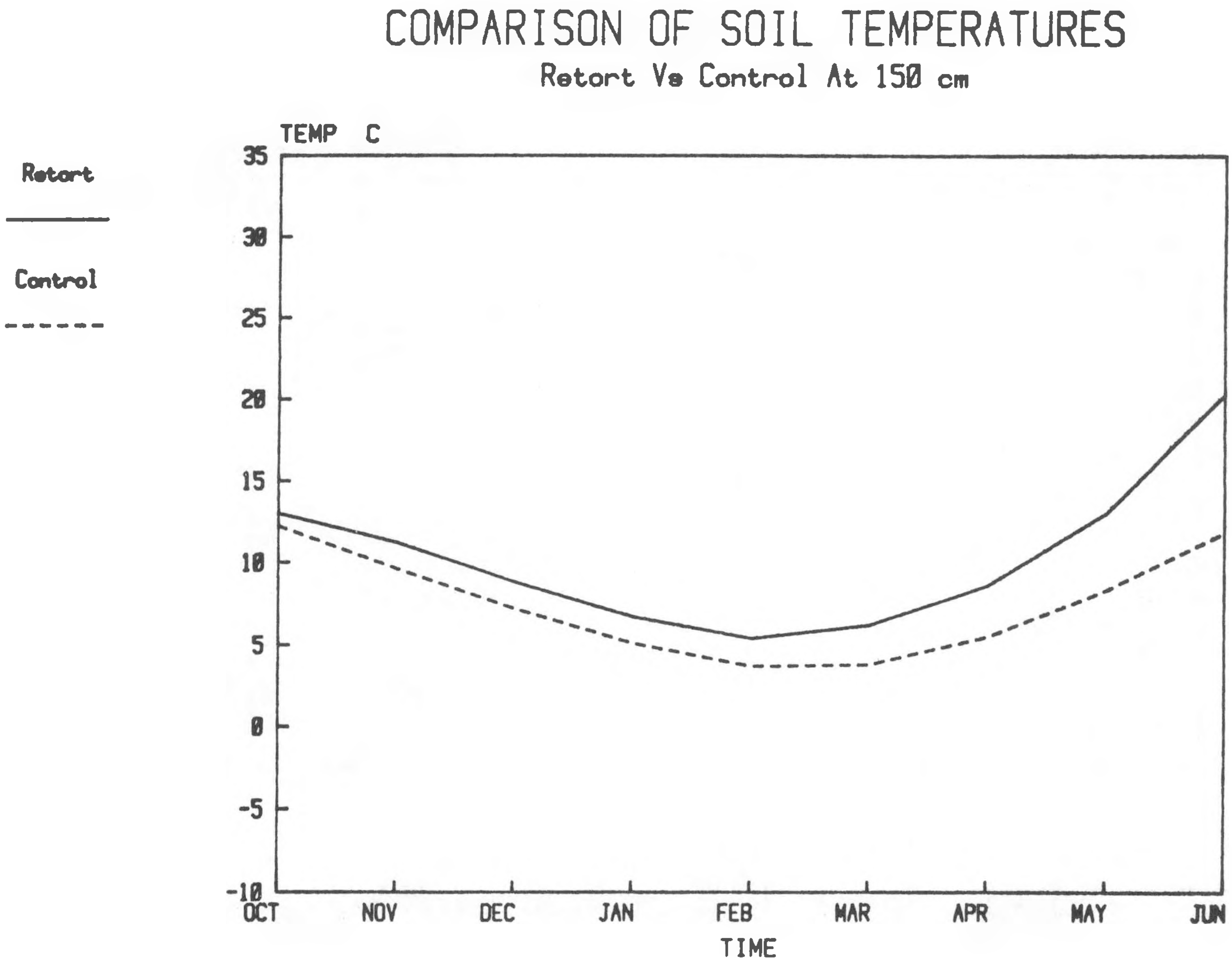

COMPARISON OF SOIL TEMPERATURES
Retort Vs Control At 150 cm
TEMP C
Retort
Control
35
30
25
20
15
10
5
0
-5
-10
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
TIME

Figure 55.

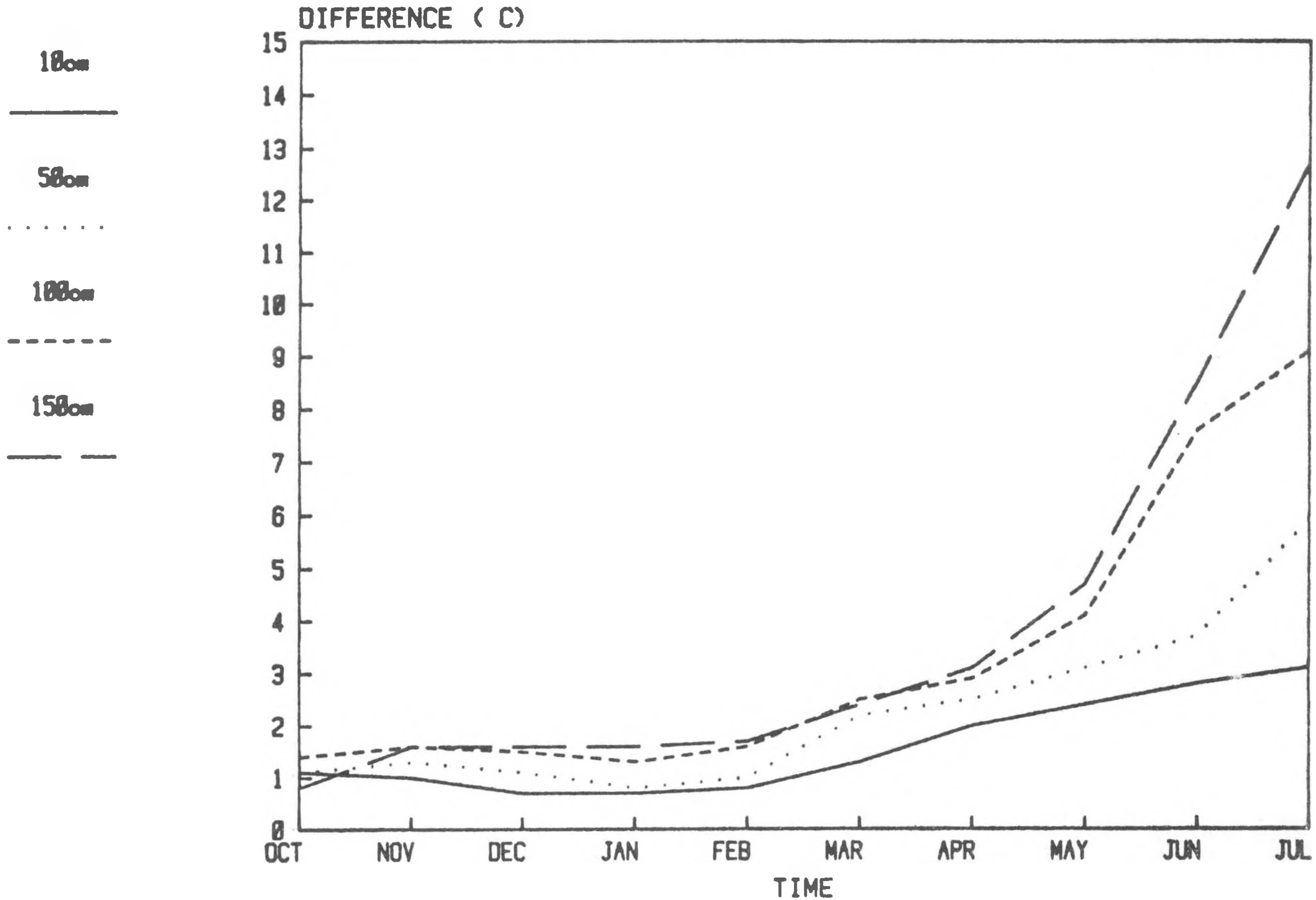



Figure 56. Differences in Soil Temperature Means Between Retort and Control Sites

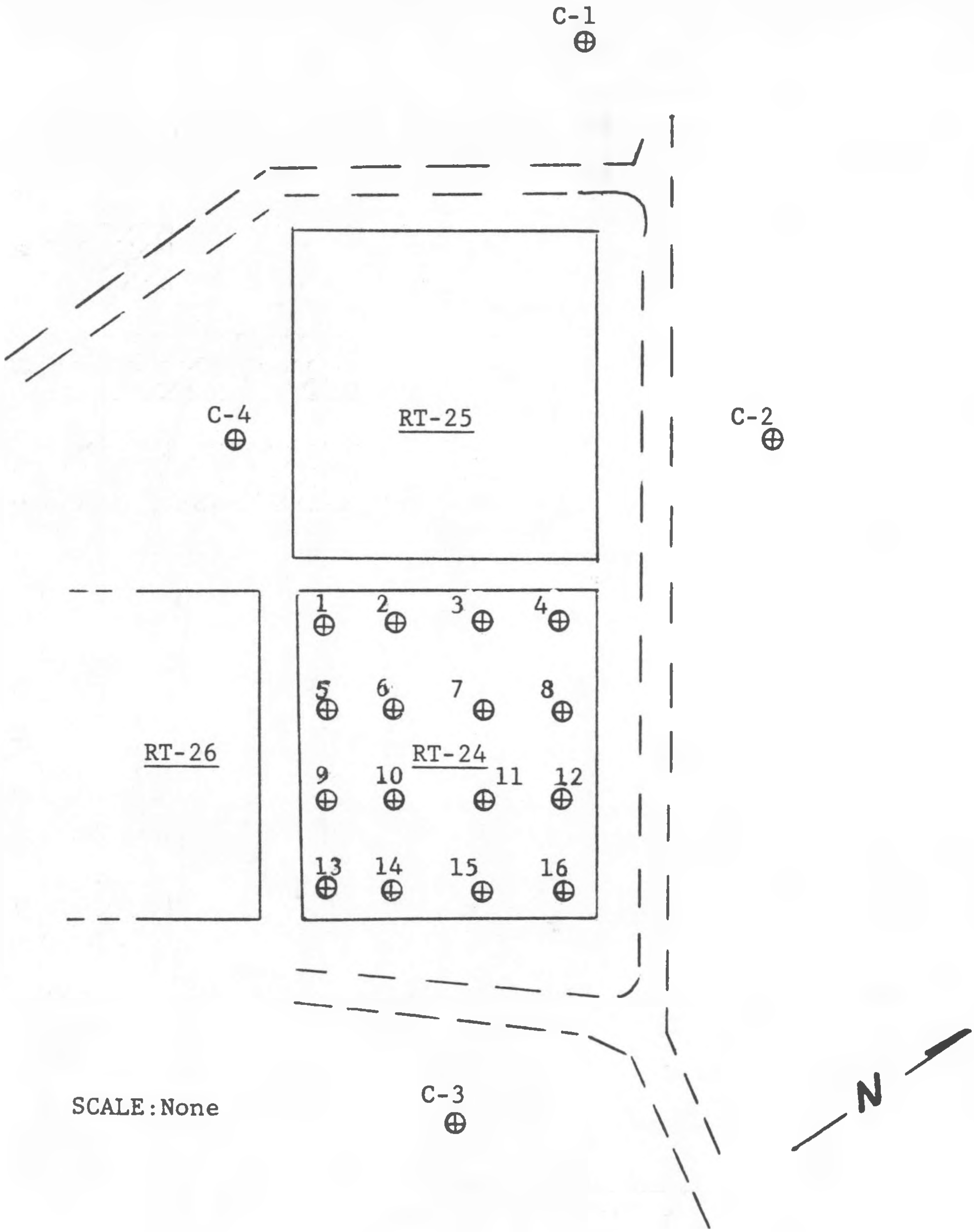



Figure 57. Soil Temperature Probe Locations
Retort #24

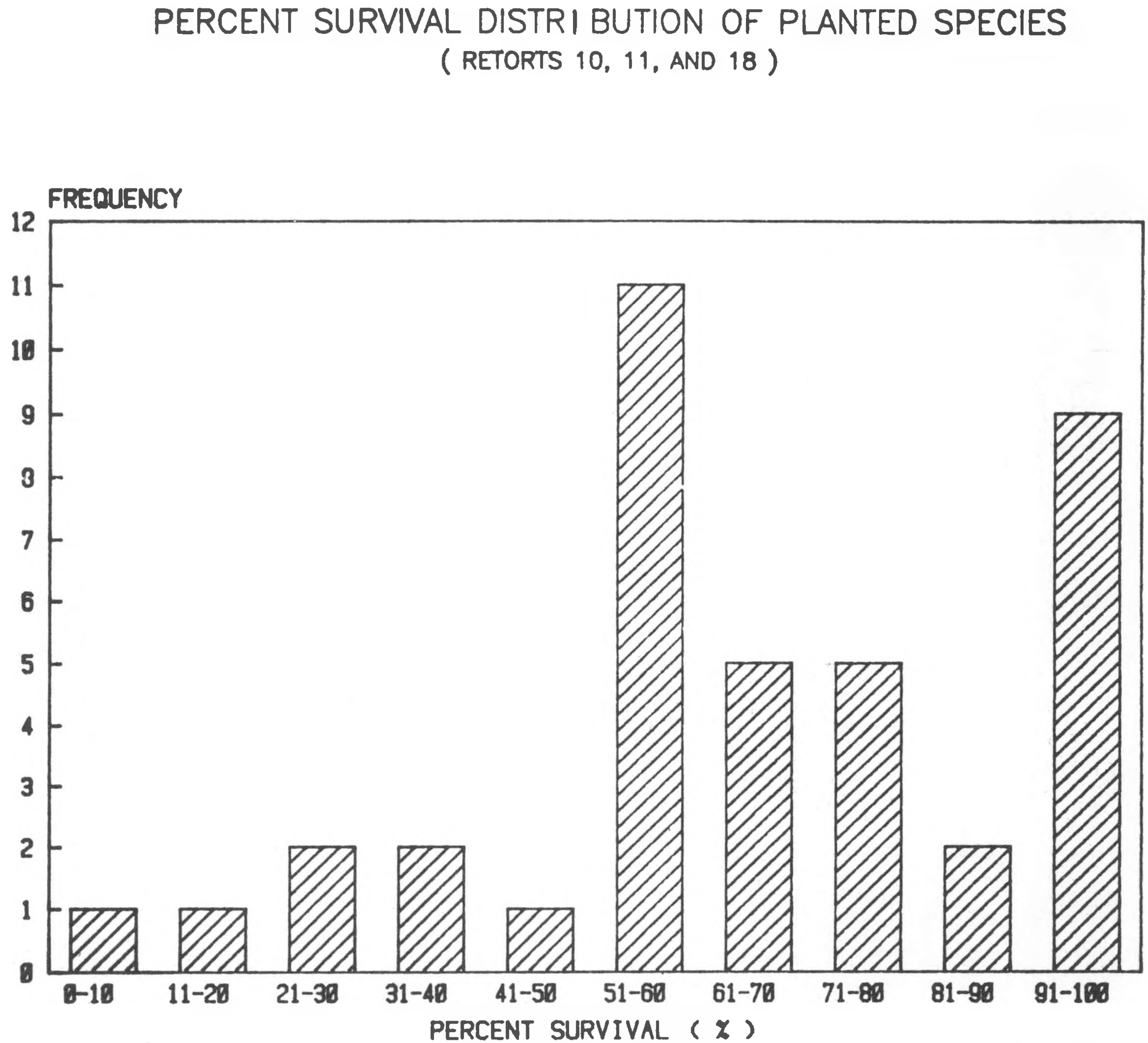


Figure 58. Percent Survival Distribution of Planted Species (Retorts 10,11,&18)

COMPARISON OF SPRING PRECIPITATION AMOUNTS ( 1982 )
WITH LONG TERM RECORDS

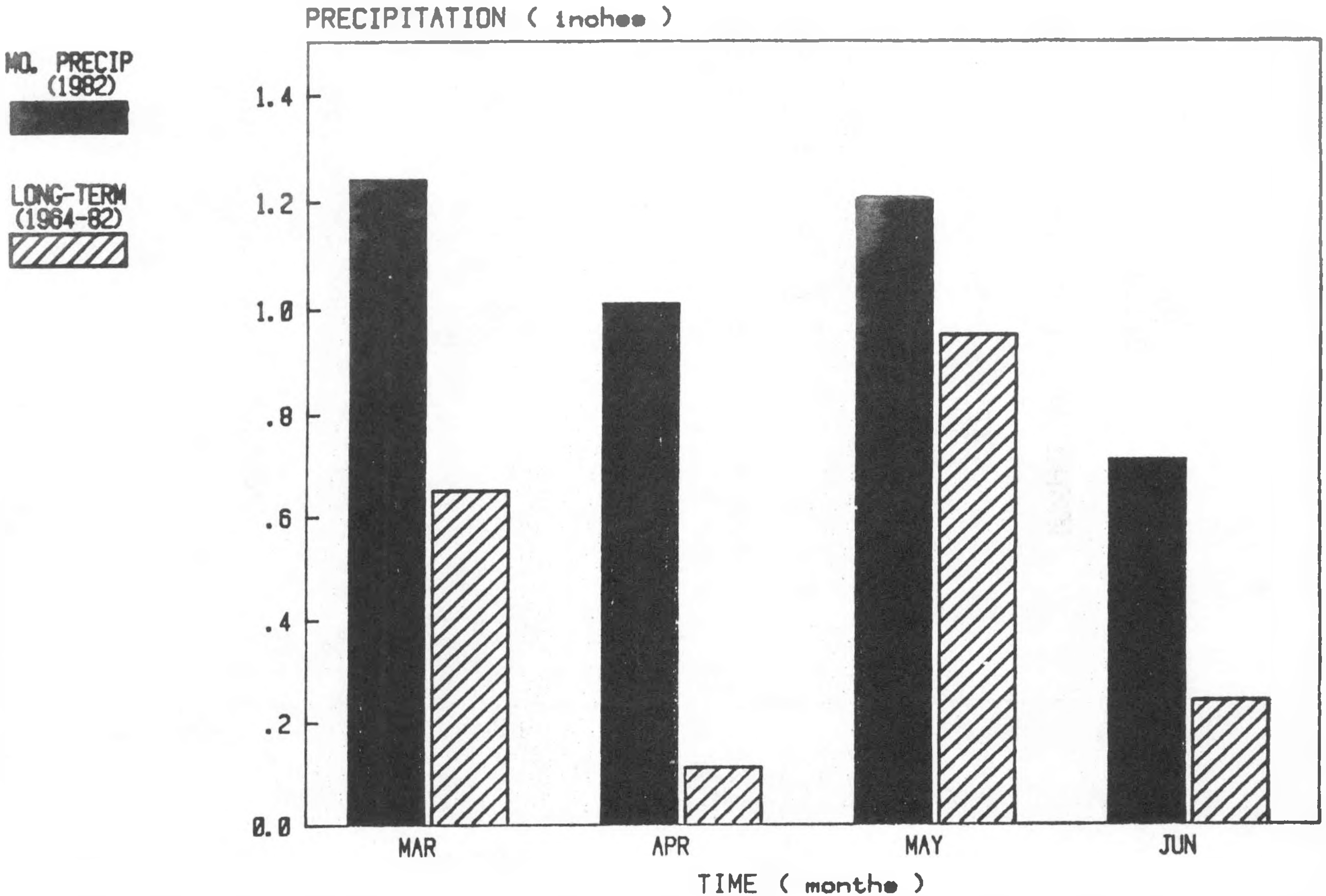



Figure 59. Comparison of Spring Precipitation Amounts (1982) with Long Term Records

**AVERAGE MONTHLY PRECIPITATION (1963-1981)
IN THE VICINITY OF GEOKINETICS SEEP
RIDGE SITE (MAYO CABIN - BLM)**

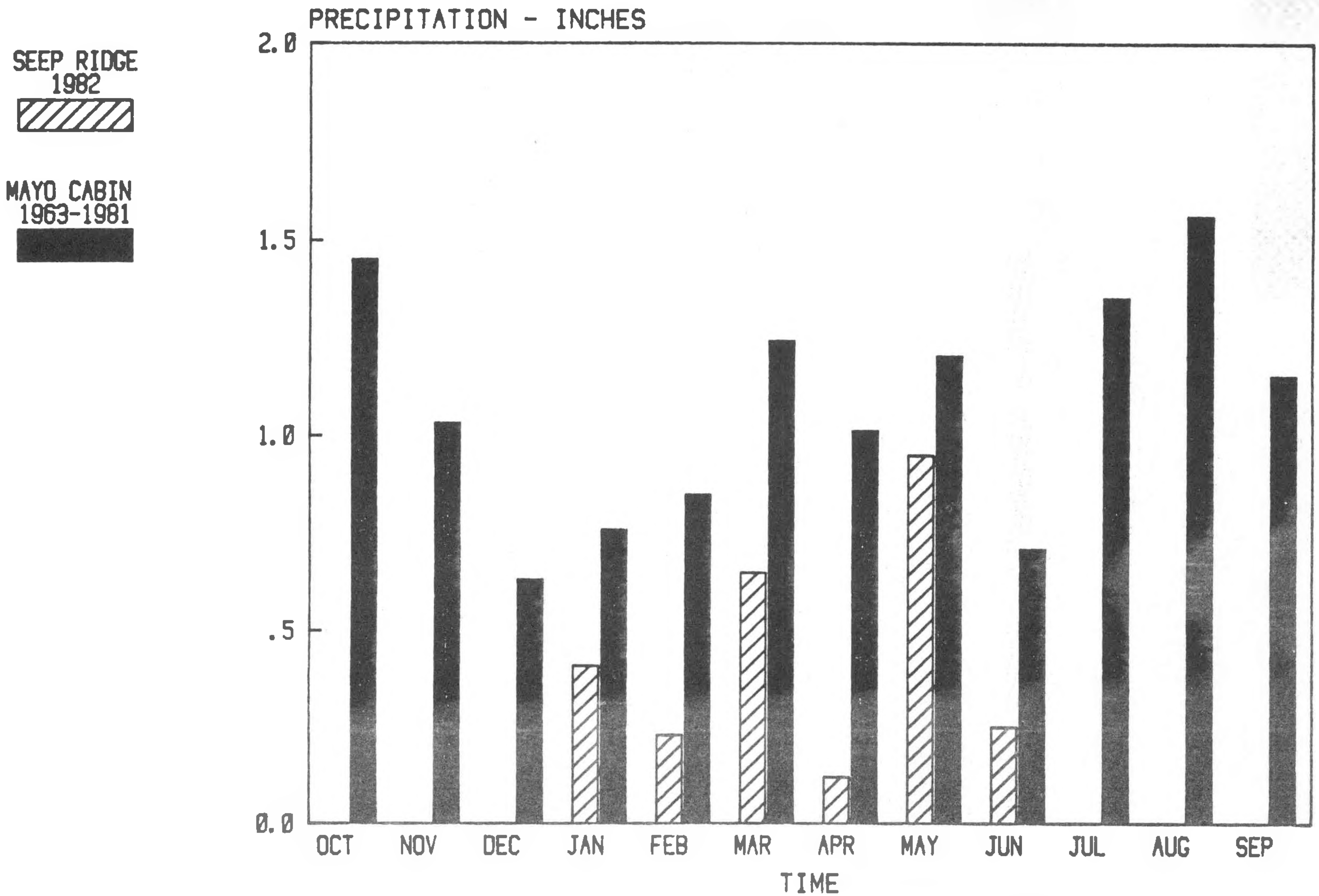



Figure 60. Average Monthly Precipitation (1963-1981)

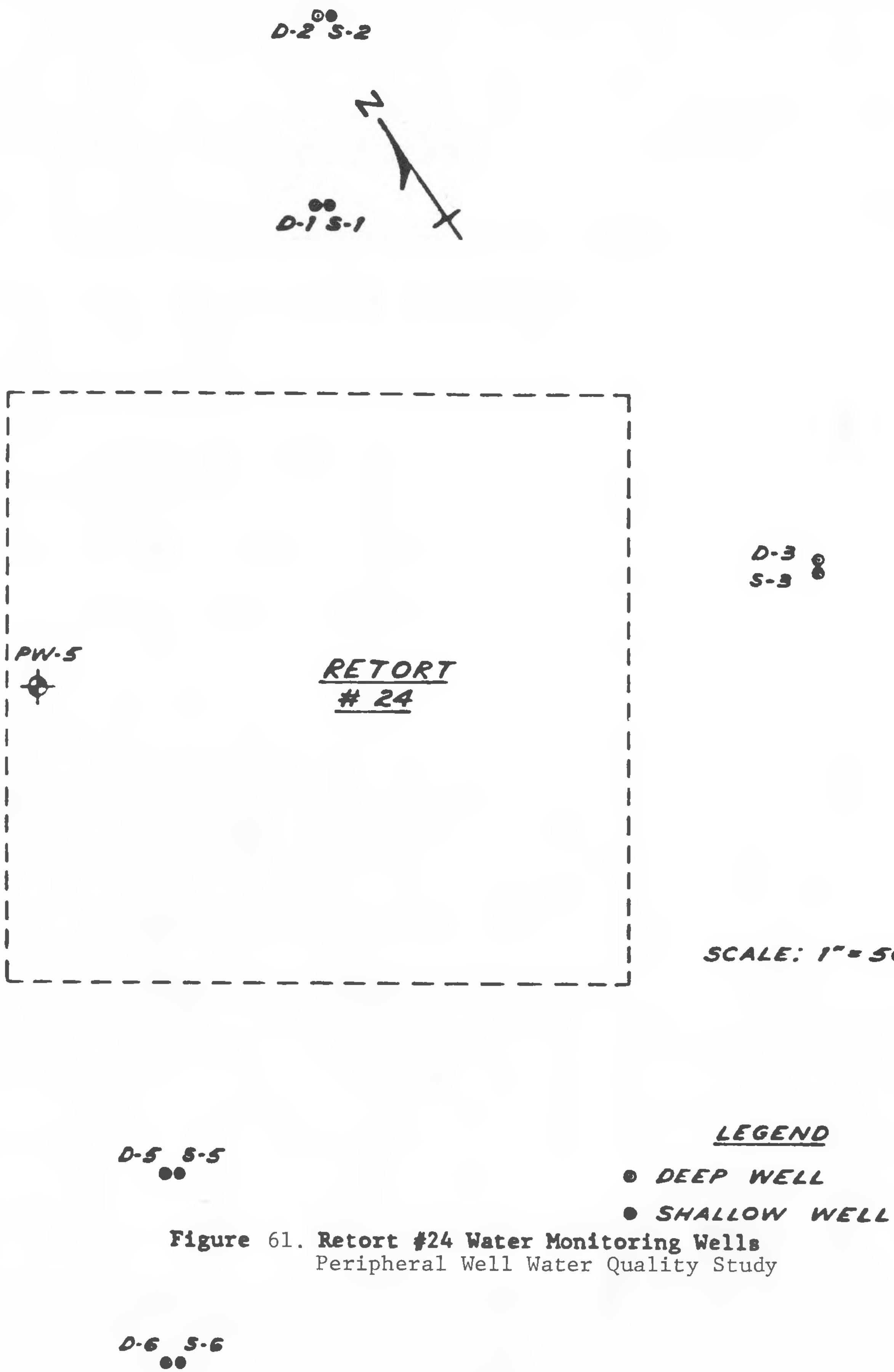



**Figure** 61. **Retort #24 Water Monitoring Wells**
Peripheral Well Water Quality Study

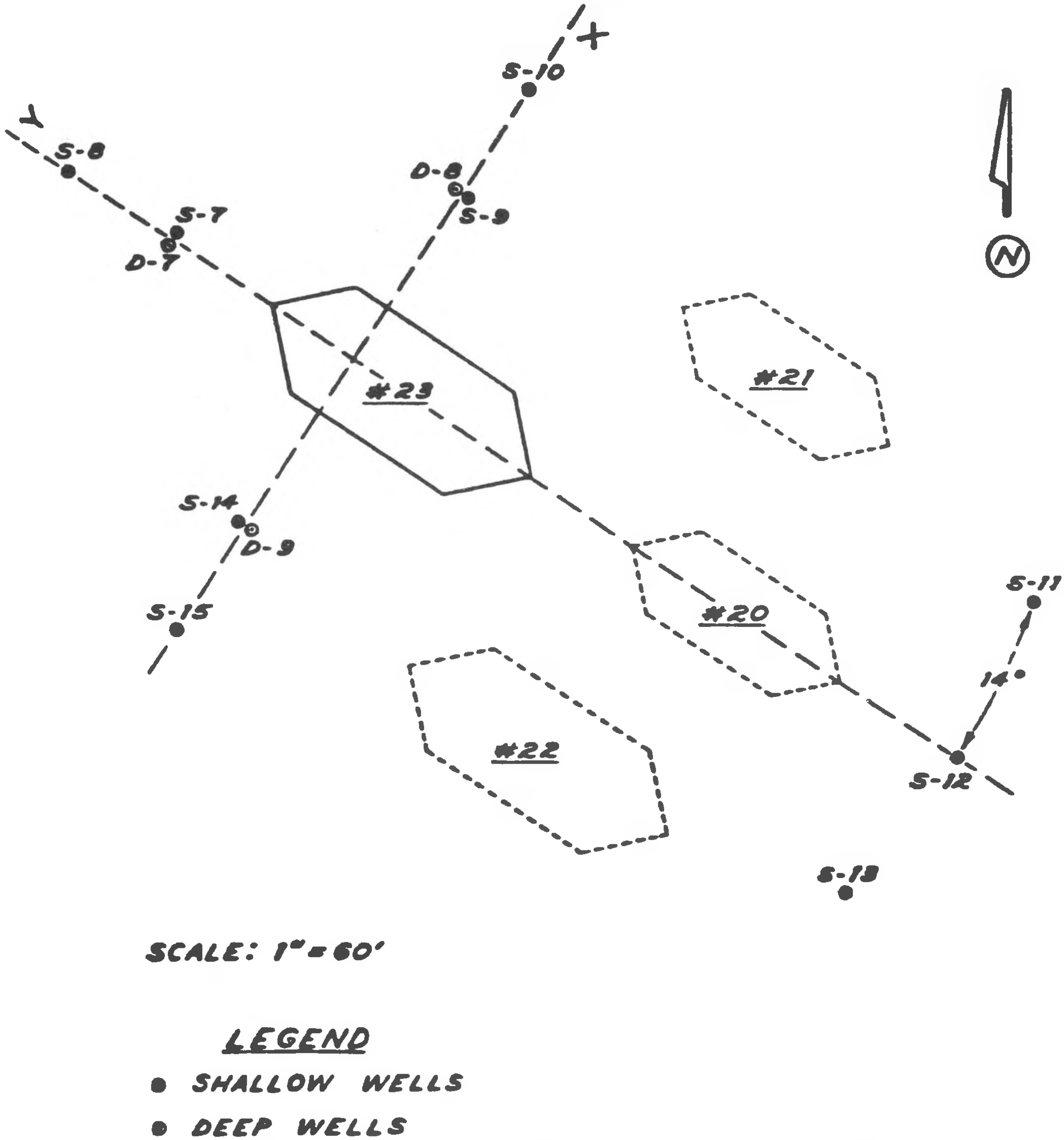



**Figure** 62. **Retort #23 Water Monitoring Wells**
Peripheral Well Water Quality Study

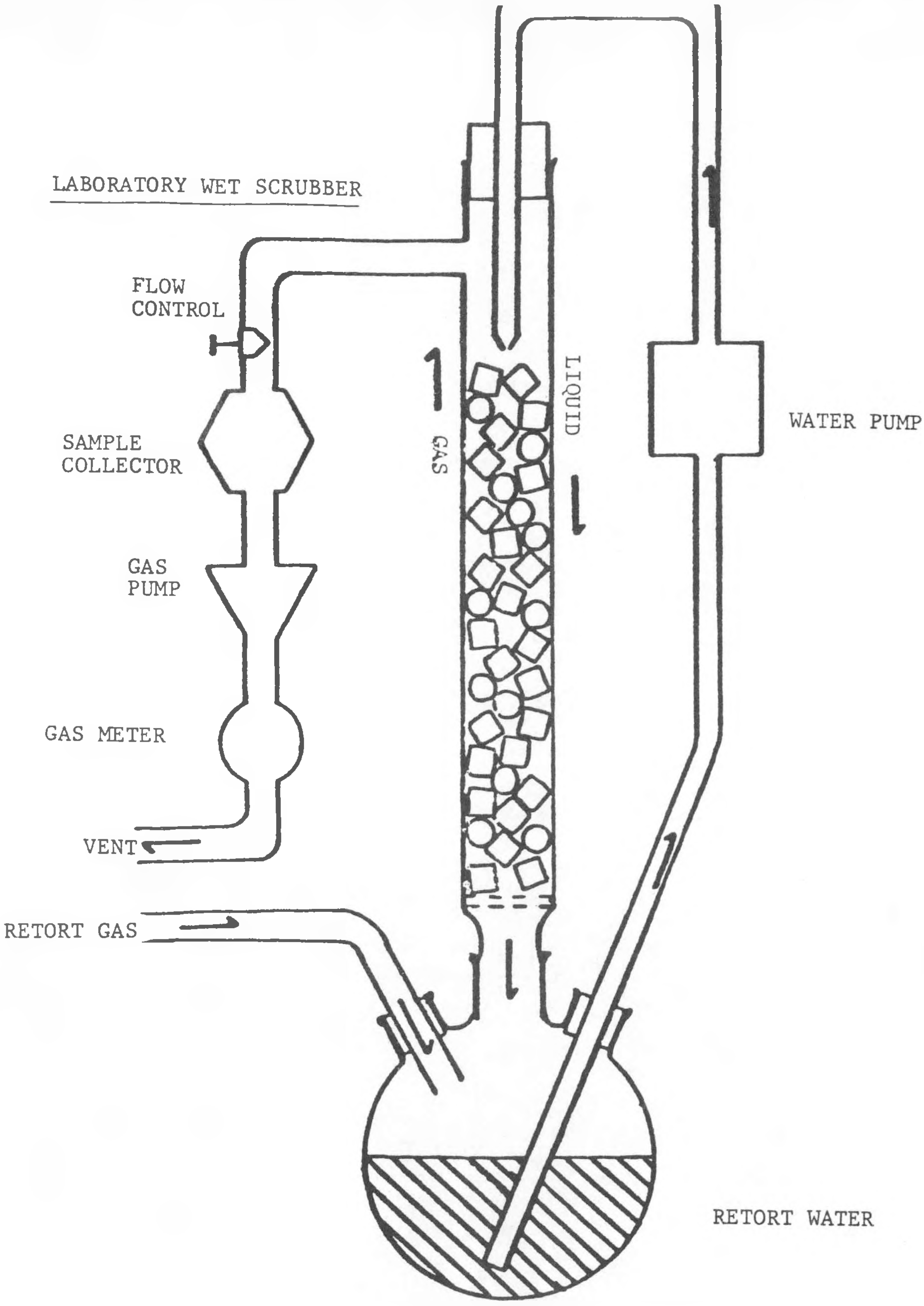



**Figure** 63. **Laboratory Wet Scrubber** for H2S Removal

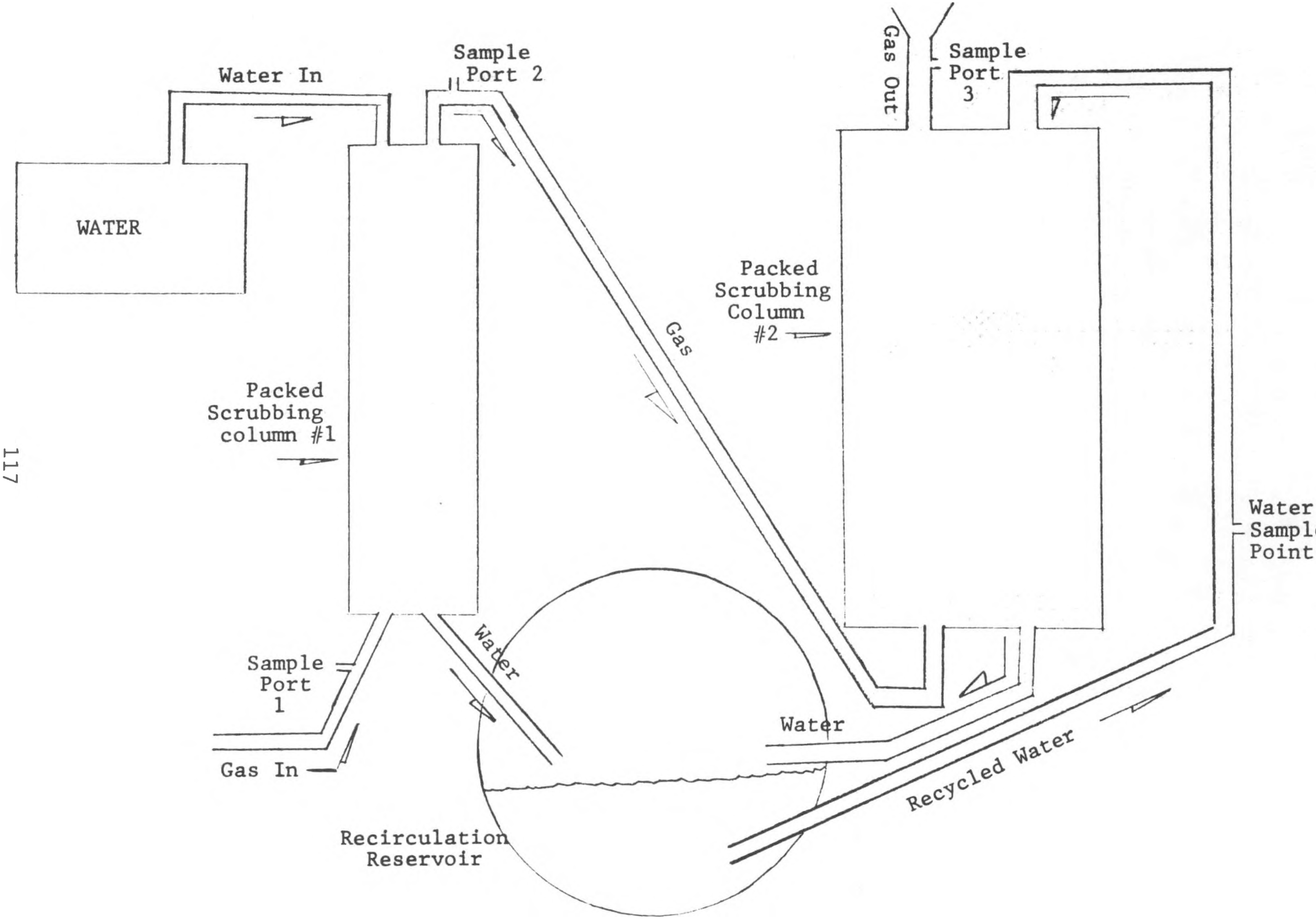



Figure 64.- Double-Column Laboratory Wet Scrubber

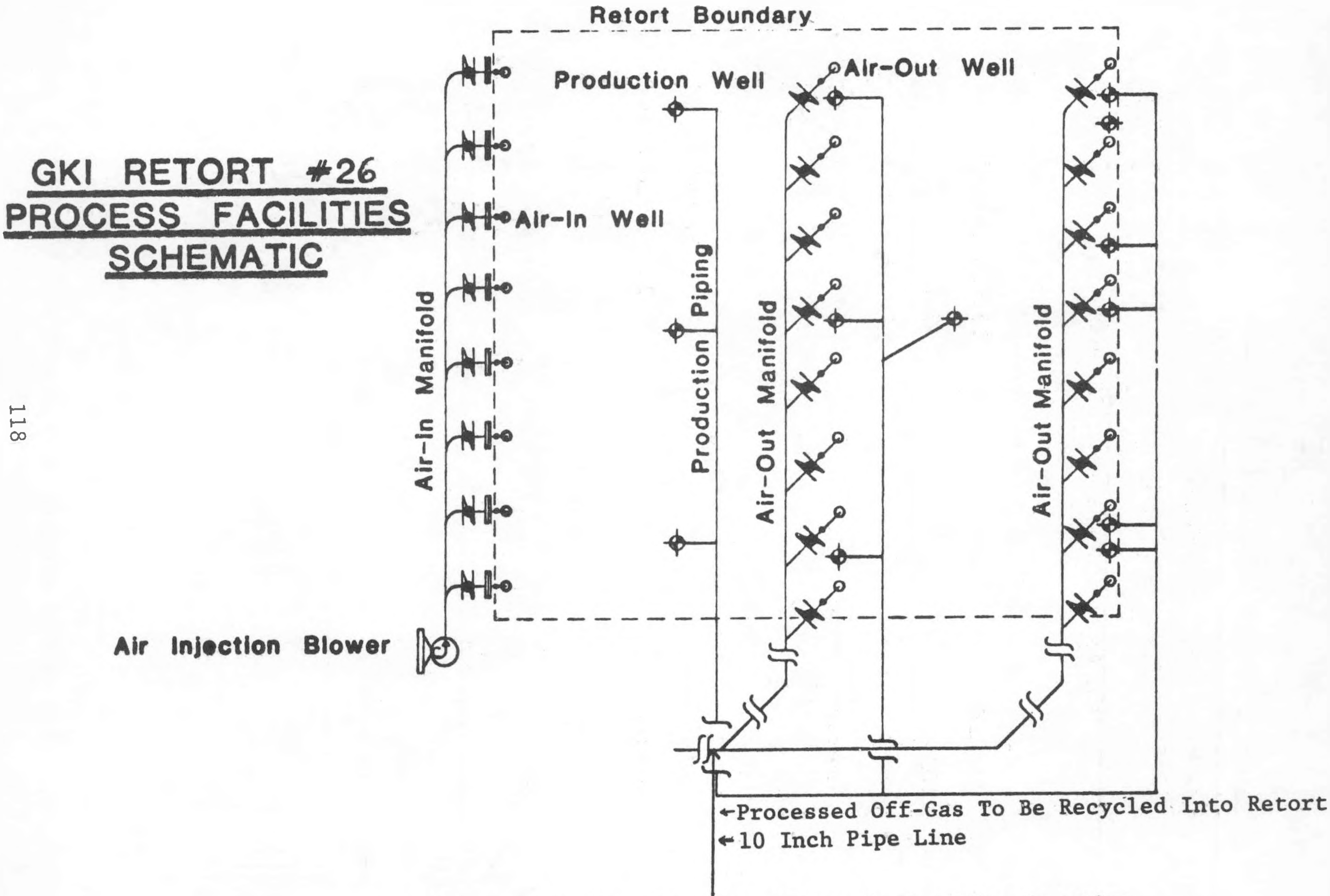



Figure 65. Retort #26 Off - Gas Recirculation Pipe Location

## TABLE 1

## RETORT #25

## OIL AND WATER PRODUCTION SUMMARY

### Oil Production

| | |
|---|---|
| Liquid | 17,935 barrels |
| Mist | 3,021 barrels |
| Total | 20,956 barrels |
| Average | 86 barrels per day |

### Water Production

| | |
|---|---|
| Total | 39,723 barrels per day |
| Average | 256 barrels per day |

TABLE 2
OFF GAS CONSTITUENTS BY 10-DAY AVERAGES
RETORT #25

| E.D.* | 2 METHYLBUTANE | PENTANE | 1-PENTENE | OXYGEN | METHANE | CARBON MONOXIDE | CARBON DIOXIDE | ETHENE | ETHANE | ISO-HEXANE | HEXANE | 1-HEXENE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1- 10 | .005 | 0.00 | 0.00 | 2.576 | 1.691 | 4.516 | 18.727 | 1.22 | 1.32 | .010 | .010 | 0.00 |
| 11- 20 | .004 | 0.00 | .002 | 1.727 | 1.546 | 4.602 | 24.107 | .231 | .299 | .003 | .005 | .000 |
| 21- 30 | .008 | .000 | .002 | 2.527 | 3.096 | 4.911 | 21.589 | .107 | .173 | .018 | .017 | .002 |
| 31- 40 | .141 | .000 | .011 | 2.077 | 3.245 | 7.260 | 21.647 | .084 | .181 | .014 | .020 | .002 |
| 41- 50 | .016 | .001 | .017 | .952 | 1.336 | 6.530 | 23.095 | .079 | .199 | .018 | .024 | .004 |
| 51- 60 | .008 | 0.00 | .000 | 1.660 | 1.295 | 6.509 | 21.234 | .057 | .187 | .003 | .010 | .002 |
| 61- 70 | .145 | 0.00 | .000 | 2.232 | 1.490 | 6.872 | 20.662 | .065 | .181 | 0.00 | .009 | .000 |
| 71- 80 | .058 | 0.00 | 0.00 | 2.130 | 1.728 | 5.484 | 21.696 | .067 | .188 | 0.00 | .007 | .000 |
| 81- 90 | .013 | .001 | .004 | 1.559 | 1.024 | 5.635 | 21.186 | .049 | .167 | .004 | .015 | .002 |
| 91-100 | .002 | .000 | .002 | 1.732 | .762 | 5.059 | 21.741 | .127 | .225 | .001 | .007 | .001 |
| 101-110 | .002 | .001 | .003 | 1.597 | .853 | 5.522 | 21.105 | .172 | .166 | .001 | .009 | .002 |
| 111-120 | .004 | 0.00 | .043 | 1.375 | .855 | 5.191 | 23.515 | .078 | .192 | .000 | .006 | .001 |
| 121-130 | .002 | .000 | .126 | 1.237 | 1.016 | 4.726 | 23.928 | .125 | .195 | .000 | .006 | .000 |
| 131-140 | .000 | 0.00 | .001 | 1.641 | 1.042 | 4.116 | 23.843 | .063 | .211 | .003 | .005 | 0.00 |
| 141-150 | .001 | 0.00 | .004 | 3.765 | 1.021 | 4.063 | 21.986 | .057 | .196 | 0.00 | .006 | 0.00 |
| 151-160 | .001 | .000 | .018 | 2.316 | 1.619 | 4.466 | 25.973 | .047 | .199 | .000 | .009 | .001 |
| 161-170 | .002 | 0.00 | .026 | 2.517 | 1.123 | 4.927 | 23.627 | .063 | .208 | .000 | .009 | 0.00 |
| 171-180 | .000 | 0.00 | .004 | 6.121 | .738 | 4.044 | 19.347 | .096 | .212 | 0.00 | .001 | 0.00 |
| 181-190 | .000 | 0.00 | .006 | 3.846 | 1.058 | 4.583 | 22.532 | .054 | .196 | .001 | .001 | 0.00 |
| 191-200 | 0.00 | 0.00 | .001 | 6.560 | .516 | 2.946 | 17.462 | .064 | .150 | 0.00 | .001 | 0.00 |
| 201-210 | .000 | 0.00 | .002 | 13.89 | .763 | 1.976 | 11.072 | .046 | .145 | 0.00 | 0.00 | 0.00 |
| 211-220 | 0.00 | 0.00 | .001 | 10.15 | .913 | 2.283 | 14.494 | .039 | .148 | .001 | 0.00 | 0.00 |
| 221-230 | .001 | 0.00 | .004 | 8.573 | 1.410 | 4.067 | 18.314 | .202 | .299 | .002 | 0.00 | 0.00 |
| 231-235 | .001 | 0.00 | .009 | 5.529 | 1.451 | 3.520 | 20.474 | .073 | .200 | .043 | 0.00 | 0.00 |
| Average | .020 | .000 | .012 | 3.353 | 1.334 | 4.884 | 21.259 | .139 | .247 | .004 | .008 | .001 |

* Elapsed day

TABLE 2 (Cont.)

| E.D* | NITROGEN | HYDROGEN | PROPANE | PROPENE | CARBONYL SULFIDE | ISOBUTANE | BUTANE | 1-BUTENE | TRANS-BUTENE-2 | CIS-BUTENE-2 | 1,3-BUTADIENE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1- 10 | 61.635 | 7.435 | .186 | .235 | .077 | .023 | .062 | .162 | .014 | .023 | .026 |
| 11- 20 | 57.550 | 9.493 | .184 | .124 | .007 | .012 | .041 | .042 | .013 | .006 | .004 |
| 21- 30 | 59.157 | 8.007 | .186 | .096 | .004 | .013 | .034 | .037 | .008 | .005 | .005 |
| 31- 40 | 55.453 | 9.480 | .190 | .088 | .006 | .013 | .034 | .034 | .010 | .006 | .004 |
| 41- 50 | 56.442 | 10.87 | .213 | .095 | .005 | .017 | .039 | .038 | .010 | .007 | .004 |
| 51- 60 | 58.126 | 10.48 | .220 | .105 | .005 | .014 | .036 | .030 | .006 | .004 | .002 |
| 61- 70 | 57.216 | 10.71 | .220 | .105 | .003 | .013 | .033 | .029 | .006 | .003 | .001 |
| 71- 80 | 57.346 | 10.86 | .234 | .103 | .004 | .014 | .035 | .033 | .007 | .004 | .001 |
| 81- 90 | 59.195 | 10.94 | .228 | .095 | .007 | .013 | .031 | .027 | .005 | .002 | .000 |
| 91-100 | 59.701 | 10.16 | .262 | .122 | .001 | .015 | .037 | .030 | .004 | .001 | .000 |
| 101-110 | 60.100 | 10.20 | .204 | .086 | .003 | .012 | .031 | .029 | .005 | .001 | 0.00 |
| 111-120 | 58.467 | 9.915 | .186 | .081 | .003 | .013 | .032 | .028 | .011 | .002 | .001 |
| 121-130 | 58.130 | 10.16 | .168 | .081 | .002 | .016 | .038 | .037 | .003 | .001 | .000 |
| 131-140 | 61.239 | 7.561 | .130 | .059 | .001 | .015 | .041 | .026 | .002 | .000 | 0.00 |
| 141-150 | 61.701 | 6.962 | .137 | .086 | .001 | .006 | .037 | .023 | .000 | 0.00 | .000 |
| 151-160 | 58.046 | 6.977 | .180 | .062 | .003 | .015 | .038 | .027 | .004 | .000 | 0.00 |
| 161-170 | 60.226 | 6.894 | .215 | .075 | .003 | .015 | .037 | .028 | .003 | .002 | .000 |
| 171-180 | 62.466 | 6.613 | .211 | .083 | .000 | .012 | .033 | .016 | .000 | 0.00 | 0.00 |
| 181-190 | 60.045 | 6.641 | .150 | .069 | .003 | .014 | .035 | .019 | .002 | .002 | .000 |
| 191-200 | 67.054 | 4.633 | .138 | .046 | 0.00 | .004 | .021 | .006 | 0.00 | .001 | 0.00 |
| 201-210 | 63.369 | 8.549 | .099 | .044 | 0.00 | .008 | .026 | .008 | .001 | 0.00 | 0.00 |
| 211-220 | 66.545 | 4.629 | .081 | .038 | .001 | .008 | .027 | .012 | 0.00 | .000 | 0.00 |
| 221-230 | 59.721 | 6.957 | .231 | .136 | .001 | .017 | .045 | .021 | .000 | .000 | 0.00 |
| 231-235 | 63.739 | 4.759 | .106 | .054 | .002 | .014 | .038 | .025 | .002 | 0.00 | 0.00 |
| Average | 59.833 | 8.475 | .187 | .093 | .006 | .013 | .036 | .033 | .005 | .003 | .002 |

* Elapsed Day

TABLE 3
AVERAGE HEATING VALUE; TOTAL BTU PRODUCED;
$H_2S$ AND $NH_3$ CONCENTRATIONS IN RETORT #25 OFF GAS

| E.D* | AVERAGE HEATING VALUE (BTU/SCF) HIGH | TOTAL BTU PRODUCED (MM BTU) | $H_2S$ CONCENTRATION (ppm) | $NH_3$ CONCENTRATION (ppm) |
|---|---|---|---|---|
| 1-10 | 121.0 | 3950.6 | 61.0 | 15.8 |
| 11-20 | 82.5 | 5287.3 | 124.7 | 12.8 |
| 21-30 | 90.5 | 6593.6 | 219.8 | 69.0 |
| 31-40 | 109.7 | 8179.3 | 479.1 | 443.7 |
| 41-50 | 89.8 | 6650.1 | 947.3 | 862.0 |
| 51-60 | 84.6 | 6447.6 | 1520.8 | 829.9 |
| 61-70 | 93.5 | 7321.4 | 1373.6 | 1029.3 |
| 71-80 | 89.1 | 6895.4 | 1582.8 | 933.0 |
| 81-90 | 80.0 | 6262.0 | 2047.6 | 869.7 |
| 91-100 | 76.2 | 5794.7 | 1753.8 | 594.5 |
| 101-110 | 75.8 | 6303.4 | 1990.2 | 974.6 |
| 111-120 | 74.0 | 5455.8 | 1734.6 | 924.6 |
| 121-130 | 78.6 | 6130.5 | 1186.4 | 1013.2 |
| 131-140 | 61.1 | 4806.8 | 3338.7 | 2770.4 |
| 141-150 | 58.6 | 4819.6 | 1801.3 | 698.9 |
| 151-160 | 67.9 | 5621.1 | 1886.1 | 839.4 |
| 161-170 | 66.0 | 5266.1 | 1605.6 | 1091.9 |
| 171-180 | 57.0 | 4461.6 | 1746.0 | 804.6 |
| 181-190 | 60.0 | 4430.3 | 1568.9 | 961.0 |
| 191-200 | 39.4 | 2970.1 | 1605.0 | 1170.7 |
| 201-210 | 50.4 | 3226.8 | 1674.0 | 1057.0 |
| 211-220 | 39.7 | 1920.9 | 1178.0 | 1920.0 |
| 221-230 | 70.8 | 4188.7 | 1373.0 | 1968.0 |
| 231-235 | 55.3 | 1630.9 | 1364.0 | 1648.0 |
| Average | 75.4 | 127644.0 | 1424.0 | 979.0 |

* Elapsed day

## TABLE 4

## Complete Summary of Oil and Water Production

### Retort #26 - E.D. 1-176

| | | OIL PRODUCTION |
|---|---|---|
| Liquid | | 18,881 barrels |
| Mist | | 664 barrels |
| | Total | 19,545 barrels |

| | | AVERAGE OIL PRODUCTION |
|---|---|---|
| Liquid | | 107 barrels per day |
| Mist | | 4 barrels per day |
| | Total | 111 barrels per day |

| | WATER PRODUCTION |
|---|---|
| Total | 23,072 barrels |
| Average | 131 barrels per day |

TABLE 5

OFF GAS CONSTITUENTS BY 10-DAY AVERAGES

RETORT #26

| E.D.* | NITROGEN | HYDROGEN | PROPANE | PROPENE | CARBONYL SULFIDE | ISOBUTANE | BUTANE | 1-BUTENE | TRANS-BUTENE-2 | CIS-BUTENE-2 | 1,3-BUTADIENE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1- 10 | 63.130 | 6.462 | .121 | .144 | .007 | .012 | .032 | .055 | .008 | .002 | .018 |
| 11- 20 | 63.992 | 5.992 | .173 | .126 | .008 | .017 | .040 | .042 | .006 | .003 | .007 |
| 21- 30 | 58.895 | 7.290 | .204 | .114 | .005 | .020 | .051 | .055 | .010 | .004 | .003 |
| 31- 40 | 54.778 | 9.936 | .272 | .142 | .006 | .029 | .058 | .046 | .007 | .002 | .002 |
| 41- 50 | 58.307 | 8.589 | .165 | .087 | .004 | .016 | .040 | .040 | .006 | .004 | 0.00 |
| 51- 60 | 59.286 | 7.576 | .177 | .094 | .005 | .017 | .043 | .042 | .008 | .004 | .002 |
| 61- 70 | 58.615 | 8.069 | .194 | .109 | .004 | .019 | .051 | .049 | .008 | .005 | .003 |
| 71- 80 | 62.960 | 7.122 | .173 | .078 | .003 | .017 | .035 | .034 | .006 | .003 | .000 |
| 81- 90 | 64.287 | 7.314 | .193 | .075 | .004 | .013 | .037 | .029 | .005 | .004 | .000 |
| 91-100 | 62.733 | 7.176 | .209 | .094 | .004 | .017 | .046 | .038 | .007 | .005 | .001 |
| 101-110 | 59.218 | 7.863 | .199 | .204 | .007 | .017 | .047 | .040 | .008 | .006 | .003 |
| 111-120 | 55.526 | 8.813 | .218 | .082 | .006 | .020 | .042 | .042 | .009 | .005 | .002 |
| 121-130 | 58.607 | 9.478 | .228 | .106 | .007 | .025 | .069 | .023 | .023 | .002 | .008 |
| 131-140 | 58.017 | 8.346 | .228 | .084 | .008 | .029 | .082 | .048 | .012 | .007 | 0.00 |
| 141-150 | 57.888 | 7.803 | .164 | .069 | .006 | .022 | .060 | .046 | .010 | .002 | .000 |
| 151-160 | 59.075 | 7.888 | .181 | .074 | .008 | .020 | .053 | .029 | .006 | .001 | .001 |
| 161-170 | 55.221 | 8.074 | .186 | .067 | .008 | .029 | .059 | .044 | .009 | .003 | .010 |
| 171-177 | 62.621 | 4.984 | .160 | .056 | .005 | .078 | .050 | 2.27 | .007 | .002 | .002 |
| Average | 59.736 | 7.761 | .193 | .100 | .006 | .021 | .050 | .099 | .009 | .004 | .003 |

* Elapsed day

TABLE 5 (Cont.)

| E.D.* | 2 METHYLBUTANE | PENTANE | 1-PENTENE | OXYGEN | METHANE | CARBON MONOXIDE | CARBON DIOXIDE | ETHENE | ETHANE | ISO-HEXANE | HEXANE | 1-HEXENE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1- 10 | .004 | .000 | .001 | 1.624 | 1.247 | 3.113 | 23.415 | .353 | .206 | .009 | .022 | .001 |
| 11- 20 | .004 | .000 | .005 | 5.219 | 1.117 | 2.807 | 19.958 | .230 | .239 | .002 | .012 | 0.00 |
| 21- 30 | .006 | .004 | .010 | 2.389 | 1.422 | 5.787 | 23.287 | .139 | .260 | .007 | .034 | .002 |
| 31- 40 | .008 | .004 | .027 | 2.168 | 1.422 | 7.019 | 23.356 | .218 | .337 | .062 | .039 | .014 |
| 41- 50 | .006 | .001 | .010 | 3.864 | 1.134 | 6.068 | 21.306 | .111 | .218 | .003 | .014 | .001 |
| 51- 60 | .006 | .002 | .008 | 4.124 | 1.865 | 5.411 | 17.910 | .155 | .213 | .010 | .015 | .002 |
| 61- 70 | .007 | .002 | .013 | 5.532 | 1.284 | 6.387 | 18.944 | .197 | .296 | .006 | .020 | .002 |
| 71- 80 | .007 | .001 | .003 | 7.022 | .890 | 4.446 | 16.546 | .097 | .216 | .004 | .016 | .000 |
| 81- 90 | .009 | .001 | .010 | 7.150 | .619 | 3.527 | 16.096 | .123 | .201 | .002 | .018 | .001 |
| 91-100 | .010 | .002 | .010 | 4.114 | .815 | 4.511 | 19.352 | .135 | .242 | .002 | .017 | .002 |
| 101-110 | .011 | .001 | .020 | 1.983 | 1.112 | 5.691 | 22.522 | .472 | .219 | .003 | .021 | .003 |
| 111-120 | .014 | .001 | .001 | 5.496 | 2.116 | 6.351 | 20.854 | 099 | .257 | .022 | .010 | .001 |
| 121-130 | .052 | .001 | .003 | 4.999 | 1.145 | 5.945 | 18.913 | .129 | .214 | .006 | .013 | .000 |
| 131-140 | .017 | .001 | .033 | 1.304 | 1.450 | 6.510 | 23.358 | .083 | .316 | .018 | .027 | .006 |
| 141-150 | .015 | 0.00 | .007 | 1.355 | 1.522 | 6.234 | 24.210 | .121 | .262 | .002 | .023 | .004 |
| 151-160 | .008 | .022 | .003 | 2.967 | 1.331 | 5.293 | 22.691 | .078 | .251 | .000 | .010 | .001 |
| 161-170 | .016 | .042 | .007 | 2.444 | 1.881 | 6.352 | 25.343 | .059 | .313 | 0.00 | .002 | 0.00 |
| 171-177 | .005 | .022 | .008 | 3.428 | 1.350 | 4.280 | 22.704 | .049 | .247 | 0.00 | 0.00 | 0.00 |
| Average | 012 | .005 | .010 | 3.841 | 1.278 | 5.332 | 20.659 | .156 | .249 | .008 | .018 | .002 |

* Elapsed day

## TABLE 6

## RETORT #26 HEATING VALUES AND $H_2S/NH_3$ CONCENTRATION OF PROCESS GAS

### RETORT #26

| *E.D. | AVERAGE HIGH HEATING VALUE (BTU/SCF) High | TOTAL BTU PRODUCED (MM BTU) | $H_2S$ CONCENTRATION (ppm) | $NH_3$ CONCENTRATION (ppm) |
|---|---|---|---|---|
| 1-10 | 65.3 | 1774.5 | 28 | 22 |
| 11-20 | 60.0 | 3445.1 | 42 | 16 |
| 21-30 | 79.1 | 5935.5 | 27 | 64 |
| 31-40 | 100.9 | 8103.9 | 85 | 277 |
| 41-50 | 75.9 | 6159.1 | 353 | 561 |
| 51-60 | 80.6 | 6712.4 | 1418 | 828 |
| 61-70 | 82.6 | 7010.4 | 1840 | 674 |
| 71-80 | 62.9 | 4738.3 | 1505 | 1215 |
| 81-90 | 58.5 | 4308.4 | 1399 | 1054 |
| 91-100 | 66.1 | 4841.2 | 1274 | 963 |
| 101-110 | 83.5 | 6375.0 | 1496 | 939 |
| 111-120 | 90.4 | 9575.1 | 1609 | 979 |
| 121-130 | 83.9 | 5890.7 | 2054 | 893 |
| 131-140 | 87.9 | 5984.8 | 1804 | 1198 |
| 141-150 | 80.2 | 5167.8 | 1835 | 893 |
| 151-154 | 75.8 | 1934.5 | | |
| 151-160 | 73.8 | 4438.0 | 1627 | 663 |
| 161-170 | 86.3 | 5276.3 | 1907 | 692 |
| 171-180 | 123.4 | 4783.4 | 1640 | 780 |
| **AVERAGE** | 78.0 | 97996.4 | 1219 | 706 |

* Elapsed day

**TABLE 7**

Geokinetics Emissions Rates

**January - December 1982**

(all values in lbs/hr)

| SOURCE | ACTUAL-AVERAGE | ACTUAL-PEAK | ALLOWABLE-PEAK |
|---|---|---|---|
| | $SO_2$ | $SO_2$ | $SO_2$ |
| Retort #26 & 26 | 66.0 | 134.8 | 135.3 |
| | $NO_x$ | $NO_x$ | $NO_x$ |
| Retort #25 & 26 | 26.8 | 87.0* | 45.1 |
| 650 KW Gen. | 31.1 | <38.9 | 38.9 |
| | HYDROCARBONS | HYDROCARBONS | HYDROCARBONS |
| Retort #25 & 26 | NIL | NIL | 1.4 |
| 650 KW Gen. | 1.2 | <1.5 | 1.5 |
| | PARTICULATES | PARTICULATES | PARTICULATES |
| Retort #25 & 26 | 0.3 | 1.0 | 1.0 |
| 650 KW Gen. | NA | NIL | NIL |
| Access Roads | NA | <1.0 | 1.0 |
| | CARBON | CARBON MONOXIDE | CARBON MONOXIDE |
| Retort #25 & 26 | NIL | NIL | NIL |
| 650 KW Gen. | 2.3 | <2.9 | 2.9 |

Exhaust emissions from the electrical generator are not directly measured - values stated above are based on manufacturer's emission factors for selected operating conditions.

NA = Not Available - Dust control measures are being applied as stipulated by the PSD approval order.

* Peak occurred during temporary waiver of $SO_2$ and $NO_x$ allowable limits as granted by the EPA and the UBAQ.

**TABLE 8**

TOTAL ANNUAL EMISSIONS

January - December 1982

(all values in tons)

| | $SO_2$ | $NO_x$ | HC | Particulates | CO |
|---|---|---|---|---|---|
| Total Emissions | 270.9 | 237.6 | 5.3 | 5.6 | 10.1 |
| Total Allowable | 592.6 | 367.9 | 12.7 | 8.8 | 12.7 |

**TABLE 9**

Process Gas Data

January - December 1982

**RETORTS #25 & #26**

(Pre Combustion in Afterburner)
(all values are % volume)

| **DATE** (days) | $N_2$ | $CO_2$ | $O_2$ | **THC** | **CO** |
|---|---|---|---|---|---|
| 1/18 | 58.87 | 21.16 | 1.53 | 1.44 | 5.44 |
| 1/25 | 58.40 | 20.61 | 1.71 | 1.54 | 6.23 |
| 2/15 | 57.68 | 23.70 | 0.96 | 1.44 | 5.08 |
| 2/26 | 60.38 | 25.57 | 1.04 | 1.64 | 3.63 |
| 3/5 | 60.53 | 25.59 | 0.98 | 1.83 | 3.89 |
| 3/17 | 65.89 | 17.68 | 7.07 | 1.38 | 2.78 |
| 3/29 | 58.66 | 24.83 | 1.46 | 1.83 | 5.66 |
| 4/14 | 66.27 | 15.99 | 6.59 | 0.93 | 3.35 |
| 4/28 | | NO SAMPLE TAKEN | | | |
| 5/4 | 58.84 | 10.95 | 15.37 | 1.20 | 2.04 |
| 5/25 | 58.99 | 13.80 | 13.85 | 1.63 | 2.69 |
| 6/9 | 63.70 | 20.50 | 5.50 | 1.54 | 3.52 |
| 7/10 | 63.13 | 23.42 | 1.62 | 2.24 | 3.11 |
| 8/11 | 55.62 | 24.39 | 0.08 | 3.10 | 8.41 |
| 8/24 | 54.83 | 23.28 | 1.09 | 2.37 | 7.65 |
| 9/19 | 61.87 | 16.09 | 6.95 | 2.75 | 5.97 |
| 9/29 | 64.66 | 13.34 | 9.69 | 1.19 | 2.81 |
| 10/18 | 60.99 | 20.15 | 2.04 | 1.97 | 6.38 |
| 10/27 | | NO SAMPLE TAKEN | | | |
| 11/10 | 59.40 | 20.06 | 1.99 | 1.94 | 6.79 |
| 11/24 | 53.27 | 24.81 | 0.97 | 0.97 | 7.56 |
| 12/10 | 66.60 | 12.48 | 9.49 | 1.12 | 2.72 |
| 12/28 | 62.29 | 23.32 | 3.06 | 1.90 | 4.54 |

**TABLE 10**

Stack Gas Data[a]

**RETORTS #25 & 26**

January - December 1982

(Post Combustion in Afterburner)

| DATE | $N_2$ | $O_2$ | $CO_2$ | HC | CO | TSP |
|---|---|---|---|---|---|---|
| | | (% in Volume) | | | | |
| 1/18 | 75.88 | 6.12 | 17.99 | BDL | BDL[b] | 6,100 |
| 1/25 | 75.98 | 5.84 | 18.18 | BDL | BDL | 3,400 |
| 2/15 | 75.91 | 5.48 | 18.62 | BDL | BDL | 5,400 |
| 2/26 | 75.96 | 5.55 | 18.49 | BDL | BDL | 3,000 |
| 3/5 | 70.60 | 5.51 | 23.89 | BDL | BDL | 2,300 |
| 3/17 | 76.83 | 3.53 | 19.64 | BDL | BDL | 2,500 |
| 3/29 | 76.51 | 4.52 | 12.66 | BDL | BDL | 2,500 |
| 4/14 | 76.40 | 1.55 | 22.05 | BDL | BDL | <1,000 |
| 4/28 | 75.32 | 5.84 | 3.68 | BDL | BDL | <1,000 |
| 5/4 | 78.15 | 12.66 | 9.18 | BDL | BDL | 3,000 |
| 5/25 | 81.12 | 11.46 | 7.42 | BDL | BDL | 3,000 |
| 6/9 | 78.90 | 6.40 | 14.70 | BDL | BDL | 3,000 |
| 7/10 | 77.80 | 7.90 | 14.30 | BDL | BDL | 3,000 |
| 8/11 | 77.40 | 8.20 | 14.40 | BDL | BDL | 300 |
| 8/24 | 78.20 | 7.60 | 14.20 | BDL | BDL | 300 |
| 9/19 | 74.17 | 3.24 | 22.54 | BDL | BDL | 30,000 |
| 9/29 | 72.70 | 6.26 | 21.04 | BDL | BDL | 300 |
| 10/18 | 76.71 | 2.85 | 19.07 | BDL | BDL | 6,100 |
| 10/27 | 79.58 | 2.71 | 17.71 | BDL | BDL | 5,800 |
| 11/10 | 79.88 | 3.14 | 16.98 | BDL | BDL | 6,100 |
| 11/24 | 79.24 | 4.33 | 16.43 | BDL | BDL | 6,100 |
| 12/10 | 79.48 | 9.06 | 11.46 | BDL | BDL | 28,400 |
| 12/28 | 78.99 | 8.86 | 12.09 | BDL | BDL | 66,980 |

a. A minimum of two samples are collected each month as required by the PSD permit (except June & July when Retorts #25 and #26 burned for only half of the month).

b. BDL = Below detection limit.

## TABLE 11

Comparison of Retort #24 and Retort #27

| | RETORT #24 | RETORT #27 |
|---|---|---|
| size | 217 x 230 feet | 301 x 330 feet |
| shale thickness | 28 feet | 30 feet |
| explosive loaded | 136,667 lbs. | 283,000 lbs |
| depth of overburden | 45 feet | 46.5 feet |
| volume unfractured shale bed | 1,397,470 $feet^3$ | 2,979,900 $feet^3$ |
| volume fractured shale bed | 1,622,075 $feet^3$ | 3,650,429 $feet^3$* |
| void | 224,595 $feet^3$ | 670,529 $feet^3$* |
| % void (% of fractured zone that is occupied by space) | 13.8% | 18.4%* |
| lbs. of explosives used/volume of void created | .61 $lbs/foot^3$ | .42 $lbs/foot^3$ |

* This figure does not include the volume underneath a narrow surface trough which subsided on Retort #27. This trough was 6.8% of the Retort's surface area and % void in this region is higher than 18.4% given as the % void for Retort #27.

TABLE 12

Meteorological Monitoring Stations

SEEP RIDGE SITE

| Station | Parameter | Monitoring Equipment |
|---|---|---|
| A-01 | Surface temperature | Max-Min thermometers (Science Associates III) |
| A-02 | Net Evaporation | Recording evaporimeter[b] (Belfort 6075) |
| | Total wind travel | Totalizing anemometer (Casella W1204/2) |
| A-03 | Solar radiation | Pyrheliometer[b] (Belfort 6075) |
| A-04[a,b] | Wind speed and direction @ 100 ft. Wind speed and direction @ 33 ft. | Wind speed and direction sensors (Texas Instruments 2011 & 2010) |
| | Temperature @ 100 ft., 33 ft., 10 ft. | Temperature Sensors (Yellow Springs Instrument 703) |
| | Precipitation | 8 inch tipping bucket rain gauge (MRI 304) |
| A-04B | Surface temperature | Max-Min thermometers (Science Associates III) |
| | Temperature and relative humidity | Hygrothermograph (Bendix 594) |
| | Precipitation | Standard 8 inch rain gauge |
| A-05 (new office site) | Barometric pressure | Microbarograph (Belfort 800) |
| | Wet/dry bulb temp. | Electric Psychrometer (Bendix 566) |
| | Barometric pressure | Mercurial Barometer (Princo-U.S. Signal Corp Type) |
| A-06 | Daily sunshine duration | Solar duration recorder (Cambell-Stokes) |
| A-07[a,b] (Met.tower) | Wind speed and direction @ 33 ft. | Wind speed and direction sensors (Texas Inst. 2011 & 2010) |
| | Temp. @ 33 ft. | Temperature sensors (Yellow Springs Inst. 703) |

a. Electrical weather stations (WestAq Corp.)-data recorded on cassette tapes.
b. Powered by photovoltaic cells

TABLE 13

New Meteorological Monitoring Station

| Parameter | Monitoring Equipment |
| --- | --- |
| Wind Speed | Wind Speed Sensor (Weathermeasure W203) |
| Wind Direction | Wind Direction (Weathermeasure W204) |
| Temperature | Temperature sensor (Yellow Sprins Ins. 703) |
| | Data Acquisition System (Handar 540A) |

TABLE 14

Pellet transect results of species other than mule deer. For cottontails, 40 quadrats, $3m^2$ each, were sampled per transect; for other species, 80 quadrats, $10m^2$ each, were sampled per transect. All quadrats had been cleaned the previous sampling period.

| | Number of Quadrats with Animal Sign Present | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Elk | | Cottontail | | Coyote | | Pocket Gopher | | Cattle | |
| Transect | S* | W | S | W | S | W | S | W | S | W |
| Pinyon-Juniper | | | | | | | | | | |
| W8 | 1 | 0 | 0 | 24 | 0 | 0 | 0 | 0 | 5 | 3 |
| W10 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 0 | 5 | 1 |
| W14 | 0 | 0 | 0 | 14 | 0 | 0 | 3 | 2 | 1 | 7 |
| W15 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 22 | 14 |
| Sagebrush | | | | | | | | | | |
| W6 | 0 | 0 | 4 | 26 | 0 | 0 | 0 | 2 | 7 | 2 |
| W9 | 1 | 0 | 3 | 7 | 0 | 0 | 10 | 6 | 11 | 22 |
| W11 | 0 | 0 | 1 | 9 | 0 | 0 | 27 | 32 | 18 | 41 |
| W16 | 0 | 0 | 1 | 9 | 0 | 0 | 4 | 7 | 25 | 24 |

* S = Summer period (counts conducted in the fall, October 1981)
W = Winter period (counts conducted in the spring, May and June 1982)

TABLE 15

Results of road counts conducted along a 10-mile route.

| | Number of Animals Observed | | | | |
|---|---|---|---|---|---|
| | Deer | Elk | Grouse | Deer Road-kills | Raptors |
| 1981 | | | | | |
| JUN 3 | | | | 1 | |
| 28 | | | | | |
| JUL 10 | | | | | |
| 29 | | | | | |
| AUG 9 | | | | | |
| 25 | | | | | |
| SEP 7 | | | | | |
| 28 | | | | | 1 rough-legged hawk(?) |
| OCT 19 | | | | | 1 red-tailed hawk |
| 28 | 5 | | | | |
| NOV 12 | | | | | |
| 24 | | | | | |
| DEC 14 | | | | | |
| 29 | | | | | |
| 1982 | | | | | |
| JAN 12 | 5 | | | | |
| 26 | 3 | | | | |
| FEB 12 | | | | | |
| 26 | | | | | |
| MAR 15 | | | | | 1 red-tailed hawk and 1 rough-legged hawk |
| 24 | 13 | | | | |
| APR 9 | 14 | | | | 1 red-tailed hawk and 1 hawk (sp?) |
| MAY 12 | | | | | 1 bald eagle |
| 27 | | | | | |

TABLE 16 -- AVERAGE MONTHLY SOIL TEMPERATURES ($^{o}C$) FOR RT #25 AND CONTROL SITES

| | 10 cm | | 50 cm | | 100 cm | | 150 cm | |
|---|---|---|---|---|---|---|---|---|
| | Rt. | C | Rt. | C | Rt. | C | Rt. | C |
| OCT | 6.2 | 5.1 | 8.8 | 7.7 | 11.7 | 10.3 | 13.0 | 12.2 |
| NOV | 4.1 | 3.1 | 6.9 | 5.6 | 9.8 | 8.2 | 11.2 | 9.6 |
| DEC | 0.9 | 0.2 | 3.3 | 2.2 | 6.9 | 5.4 | 8.8 | 7.2 |
| JAN | -1.2 | -1.9 | 0.9 | 0.1 | 4.4 | 3.1 | 6.7 | 5.1 |
| FEB | -1.5 | -2.3 | 0.0 | -1.0 | 3.3 | 1.7 | 5.4 | 3.7 |
| MAR | 2.4 | 1.1 | 3.8 | 1.6 | 5.1 | 2.6 | 6.2 | 3.8 |
| APR | 6.9 | 4.9 | 8.3 | 5.8 | 8.1 | 5.2 | 8.6 | 5.5 |
| MAY | 13.4 | 11.0 | 14.7 | 11.6 | 13.2 | 9.1 | 13.0 | 8.3 |
| JUN | 20.1 | 17.3 | 20.7 | 17.0 | 21.0 | 13.4 | 20.3 | 11.8 |

TABLE 17

**Status of Proposed Endangered and Threatened Plant Taxa Known to Occur on Geokinetics Research Site**

| Taxa | Site Occurence[1] | Federal Status[2] |
|---|---|---|
| Eriogonum ephedroides (ephedra buckwheat) | Locally abundant | No longer proposed endangered or threatened. Delisted 1980. |
| Parthenium Ligulatum (fever few) | Frequently encountered and locally common | Delisted in 1980. |
| Penstemon grahamii (Graham's Beard Tongue) | Infrequently encountered. Occurs on roadsides and other waste areas. Is known to occur off-site in close proximity to the Mahogany Zone.[3] | Proposed endangered or threatened. However insufficient information is available for listing at this time. More research is needed. |
| Townsendia meansana (easter daisy) | Frequently encountered and locally common | Delisted 1980 |

(1) Final Environmental Research Report - Vegetation: Ecoclimatic and Soil Factors 1978 and 1979. ERO Associates, Consulting Ecologist-Conifer, Colorado.

(2) Federal Register, December 15, 1980. 50 CFR Part 17.

(3) Threatened and Endangered Plants of the Willow Creek Drainage Vol. 1. Meiiji Resource Consultant.

TABLE 18

RETORT PLANT SURVIVAL AND
GROWTH MEASUREMENTS - FALL 1982

RETORT NO. 18

| SPECIES (abbrev.) | NUMBER PLANTED | MEAN SURVIVAL (%) | MEAN HT. (cm) | MEAN DIA. (cm) |
|---|---|---|---|---|
| Arfr | 40 | 70 | 9.5 | 11.8 |
| Arno | 40 | 60 | 6.0 | 4.1 |
| Artr v. | 39 | 69 | 8.6 | 6.9 |
| Atca[1] | 40 | 95 | 18.1 | 23.2 |
| Atca[2] | 40 | 60 | 6.3 | 9.0 |
| Atca x Atcu | 40 | 60 | 13.0 | 15.8 |
| Befr | 40 | 33 | 2.9 | 3.2 |
| Chna | 40 | 53 | 10.8 | 11.7 |
| Cune | 40 | 0 | -- | -- |
| Epne | 40 | 65 | 7.3 | 9.3 |
| Erco | 37 | 57 | 8.0 | 10.2 |
| Lemo | 40 | 53 | 19.8 | 20.3 |
| Pest | 37 | 51 | 5.8 | 7.1 |
| Pied | 40 | 40 | 3.1 | 2.9 |
| Rhtr | 40 | 45 | 16.6 | 7.1 |
| Spam | 40 | 55 | 7.5 | 8.1 |

RETORT NO. 10

| SPECIES (abbrev.) | NUMBER PLANTED | MEAN SURVIVAL (%) | MEAN HT. (cm) | MEAN DIA. (cm) |
|---|---|---|---|---|
| Agsp x Agre | 30 | 93 | 17.8 | 8.0 |
| Bogr | 30 | 100 | 8.7 | 4.7 |
| Cost | 40 | 73 | 6.7 | 3.4 |
| Hija | 30 | 77 | 8.8 | 4.8 |
| Orhy | 30 | 97 | 17.3 | 5.7 |
| Putr | 40 | 28 | 2.4 | 2.7 |
| Sihy | 30 | 100 | 11.4 | 5.8 |
| Spai | 30 | 93 | 21.3 | 7.7 |

**TABLE 19**

**RETORT PLANT SURVIVAL AND GROWTH MEASUREMENTS - FALL 1982**

**RETORT NO. 11**

| SPECIES (abbrev.) | NUMBER PLANTED | MEAN SURVIVAL (%) | MEAN HT. (cm) | MEAN DIA. (cm) |
|---|---|---|---|---|
| Acmi | 25 | 60 | 13.7 | 12.4 |
| Atbo | 25 | 100 | 13.0 | 20.0 |
| Atid | 27 | 92 | 9.0 | 14.4 |
| Atob [1] | 25 | 80 | 6.0 | 6.9 |
| Atob [2] | 25 | 60 | 11.1 | 11.9 |
| Attr | 25 | 76 | 12.3 | 20.0 |
| Camo | 25 | 84 | 7.4 | 11.6 |
| Cela | 23 | 83 | 11.1 | 12.4 |
| Cepa | 25 | 80 | 9.2 | 9.6 |
| Hebo | 25 | 52 | 4.9 | 6.4 |
| Kopr | 25 | 100 | 19.1 | 17.0 |
| Orhy | 25 | 64 | 13.6 | 5.8 |
| Pepa | 25 | 20 | 23.4 | 12.4 |
| Poco | 25 | 68 | 8.6 | 7.6 |
| Swsa | 25 | 28 | 16.4 | 14.6 |

TABLE 20

## RETORT #25 PROCESS WATER QUALITY
**Based On n=5 Unless Otherwise Noted**
**All Concentrations Expressed As Mg/l,**
**Unless Otherwise Noted**

| PARAMETER | n-SIZE | MEAN | STD. DEV. | MIN. | MAX. |
|---|---|---|---|---|---|
| Sodium | | 4,886 | 2,483 | 2,924 | 9,036 |
| Potassium | | 103.5 | 55.3 | 65.3 | 196.0 |
| Magnesium | | 4.5 | 1.7 | 3.6 | 6.2 |
| Calcium | | 7.8 | 3.1 | 4.5 | 7.4 |
| Strontium | | 1.6 | 0.8 | 0.9 | 2.8 |
| Fluoride | | 24.1 | 9.5 | 8.3 | 33.0 |
| Chloride | | 944 | 325 | 510 | 1,328 |
| Bromide | | 4 | 2 | 2 | 5 |
| Phosphate | | 8 | 4 | 3 | 10 |
| Nitrate | | 118 | 72 | 5 | 419 |
| Sulfate | | 393 | 178 | 159 | 616 |
| Bicarbonate | | 14,584 | 2,989 | 11,660 | 19,099 |
| Carbonate | | 2,747 | 789 | 1,723 | 3,616 |
| Antimony | | 0.39 | 0.22 | 0.20 | 0.47 |
| Arsenic | 4 | 27.11 | 9.15 | 15.31 | 37,63 |
| Boron | | 354 | 109 | 223 | 522 |
| Iron | 4 | 1.35 | 0.71 | 0.48 | 2.05 |
| Lead | | 0.072 | 0.049 | 0.05 | 0.16 |
| Silicon | | 6.2 | 1.2 | 5.1 | 8.1 |
| Molybdenum | | 1.85 | 1.32 | 0.74 | 4.13 |
| Selenium | 4 | 0.015 | 0.003 | 0.013 | 0.019 |
| Oil & Grease | | 287 | 79 | 200 | 400 |
| Phenols | | 58 | 20 | 27 | 80 |
| TOC | 4 | 1,816 | 190 | 1,533 | 2,063 |
| TKN | 4 | 4,352 | 896 | 3,515 | 5,480 |
| BOD | 4 | 2,140 | 454 | 1,512 | 2,598 |
| Ammonia | | 1,036 | 294 | 640 | 1,439 |
| Ammonium | | 2,674 | 608 | 1,760 | 3,360 |
| Cyanide | | 73.5 | 87.0 | 20.2 | 227.0 |
| Sulfide | 3 | 150 | 74 | 65 | 197 |
| Thiocyanate | | 303 | 114 | 178 | 432 |
| Thiosulfate | | 2,137 | 744 | 1,281 | 3,081 |
| Alkalinity | | 16,535 | 2,622 | 12,430 | 19,568 |
| COD | | 7,355 | 2,938 | 2,410 | 9,565 |
| TIC | 4 | 2,465 | 342 | 2,155 | 2,821 |
| Conductivity $umhos \cdot cm^{-1}$ | | 18,620 | 1,526 | 16,800 | 20,900 |
| pH units | | 9.08 | 0.16 | 8.92 | 9.27 |
| TDS | | 16,117 | 6,809 | 9,857 | 27,100 |
| TSS | 4 | 122.8 | 87.3 | 32.3 | 2[illegible]3.7 |

TABLE 21-- COMPARISON OF GEOKINETICS RETORT WATER QUALITY ANALYSIS AMONG RESULTS FROM GEOKINETICS AND AN OUTSIDE LABORATORY

Mean Values In Mg/l Unless Otherwise Noted

| | GEOKINETICS | | |
|---|---|---|---|
| PARAMETER | RT. #25 | OTHER [1] | MONSANTO [2] |
| Sodium | 4,886 | 9,392 | 3,030 |
| Potassium | 103.5 | 121.4 | 281 |
| Magnesium | 4.5 | 17.49 | 3.4 |
| Calcium | 7.8 | 32.6 | 4.43 |
| Strontium | 1.6 | 0.002 | 0.20 |
| Fluoride | 24.1 | 35.2 | 1.8 |
| Chloride | 944 | 3,016 | 2,057 |
| Bromide | 4 | 0.18 | |
| Phosphate | 8 | 2.1 | 1.6 |
| Nitrate | 118 | 34.2 | |
| Sulfate | 393 | 609 | |
| Bicarbonate | 14,584 | 17,174 | 12,800 |
| Carbonate | 2,747 | 2,825 | 3,800 |
| Antimony | 0.39 | 0.01 | |
| Arsenic | 27.11 | 2.55 | 9.23 |
| Boron | 354 | 60.6 | 107 |
| Iron | 1.35 | 13.99 | 1.59 |
| Lead | 0.07 | 0.64 | 0.34 |
| Silicon | 6.2 | 17.95 | 0.62 |
| Molybdenum | 1.85 | 11.91 | 1.19 |
| Selenium | 0.02 | 0.22 | 0.07 |
| Phenols | 58 | 11.56 | |
| TOC | 1,816 | | |
| TKN | 4,352 | | 1,120 |
| BOD | 2,140 | | |
| Ammonia | 1,036 | 1,270 | 2,590 |
| Ammonium | 2,674 | | |
| Cyanide | 73.5 | 13.31 | 0.004 |
| Sulfide | 150 | 447 | |
| Thiocyanate | 303 | | |
| Thiosulfate | 2,137 | | |
| Alkalinity | 16,535 | 17,836 | 16,600 |
| COD | 7,355 | 3,682 | |
| TIC | 2,465 | | |
| Conductivity umhos·cm $^{-1}$ | 18,620 | 34,036 | |
| pH units | 9.08 | 8.56 | |
| TDS | 16,117 | 22,145 | 25,684 |
| TSS | 122.8 | | 322 |

[1] Environmental Assessment, Geokinetics Inc. Oil Shale Research Project, Uintah County, Utah D.O.E. 1979.

[2] Oil Shale Wastewater Analysis And Characteristics. Monsanto Research Corporation 1981.

TABLE 22

RETORT GAS SCRUBBING TESTS

RETORT #26

**November 1982**

| Date | Packing Area $ft^2$ | Gas Flow L/min | Gas Flow SCFM | Water Flow L/hr | Water Flow gph | Gph at 6000 scfm | Flow/Area scfm/$ft^2$ | Ave. $H_2S$ in ppm | Ave. $H_2S$ Out ppm | Removal % | Temp. °F. | S=in Water Ave. ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11-01-82 | .342 | 4.0 | .1106 | .078 | .0206 | 1118 | .323 | 674 | 552 | 18.1 | 73 | 160 |
| 11-01-82 | .342 | 4.0 | .1106 | .448 | .129 | 6994 | .323 | 778 | 537 | 31.0 | 97 | 99 |
| 11-02-82 | .342 | 4.0 | .1106 | .428 | .113 | 6134 | .323 | 649 | 214 | 67.0 | 134 | 44 |
| 11-15-82 | .342 | 4.0 | .1106 | .440 | .116 | 6306 | .323 | 1806 | 1298 | 28.1 | 139 | --- |
| | | 4% $O_2$ in gas stream | | | | | | | | | | |
| 11-17-82 | .342 | 4.0 | .1106 | .45 | .119 | 6449 | .323 | 800 | 441 | 44.9 | 137 | --- |
| | | 5.5% $O_2$ in gas stream | | | | | | | | | | |
| 11-17-82 | .342 | 4.0 | .1106 | .45 | .119 | 6449 | .323 | 1025 | 473 | 53.9 | 139 | --- |

**TABLE 22**

Retort Gas Scrubbing Tests

**Retort #26 - December 1982**

| Date | Packing Area $Ft^2$ | Gas Flow SCFM | Water Flow gph | Gas Flow Area $SCFM/ft^2$ | WATER Ammonia ppm | WATER pH | WATER Sulfide ppm | Ave. $H_2S$ In (ppm) | Ave. $H_2S$ Out (ppm) | Removal % | Column Temp. °F |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12-06-82 | 2.893 | .456 | 1.259 | .1575 | --- | --- | --- | 994 | 443 | 53.1 | 96 |
| 12-07-82 | 2.893 | .456 | 1.259 | .1575 | 4,912 | --- | 8-138 | 814 | 557 | 31.6 | 96 |
| 12-07-82 | 2.893 | .456 | 1.259 | .1575 | 12,000 | --- | --- | 774 | 574 | 25.8 | 95 |
| 12-08-82 | 4.089 | .376 | .396 | .092 | 4,472 | 8.8 | 8 | 820 | 401 | 51.1 | 99 |
| 12-09-82 | 4.089 | .362 | .872 | .089 | 200 | 8.3 to 7.4 | 0-70 | 668 | 339 | 49.2 | 115 |
| 12-10-82 | | | | | | | | | | | |
| Col. #1 | 4.089 | .489 | .048 | .120 | --- | --- | --- | 774 | 664 | 14.2 | 122 |
| Col. #2 | .873 | .489 | .705 | .560 | --- | --- | --- | 664 | 852 | -10.1 | 122 |
| 12-15-82 | | | | | | | | | | | |
| Col. #1 | .701 | .1465 | .252 | .209 | --- | --- | 278-182 | 1019 | 866 | 15.0 | 70 |
| Col. #2 | 4.089 | .1465 | 2.821 | .036 | --- | --- | | 866 | 937 | -8.2 | 70 |
| 12-16-82 | | | | | | | | | | | |
| Col. #1 | .701 | .1465 | .192 | .209 | --- | 10.0 to 9.0 | | 788 | 278 | 64.7 | 70 |
| Col. #2 | 4.089 | .1465 | 2.948 | .036 | --- | | 219-385 | 278 | 698 | -151 | 70 |
| 12-20-82 | | | | | | | | | | | |
| Col. #1 | .701 | .1465 | .195 | .209 | --- | 12.3 to 9.0 | 128-582 | 807 | 95 | 88.2 | 70 |
| Col. #2 | 4.089 | .1465 | 2.932 | .036 | --- | | | 95 | 668 | -603 | 70 |
| 12-22-82 | .701 | .1465 | .187 | .209 | -- | 11.5 to 9.3 | 161-621 | 729 | 429 | 41.2 | 70 |



☆U.S. GOVERNMENT PRINTING OFFICE: 1983-646-069/723