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DESIGN, CONSTRUCTION, AND INITIAL OPERATION OF THE ANL RESEARCH SALT-GRADIENT SOLAR POND

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

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ABSTRACT

The design consideration of a 1/4 acre research salt-gradient solar pond is described. Experience learned during the construction of the solar pond is presented. Initial operation of the pond indicates that the construction of the pond is sound and no leakage has occurred. The pond began to warm up during March of 1981. The maximum pond temperature reached 63°C at the end of July and it is still rising. All signs indicate that the operation of the well instrumented pond will be a success and the performance of the pond will be as expected, if not better.

I. INTRODUCTION

A salt-gradient solar pond is a body of water which contains a significant amount of dissolved salt. Salt-gradient solar ponds have the distinct advantage of combining the collection and the storage of solar energy into one single operation. Solar radiation is absorbed and stored in the water at the lower levels of the pond. The water temperature at the lower levels of the pond can be as high as 70-100°C, while the surface temperature remains very close to the ambient air temperature. Convection is prevented by establishing a salt-gradient in the pond such that the salt concentration varies from a few percent at the surface to ~ 25% at the bottom of the pond. As a result of the presence of the salt-gradient, the fluid density at the lower levels of the pond is higher than that near the surface, thus preventing the hotter fluid at the lower levels of the pond from moving upward. The concept of collecting and storing solar energy by means of salt-gradient solar ponds was derived from studies of various natural lakes that had a salt concentration gradient. A salt-gradient solar pond normally consists of three zones; a thin convective zone at the surface, a non-convective gradient zone that provides thermal insulation in the middle, and a convective storage zone at the bottom (see Fig. 1). The pond collects and stores solar energy all year round and the available thermal energy in the pond can be extracted via a heat exchanger for various uses.

A salt-gradient solar pond can provide relatively low-cost solar energy collection and long-term storage of low-temperature heat. A most recent study [1] estimates that the cost of energy for using a large solar pond (10 acres) is $7.06 per million Btu which is competitive with the energy costs of either coal ($9.13/MBtu), or natural-gas ($10.24/MBtu) and is cheaper than the energy cost for using oil ($16.64/MBtu).

Salt-gradient solar ponds have many potential applications which include:

Residential and commercial space and water heating

Agricultural and industrial process heat

Electric Power Generation

Desalination

Several ponds with specific applications are in operation in this country. For example, in Miamisburg, Ohio, a 2020 m^2 solar pond was constructed in 1977 to provide heat for an outdoor swimming pool in the summer and an adjacent recreational building from October to December[2]. In Wooster, Ohio, a 156 m^2 solar pond was constructed in 1975 to heat a greenhouse in the winter[3]. The Salton Sea Solar Pond Project in Southern California is directed toward electric power generation[4]. A 5-MWe electric power generation system will be designed. Three research ponds are also in operation in this country. The research pond at the University of New Mexico has a surface area of 175 m^2. The other two research ponds are in Columbus, Ohio, and are under the supervision of Dr. C. E. Nielsen.

Even though solar ponds have been demonstrated to be technically feasible and appear to be economically competitive, there are still unresolved problems and plenty of room for improvement. For example, in Ref. 5, five major categories requiring further research were identified: (1) surface influences, (2) brine transparency, (3) maintenance of salinity profile, (4) thermal behavior, and, (5) practical utilization. In 1979, the management at ANL decided to build a research salt-gradient solar pond at Argonne using internal funds. The primary objective of constructing the research solar pond is to conduct research projects which might lead to improvements in using thermal energy from solar ponds for all kinds of applications. This research solar pond is designated as Argonne National Laboratory Research Salt Gradient Solar Pond (ANL-RSGSP). It is anticipated that ANL-RSGSP will be included as a member of a National Solar Pond Program to be formulated by DOE. Furthermore, ANL-RSGSP is available as a regional resource for the Mid-Western States which may have different emphasis from other regions of the conuntry in how to utilize the energy from solar ponds.

II. DESIGN

II.1 Size

ANL-RSGSP is primarily a research facility. However its size should be large enough to simulate closely the real behaviors (such as surface waves and ground heat loss) of large prototype ponds. Furthermore, funding limitations dictate what the maximum size of the pond should be. It was decided to build a solar pond with a surface area of approximately one-quarter acre. The actual dimensions of the pond are shown in Fig. 2. The pond is 43 m x 25 m (142 ft x 82 ft) at the top with sides tapered at an angle of 45° to a depth of 4.27 m (14 ft). There is a slight slope towards the center of the pond in the north-south direction as shown in Fig. 2. The 1-to-1 slope (45°) was adopted from the Miamisburg pond and the reason for this choice is to provide more storage capacity for a given size of a pond. In retrospect, it is our opinion that a gentler slope is probably more desirable. Even though the 45° slopes of the ANL-RSGSP are holding well up to now, a 3-to-1 or a 2-to-1 slope is less likely to have soil movement. According to the contractor (MWM Contracting Corporation, who is specialized in building industrial ponds), most ponds they build have a 3-to-1 slope. A 2-to-1 slope with good compaction is probably adequate.

The vertical depth of the pond is 4.2 m, measured from the bottom of the slopes. This depth is selected in view of the following estimate:

Surface convective layer	0.20 m
Gradient layer	1.00 m
Storage Layer	2.46 m
Margin for overflow	0.61 m
TOTAL	4.27 m

Since the ANL-RSGSP is primarily for research, various applications and tests will be performed. Thus, there is no optimum depth for the pond. It is always desirable to build a deeper pond rather than a shallow one since a deeper pond can readily be converted to a shallow pond.

There were no drain holes provided for the ANL-RSGSP in case of overflow. Drain holes require penetrations through the liner and the berm which will add complications to the construction. It was decided not to employ drain holes for the following reasons. First, the largest one-time rainfall in Illinois is considerably less than the overflow margin. Furthermore, if the water level is unusually high, near surface pumping can be initiated to reduce the water level to the normal level. This operation does not require additional equipment since the pump and pipe system is part of the maintenance system for water clarity and salt gradient modification. For prototypical ponds, drain holes or other overflow provisions may be necessary.

The dirt from excavating was used to build a berm above the original ground level. By doing so, we not only eliminated the cost of hauling the dirt away, but also reduced the total depth of excavation. Along the edge of the pond, the berm is 1.22 m (4 ft) above the original ground level. Thus, the actual excavation required was only 3.05 m (10 ft). The berms are sloped slightly away from the pond in all four directions for drainage purposes. Original calculations indicated that the amount of dirt from the excavation was enough to build a berm 1.22 m high and 10.7 m (35 ft) wide in all directions. However, because the original ground level in the north-east corner of the pond site was relatively low, a significant amount of dirt was used to compensate this low land. The final width of the berm was only approximately 6.1 m (20 ft).

II.2 Surface Preparation

It was originally planned to cover the slope and the bottom of the pond with 2.5 cm (1 in.) of sand to maintain relatively smooth soil surfaces.

However, it was realized that the 45° slope was not gentle enough to hold the sand permanently. It was decided to put all the sand on the bottom of the pond and increase the depth to 15.2 cm (6 in). This thickness was suggested by the Soil Testing Services[6] who provided consulting services to the construction of the solar pond. According to Soil Testing Services, sustained heating of the soil below the liner could result in soil moisture transforming into vapor. If this vapor escapes, shrinkage of soil can occur as a result of the decrease in water content. To minimize the chances of soil shrinkage, 15.2 cm of sand was suggested, which should allow for additional flexibility and mobility of the liner and a better healing potential for any heat related soil shrinkage.

There are two extremely important factors in surface preparation. The first is the compaction of the soil on the slope, and the second is the smoothness of the surface on the slope. Good compaction is essential in order to minimize soil movement later. If the ground does move, the liner will be stretched and stressed, which may result in leakage (particularly at the seams) through the liner. The smoothness of the surface is important for the same reason. Furthermore, the soil surface should be free of sharp projections such as roots and rocks. To assure compactness of the soil, it was specifically stated in the contract requirement that the soil shall be compacted to a 90% relative density which is the terminology commonly used in construction for good compaction.

II.3 Liner

The liner selected was XR-5 manufactured by Shelter-Rite (a division of the Seaman Corporation in Millersburg Ohio). XR-5 is a chemical resistant fabric, particularly designed for pond liners and chemical storage. Salt water at 82°C (180°F) has little or no effect on this liner[7]. It has fairly low water permeability. The color of the liner was chosen to be gray instead of black (standard) since experience from the solar pond at the University of New Mexico indicates that a black liner may have caused additional convection on the pond bottom and sides. It is questionable whether the black liner is superior to the gray liner even though the former is a better light absorber[8]. The dimensions of the liner were specified to include a 3 to 5% margin so that the liner could be loosely fitted on the soil. In retrospect, it is better to specify a margin of 10 to 15% which would ensure a loose fit in most places. A loose fit will provide some allowance for ground movement without stressing the liner. The liner extends over the top of the berm for a distance of 1.83 m (6 ft) and half of the 1.83 m is buried underneath the berm to hold down the liner. An important observation is that leaks (if they do occur) typically occur at the joints and seams. Factory- or plant-seamed liners usually exhibit better performance than field-seamed liners. Therefore, factory seams should always be preferred. If the pond size is fairly large (greater than 1/4 acre), one can specify several large pieces of liners and each piece should be factory-seamed. Each large piece will then be seamed on site when it is placed in position. The factory-seams should have a width (overlap) of at least 5.1 cm (2 in) and a strength comparable to that of the mother material. Field-seams should have a width of 15.2 cm (6 in). Special care should be exercised in order not to damage the liner during transportation of the liner and during construction of the pond.

II.4 Fence

Since the ANL-RSGSP was built at the Laboratory, it was necessary to isolate the pond for safety purposes. Fairly inexpensive cedar was selected as the fence material. A wood fence is preferred since it has the side benefit of reducing the amount of leaves and dust being blown into the pond. The fence is 1.83 m (6 ft) tall and located 4.57 m (15 ft) away from the edge of the bank. One small pedestrian gate and one large gate for construction were provided in the south-west corner of the fence. If future funding permits, reflective material such as aluminum sheets will be installed to the north, east, and west sides of the fence. Thus the fence can be utilized as a reflecting wall.

II.5 Leakage Detection Systems

One major concern in building a salt-gradient solar pond is the potential problem of leakage of brine into the surrounding soil. This may pollute the nearby underground water or may have an adverse effect on the growth of plants. Furthermore, if the leak is not detected and stopped in time, there could be a significant loss of salt inventory in the pond. Loss of salt is not only environmentally unacceptable in some cases, it is also a financial loss since the salt is a major cost in the construction of a solar pond. A significant loss of salt inventory in the pond could result in degrading the thermal performance of the pond. Therefore, leakage prevention is of the utmost importance for the successful operation of a solar pond. The XR-5 liner described previously is likely to minimize the effect of the leakage problem. However, if a leak should occur, provisions must be made for early detection.

Two methods of leakage detection are provided for the ANL-RSGSP. The first one employs the drain tile system shown in Fig. 3. A ditch approximately 0.3 to 0.4 m deep is excavated along the centerline of the pond bottom in the east-west direction. This ditch is sloped slightly towards the west so that the center of the west end of the pond bottom is the lowest point (a sump). Drain tiles with 10.2 cm (4 in) diameter are placed in the ditch. A 10.2 cm (4 in) cast iron pipe is buried under the west slope. A garden hose is placed inside the cast iron pipe with one end of the hose extending into the drain tile and the other end extending above the top of the berm as shown in Fig. 3. The drain tiles are covererd with gravel which lies beneath a thick layer of sand. The sand and the gravel are quite permeable to water. Therefore, any leakage through the liner will probably accumulate in the drain tile. A high-suction low-capacity pump can be connected to the garden hose to obtain sample water from the drain tile system. The salinity of the water sample provides a means of determining whether a leak has developed or not. Even though this method is capable of leak detection for the pond as a whole, it is not able to isolate the location of the leak. A typical leak may occur in an area the size of a brick, which is small compared to the area covered by the liner. It is time consuming, sometimes difficult if the pond is hot, to find out exactly where the leaks are by sending a diver down there. The following method provides a means of isolating the loction of the leak.

The electrical conductivity of soil is primarily a function of temperature, water content, and salinity. Thus, by strategically locating soil conductivity probes beneath the pond, it is possible to locate an area which has unusually high conductivity as a result of brine leakage. The soil conductivity probes used for the ANL-RSGSP are made of copper pipes. 5.1 cm (2 in) diameter copper pipes are cut into 7.6 cm (3 in) sections and each section is then split into two halves to form two electrodes. Electrical cables are attached to the electrodes by means of silver solder. The two electrodes are spaced approximately 7.6 cm (3 in) apart and buried 15 cm (6 in) below the ground surface. The conductivity probes are buried both beneath the bottom and the slopes of the pond. The exact locations of these probes are shown in Fig. 4. The degree of success of this method in isolating the leakage location remains to be seen.

II.6 Site Selection

There are many factors, such as ground water, soil condition, and solar access, that should be considered in selecting a site for a solar pond. However, the selection of a site for the ANL-RSGSP was limited by what is available inside the Laboratory. Furthermore, the site had to be close enough to one of the buildings that belongs to the Components Technology Division so that the operation of the pond could be closely monitored using existing data acquisition systems. The site selection was finally narrowed down to the area east of Building 309. Soil testing of this site was conducted by H. H. Holmes Testing Laboratories, Inc.[9]. Samples were analyzed from two soil borings, each 7.6 m (25 ft) deep. The results showed that the soil is mostly hard brown silty clay. This type of soil is unlikely to have movement and is suitable for a solar pond. No ground water was found up to a depth of 7.6 m (25 ft). In retrospect, the soil boring should have been conducted to a depth of 15.2 m (50 ft) to determine the level of ground water which is a heat sink as a result of its movement. Thermal performance of the pond can be degraded if ground water is located nearby. Other information indicates that the free ground water table for the proposed site is probably at a level 33.5 m (110ft) below the original ground level[6].

The north and east sides of the proposed pond site are part of Argonne's woods located approximately 12 m (40 ft) from the banks. Locating the pond so close to these trees may cause some problem during the fall when leaves begin to fall into the pond. More than 30 m (100 ft) away on the west side of the pond is the high-bay area of Building 308. This tall building will block some insolation during late afternoon. These are some undesirable aspects of the proposed pond site. However, as described previously, the selection of the site for the ANL-RSGSP was dictated by other constraints unrelated to the performance of the pond. A digging permit was obtained from the Argonne Plant Systems Division.

II.7 Environmental Effects

Possible adverse environmental effects associated with the ANL-RSGSP are all related to the escape of salt from the pond. The salt can escape into the air through the surface of the pond; however, this effect is probably negligible since the surface concentration of the pond will always be kept very low, which minimizes the potential for salt to diffuse into the air. The other path for salt to escape is through the soil in case a leak develops in the liner. This is a potentially serious problem. Even with the leakage detection systems described in Sec. II.5, it is still possible for leaks to occur undetected for a certain period of time. It is, therefore, necessary to assess the impact of salt leakage for an extended period of time. According to the analysis provided by Soil Testing Services[6], it would take many years for fluid in an unlined storage pond with clay-type soil similar to that at the ANL-RSGSP site to reach the roots of the nearest oak trees located about 12 m (40 ft) north of the pond. This time scale is much larger than the expected period of undetected leakage. Therefore, the impact of this potential problem is not considered to be significant at the selected site.

A question was raised regarding treatment of the brine after the pond is decommissioned. One possible solution is to spray the brine on icy roads during the long winter here since the salt used is the common rock salt used for melting ice on the roads. Another alternative is to pump the brine into the sewage system, if environmental circumstances permit.

III. CONSTRUCTION

When all the requirements were determined, technical specifications for the construction of the solar pond were prepared and issued for competitive bidding. The lowest bidder was selected and construction began. A series of construction events are shown in Figs. 5 to 23.

III.1 Excavation and Surface Preparation

Excavation started on June 16, 1980. A front-end loader (see Fig. 6) was the only machine needed for digging. On the fourth day of excavation, a 0.4 m (16 in) steel pipe was exposed (fortunately, the operator of the front-end loader was able to stop the machine before causing any damage) at a depth of 2.4 m (8 ft) below the original ground level and approximately 12 m (40 ft) east of the west bank of the originally proposed site. Plant Systems personnel were notified immediately to identify the function of this pipe. It turned out that it is the canal cooling-water pipe running south-north to supply cooling water for various experiments at Argonne. This pipe has been there for many years and some of the new maps did not even show the existence of such a pipe. In any case, relocating the pond site eastward 20 m (65 ft) solved this problem. This unexpected problem caused a slight delay and some additional expense for the construction of the pond. The slopes of the pond were finished by the back-hoe (Fig. 7). Preliminary excavation was completed (Fig. 8) on July 13, 1980.

During construction of the pond, there was a five-week period for installing the underground thermocouples (Figs. 9 and 10) and conductivity probes right after the excavation and before the application of sand on the bottom of the pond. During this same period, the drain tile system was also installed. The underground instrumentation and drain tile work were completed on August 15. During the month of August, there was unusually high rainfall in this area which caused significant erosion of soil on the slopes. Erosion channels as deep as 0.3 m (1 ft) were observed in certain places. It was decided that the slopes had to be refinished. This would cost an additional $2850. The back-hoe came back to prepare the slopes again and this time the slopes were covered with inexpensive plastic sheets as soon as they were finished to prevent further erosion (Fig. 11). During the entire excavation period, a sump pump (Fig. 12) was used to get rid of most of the water accumulated in the pond. When all the slopes were finished, the plastic sheets were removed gradually. In the meantime, intensive labor began to remove roots and rocks projecting above the surfaces (Fig. 13). Mud from the bottom of the pond was used to fill large holes and dents on the slopes. This was part of the effort to make the surfaces of the pond slopes as smooth as possible in order to minimize the probability of damaging the liner. Large rocks were also removed from the bottom of the pond before sand application. A total of 200 tons (10 truck loads) of mason sand was applied which provided a layer of sand with a thickness of 15 cm (6 in) on the bottom of the pond (Fig. 14).

In retrospect, the period between the completion of the excavation (including surface preparation) and the installation of the liner should be kept as short as possible in order to minimize the effect of soil erosion due to rainfall. This should be the case in construction of most commercial solar ponds. If an extended period of time is required, as in the case of the ANL-RSGSP, for installing underground instrumentation, inexpensive plastic sheets should be used to cover the surfaces on the slopes to protect them from erosion.

III.2 Liner Installation

The XR-5 Shelter-Rite liner was transported to Argonne from a local distributor (M. Putterman Company of Chicago). It came as one piece folded into a 1.8 m (6 ft) cubicle and was stored near the pond site. The surface condition of the pond was inspected carefully by Argonne staff and by the Contractor, and final approval was given for the installation of the liner. The liner was first moved to the northwest corner of the pond by a fork-lift truck and then unflolded along the west bank with the help of a front-end loader (Figs. 15 and 16). The front-end loader was then moved to the east bank to help unfold the liner across the pond. A specially designed clamp was used to hold the liner at midplane. The clamp was connected to the front-end loader via a rope. As the front-end loader moved eastward, the liner began unfolding (Figs. 17 and 18). In the meantime, several persons were trying to swing the front-end of the liner up and down in order to get more air underneath the liner to reduce friction. When 2/3 of the pond was covered by the liner, the clamp broke loose as a result of too much friction between the ground and the liner. The contractor decided to make a cut in the north-south direction at the center of the liner so that the clamp could be applied there. This would enable the front-end loader to pull only the second half of the liner and reduce the friction significantly (Fig. 19). The cut was about 2.4 m (8 ft) long and was repaired later by thermal seams (Fig. 20). Double seams were used. The first seam was 0.3 m by 3 m and on top of this seam was the second seam (0.6 m by 4 m) which totally enclosed the first seam. After the liner was securely in place (Fig. 21), it was thoroughly examined to determine if any defect or damage existed. Only one small defect was found and repaired by thermal seam. The entire process of liner installation took about one day. The final grading of the berm was completed shortly after that.

According to the contractor, this is the largest one-piece liner they have ever installed. It appears that the technique of liner installation is rather primitive and there is room for improvement. However, until more experience is accumulated and techniques are improved for liner installation, it seems appropriate to consider installing the liner in several large pieces for large ponds. The size of each piece should not be greater than, say 1000 m^2, for easy handling. The price one has to pay would be to connect each large piece using a field-seam technique which is considered inferior to factory-seams.

III.3. Fence, Water, and Salt

Construction of the fence is straightforward. Cedar was the material for both the fence and the posts. The posts were reinforced underground by concrete for a depth of 1 m.

Argonne's Water Department supplied 1892 m^3 (500,000 gallons) of water through the nearby fire hydrant. This took about one week. The total amount of water planned for the pond is approximately 3028 m^3 (800,000 gallons). The remaining 1136 m^3 (300,000 gallons) of water will be injected later after the salt has been added.

The salt, donated by Morton Salt Company, was white-crystal rock salt which is one grade higher than the brown crystal commonly used for melting ice on roads. It came in tanks loaded on trucks. Each tank contained approximately 23 tons of salt. The trucks were equipped with a special hose and air system so that the salt could be blown into the pond (Fig. 22). It took about one hour to unload one tank. There are at least two advantages to this air/hose system for adding salt to the pond. First is that the salt can be fairly evenly distributed in the pond by moving the hose along the bank. Secondly, the truck does not have to move on top of the berm to unload the salt which may ruin the newly constructed berm as a result of the weight of the truck and the tank. A total of 30 tanks were unloaded, which added up to 700 tons of salt in the pond. The total amount of salt donated by Morton Salt Company was 800 tons. 100 tons of salt was reserved for future use. Most of the salt settled down at the bottom of the pond. It will take a long time before most of the salt becomes dissolved. During the process of adding salt to the pond, salt dust may escape from the pond and reach the nearby plants. Applying a water jet on top of the hose helped to suppress the amount of salt dust blown away from the pond. Figure 23 is an entire view of the completed pond.

IV. INSTRUMENTATION AND MAINTENANCE EQUIPMENT

IV.1 Underground Thermocouples

The ANL-RSGSP is equipped with 165 underground thermocouples (E type). The locations of these thermocouples are shown in Fig. 24. There are 35 holes shown in Fig. 24 and each hole hosts five thermocouples as shown in Fig. 25. Five thermocouples were attached to a wood stick (2.5 cm x 2.5 cm x 3.6 m) with predetermined spaces between each thermocouple. One wood stick was lowered into each hole drilled vertically down into the ground. Four holes (5B, 8, 5J, and 2) were drilled on the slopes. The rest of the holes were either located on the bottom of the pond or on the berm. The top of each stick was placed 8 cm below the excavated surface. The upper thermocouple on each stick is 15 cm below the top of the stick, so the upper thermocouple at each location is 23 cm below the excavation surface. For thermocouples below the pond bottom (3, 4, 5C-5H, 6B-6E, 7B-7E), an additional 15 cm of sand is between the excavation surface and the pond liner. The top thermocouple for these positions is then 38 cm below the pond bottom. As soil shrinkage under the pond progresses, the depth of sand at any given position will change with time and was not carefully monitored. The estimated maximum uncertainty in position is 4 cm. These thermocouples will be used to measure the soil temperature distribution below and around the pond. The large number of thermocouples associated with the ANL-RSGSP is entirely for research purposes. It is not essential for propotypical ponds with specific applications to have this many thermocouples.

IV.2 Diffuser Assembly

A diffuser assembly was built for establishing and modifying the salt gradient in the pond. The diffuser is made of two circular plexiglass plates. Each plate is approximately 1.8 m (2 ft) in diameter and 2.5 cm (1 in) thick. The space between the two plates is variable and is usaually set between 0.64 cm (1/4 in) and 0.32 cm (1/8 in). A 5.1 cm (2 in) plastic pipe was threaded to the top plate at the center so that water can flow into the diffuser vertically down and leaves the diffuser radially (horizontally) in all directions. This diffuser was then mounted beneath a rectangular raft in such a way that the distance between the raft and the diffuser can be adjusted. Additional sections of straight vertical pipe can be added to the diffuser so that scanning of the diffuser can take place at any depth in the pond. Four large plastic bottles (0.3 m in diameter and 0.6 m in length) were attached to the four corners of the raft (Fig. 26). The raft was anchored at the center of the pond by two stainless steel pipes and a large circular plate sunk at the bottom of the pond. The raft always floats near the surface and its level can be adjusted by adding water to the plastic bottles or by putting lead blocks on the raft.

IV.3 Vertical Scanning System

To measure the vertical temperature and concentration profiles, a vertical scanning system has been designed and built. The scanning system consists of a reversible motor which drives a drum. A stainless steel cable is wrapped around the drum and then extends from the berm to the center of the pond in the air where it passes over a pulley and is then attached to a plastic mounting assembly containing lead weights. A thermocouple and conductivity probe is attached to the mounting assembly in such a way that the sensing elements are always at the same depth. As the drum unwinds, the weight on the assembly lowers the probes deeper into the pond. Reversing the motor raises the probes toward the surface.

IV.4 Instruments and Maintenance Equipment

Instruments and equipment that have been acquired so far include:

1. 165 type E underground thermocouples.
2. A type E stainless sheathed thermocouple used in the scanning system.
3. A digital thermometer.
4. A Beckman electrodeless conductivity probe with signal transmitter used in the scanning system.

5. Three vapor-actuated 12" dial thermometers
6. An Epply black and white surface pyronometer.
7. An Epply black and white underwater pyronometer and an electronic integrator.
8. A high-suction low-flow pump for taking water samples from the drain tile system.
9. A 75 gpm sand filter.
10. A 3 horse-power plastic self-priming pump.
11. A swimming-pool-type surface skimmer.
12. Granulated chlorine and copper sulfate solution for algae control.
13. An air-inflated rubber boat.

IV.5 Data Acquisition System

A Data Acquisition System (DAS) is currently being assembled. It includes the following major components:

1. A 2402 DVM and a HP 2311X Bar scanner (200 channels).
2. A HP 3030 Magnetic tape drive.
3. A 2116 C HP mini-computer.

This equipment was acquired from the Components Technology Division at no charge, although some repair and calibration work had to be done. The DAS will greatly increase the capability of collection, manipulation, and analysis of the data from the solar pond. The DAS is currently housed in an air-conditioned trailer on the west berm of the pond.

V. COST ANALYSIS

The major costs of constructing a salt-gradient solar pond (excluding land) are excavation, liner, salt, and heat extraction equipment. The heat extraction equipment is not needed during the initial construction of the pond since it takes time for the pond to heat up. Following is a breakdown of all the costs for construction of the ANL-RSGSP.

1.	Excavation	$13,400.00
2.	XR-5 liner	16,600.00
3.	Liner installation	5,800.00
4.	Sand	2,773.00

5.	Salt (700 tons at $30/ton)	21,000.00*
6.	Salt transportation ($7.60/ton)	5,320.00**
7.	Fence and Gates	6,540.00
8.	Drain tile system	1,600.00
9.	Water ($3.00/1,000 gallons)	2,710.00***
10.	Miscellaneous	3,455.00†
11.	Pond relocation due to presence of water pipe	5,600.00
12.	Additional sloping work due to heavy rainfall	2,850.00

Items 11 and 12 are unexpected costs and should not apply to most ponds. The realistic cost for the construction of the ANL-RSGSP is then (excluding items 11 and 12) $79,198. The surface area of the ANL-RSGSP is 1082 m^2 (11644 ft^2). Thus, the construction cost per unit area was $73/$m^2$ ($6.8/$ft^2$). For larger ponds, the cost per unit area may be reduced. It should be pointed out that the cost of $73/$m^2$ does not include the costs for instrumentation, maintenance equipment, and the heat extraction system.

VI. INITIAL OPERATION

Construction of the ANL-RSGSP was completed in November of 1980. By this time, the pond contained approximately 500,000 gallons of water and 700 tons of salt. Since winter was almost here, it was decided not to establish the salt gradient by artificial means until the next spring (a natural salt-gradient should develop). Throughout the winter of 80-81 the pond maximum temperature was monitored. In March of 1981, the pond began to heat up. A small modification of the naturally-occurring salt-gradient was established by injecting fresh water at a level of approximately 0.3 m (1 ft) below the surface. A total of 40,000 gallons of water was injected through the diffuser. A more detailed account of the salt-gradient modification will be reported separately. In this report, the results of initial operation of the pond can be summarized in Figs. 27 to 29. Figure 27 shows the maximum pond temperature variation with time. Figure 28 shows the vertical temperature and concentration profiles of the pond in the spring. The salt concentration distribution in Fig. 28 is the result of natural diffusion. Figure 29 shows the temperature and concentration distributions obtained in July after some modification

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* Donated by Morton Salt Company.

** ANL paid $4,200; the difference of $1,120 was again donated by Morton Salt Company.

*** This is the rate charged by Argonne's Water Department.

† This includes soil testing and analysis, services from other divisions at Argonne, etc.

of the original salt-gradient. At the end of July, the maximum pond temperature had already reached 63°C (146°F).

During the heating-up period, the clarity of the water degraded several times as a result of algae growth. This problem was solved by either adding granular chlorine or copper sulfate solution. It was interesting to note that when the conditions are right for algae growth, the water clarity can become very poor in a relatively short period of time (say, 12 hours). Copper sulfate is very effective in controlling algae and is inexpensive compared to chlorine. Furthermore, copper sulfate does not dissipate, and therefore there is no need to add it constantly as in the case of chlorine.

The pump and filter system is also operational. Since there are not enough leaves in the pond now to warrant use of the pump-filter system, it is not being used frequently. However, this system is expected to be very useful in the fall when the leaves begin to fall, in view of the proximity of the pond site to the nearby woods. The plastic pump has multiple uses. It can be used to filter the water and it can also be used to modify the salt-gradient.

Water samples were obtained from the drain tile system in June. The salinity of these water samples was measured by weighing. It was found that there was no salt in the soil water to within 0.1% by weight. This is a good indication that there is probably no leakage of salt water through the liner. This type of measurement should be performed at least once a month to ensure proper detection of leakage.

VII. SAFETY RULES

There are a few safety hazards associated with the operation of a salt-gradient solar pond. The most obvious hazard is that someone may accidentally fall into the pond. When the pond is hot, skin burns are a potential hazard. According to a study[10], exposure of the skin to hot surfaces at various temperatures have produced the following thresholds for tissue destruction

Temperature	Time of Injury
158F	1 sec.
140F	5 sec.
125.6F	60 sec.
120.2F	15 min.
113F	6 hrs.

Furthermore, at levels below those causing immediate injury, pain response may cause incapacitation or even loss of consciousness which would hamper rescue efforts. In view of these potential hazards, the following safety rules were proposed for the ANL-RSGSP:

1. When unattended, all pond gates will be locked.

2. Access to the pond will be limited to authorized personnel only.

3. Any person working alone inside the pond enclosure must wear a flotation type life vest. (Not required when inside the instrument building.)

4. All persons working aboard the inflatable boat must wear a flotation type life vest. When the boat is in use, at least one person must be on shore to observe boat operations.

5. Heavy knotted lines shall be hung over all four sides of the pond to assist any one who may have fallen into the pond.

6. At least 4 ring-type flotation devices attached to hand lines will be available in the pond area.

It should be emphasized that these safety rules are preliminary and will be modified as more information becomes available.

ACKNOWLEDGEMENT

This project draws the talent of many individuals at ANL and its success is the result of hard work of those individuals. Following is a list of some of the people and organizations that contributed significantly to the project.

Drs. J. J. Roberts, W. W. Schertz, Messrs. R. S. Zeno and G. S. Rosenberg supported and provided the funding for this project. Mr. D. D. Finucane, who served as the assistant project manager, assisted in preparing the initial technical specification of the pond and provided many invaluable services during the construction and initial operation of the pond. A number of technicians of the Components Technology Division helped during the construction of the pond. In particular, the effort of Messrs. A. Mele (who had a hard time keeping his shoes and clothes clean while working in the mud) and W. E. Brewer are appreciated. Mr. M. J. Featherstone designed and built the diffuser assembly and the vertical scanning system.

Professor S. L. Soo of the University of Illinois, and Professor C. E. Nielsen of Ohio State University provided consulting services during the design stage of the pond.

Special thanks go to Morton Salt Company of Chicago. A total of 800 tons of salt was donated. In addition, Morton Salt Company also paid a portion of the salt transportation cost. Mr. M. Eikleberry and Ms. M. Hunt of Morton Salt Company helped a great deal in making this transaction a pleasant one.

The contractor for the construction of the pond was MWM Contracting Corporation of Milford, Michigan. The excavation was done by Reinke Associated Services of Hinsdale, Illinois (under subcontract from MWM Contracting Corp.). Mr. D. T. Dillon of the Procurement Division handled smoothly all the legal and contractual matters related to this project.

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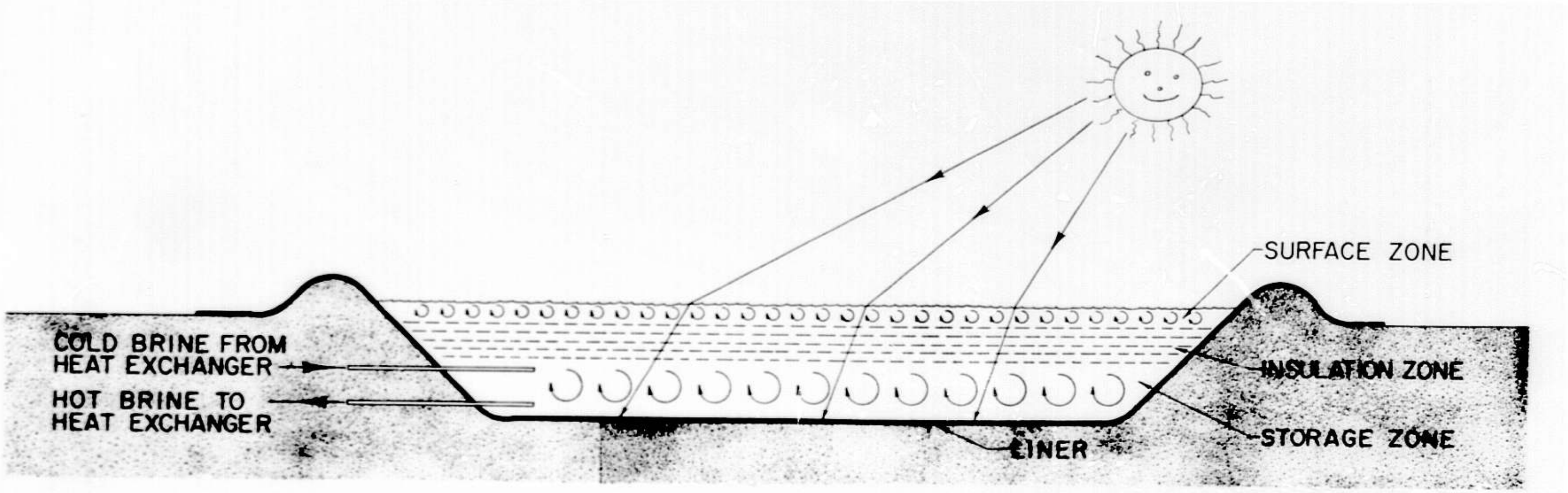
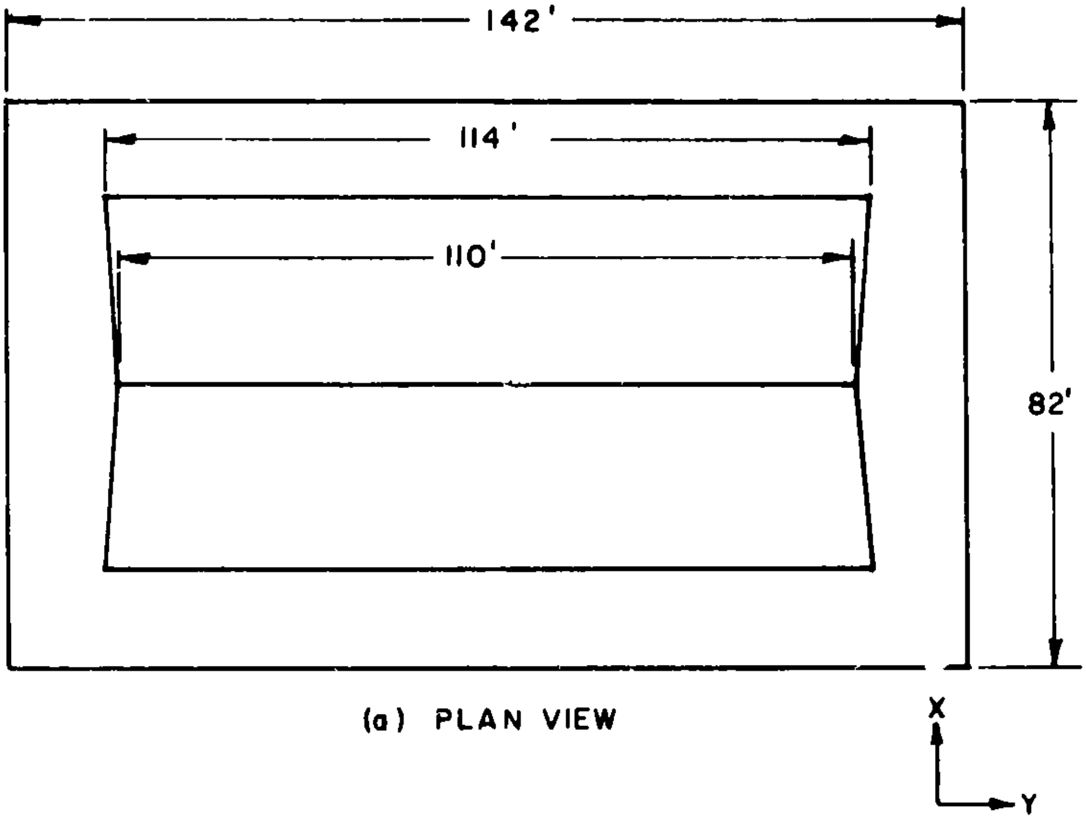
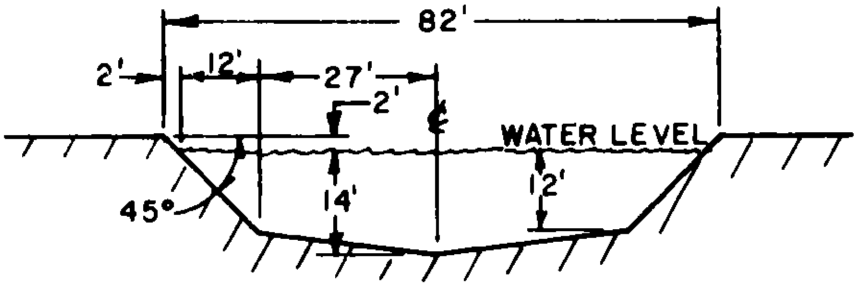


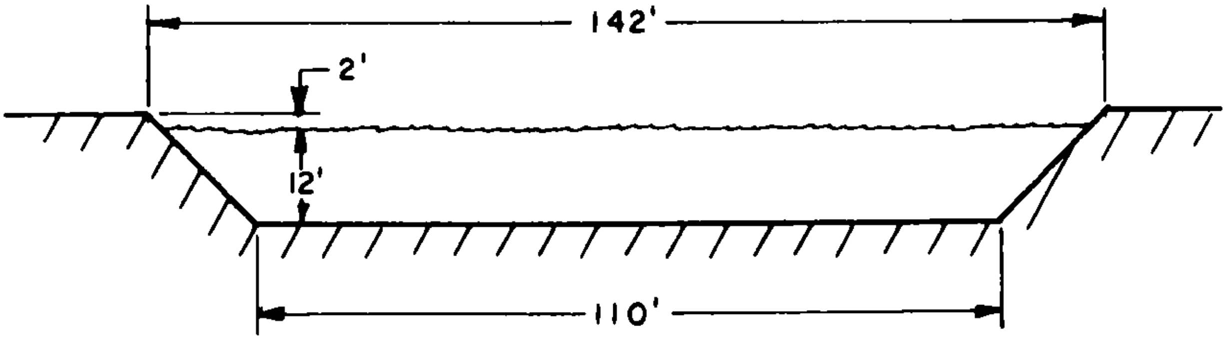
Fig. 1. Configuration of a Salt Gradient Solar Pond



(a) PLAN VIEW



(b) ELEVATION at X-Z Symmetry Plane



(c) ELEVATION at Y-Z Symmetry Plane

Fig. 2. Dimensions of the ANL Research Salt Gradient Solar Pond

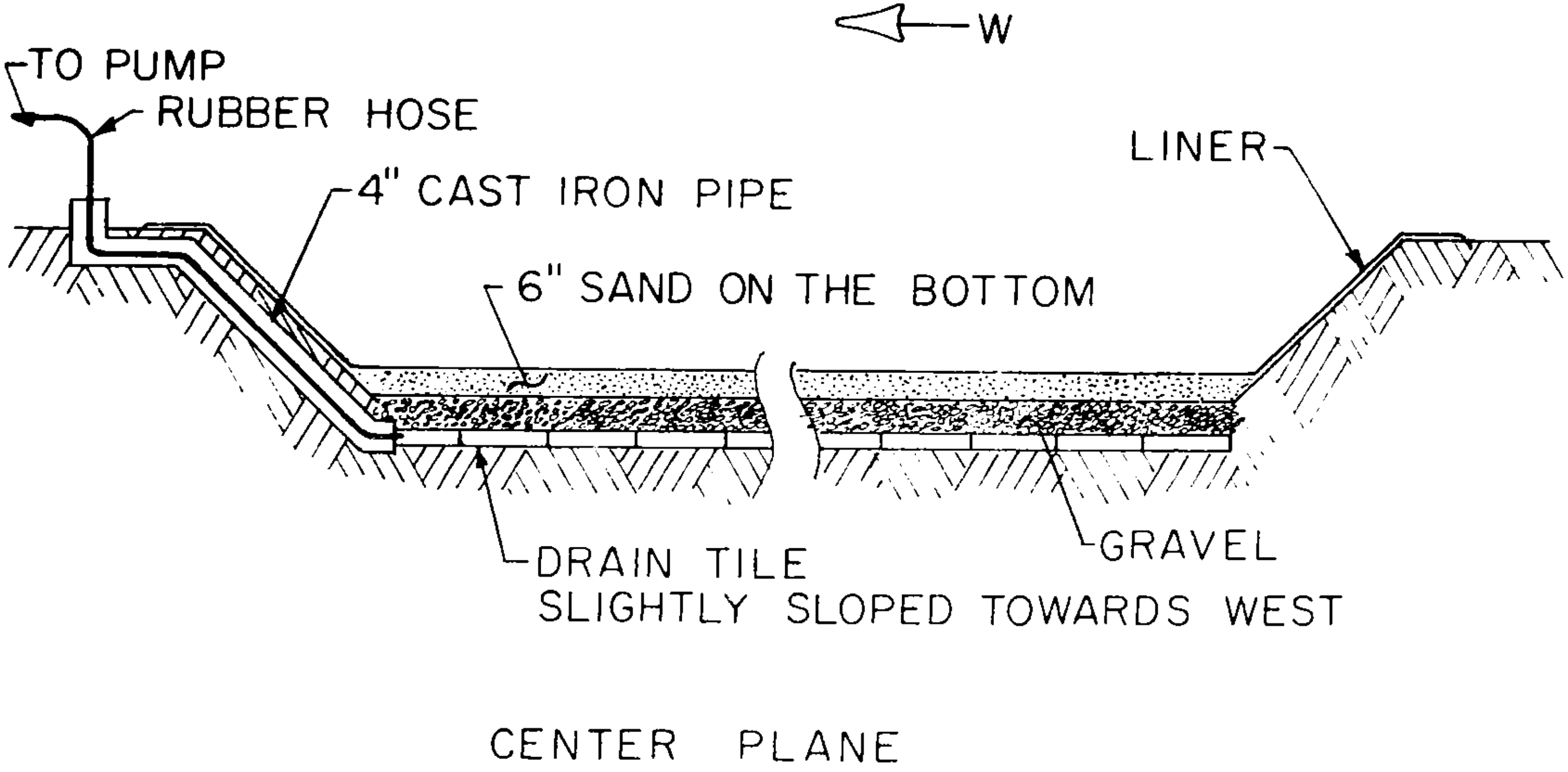


Fig. 3. Drain Tile System of ANL-RSGSP for Leakage Detection

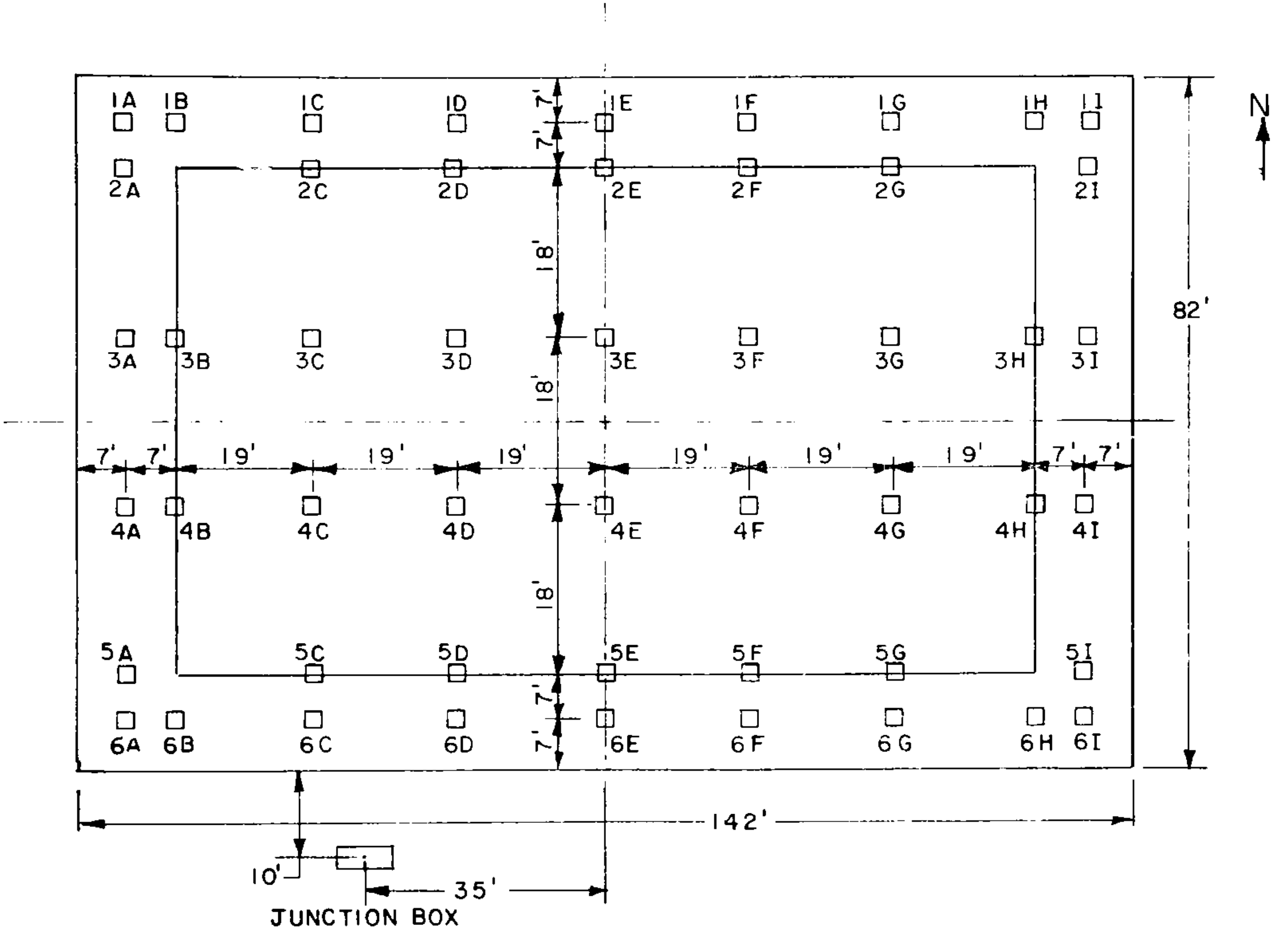


Fig. 4. Locations of Soil Conductivity Probes of the ANL-RSGSP

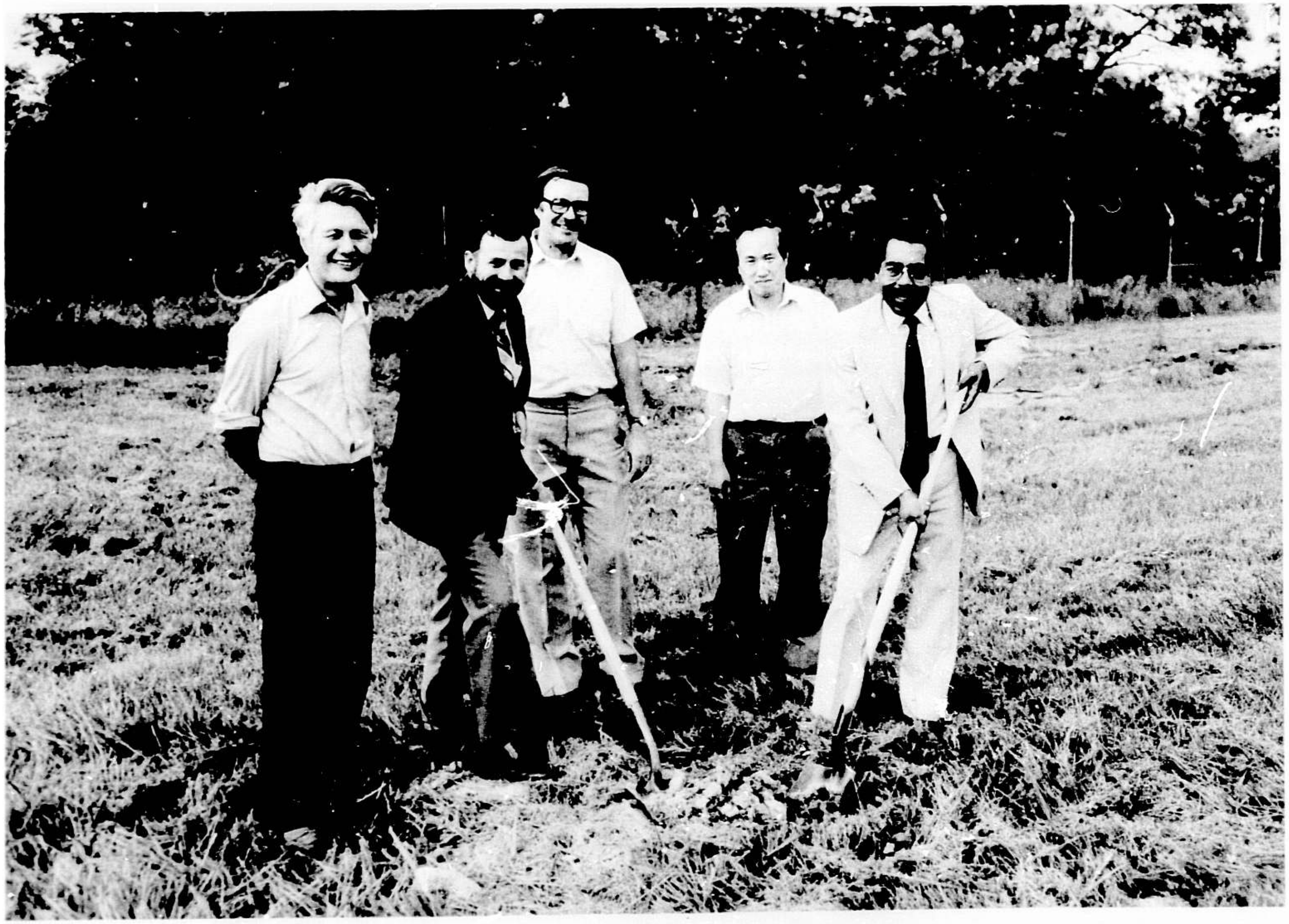


Fig. 5. Groundbreaking for Construction of the ANL-RSGSP (from left: W. T. Sha, Project Manager; W. W. Schertz, Program Manager, Solar Applications; P. R. Huebotter, Associate Director, Components Technology Division; Y. S. Cha, Principal Investigator; W. E. Massey, Laboratory Director)

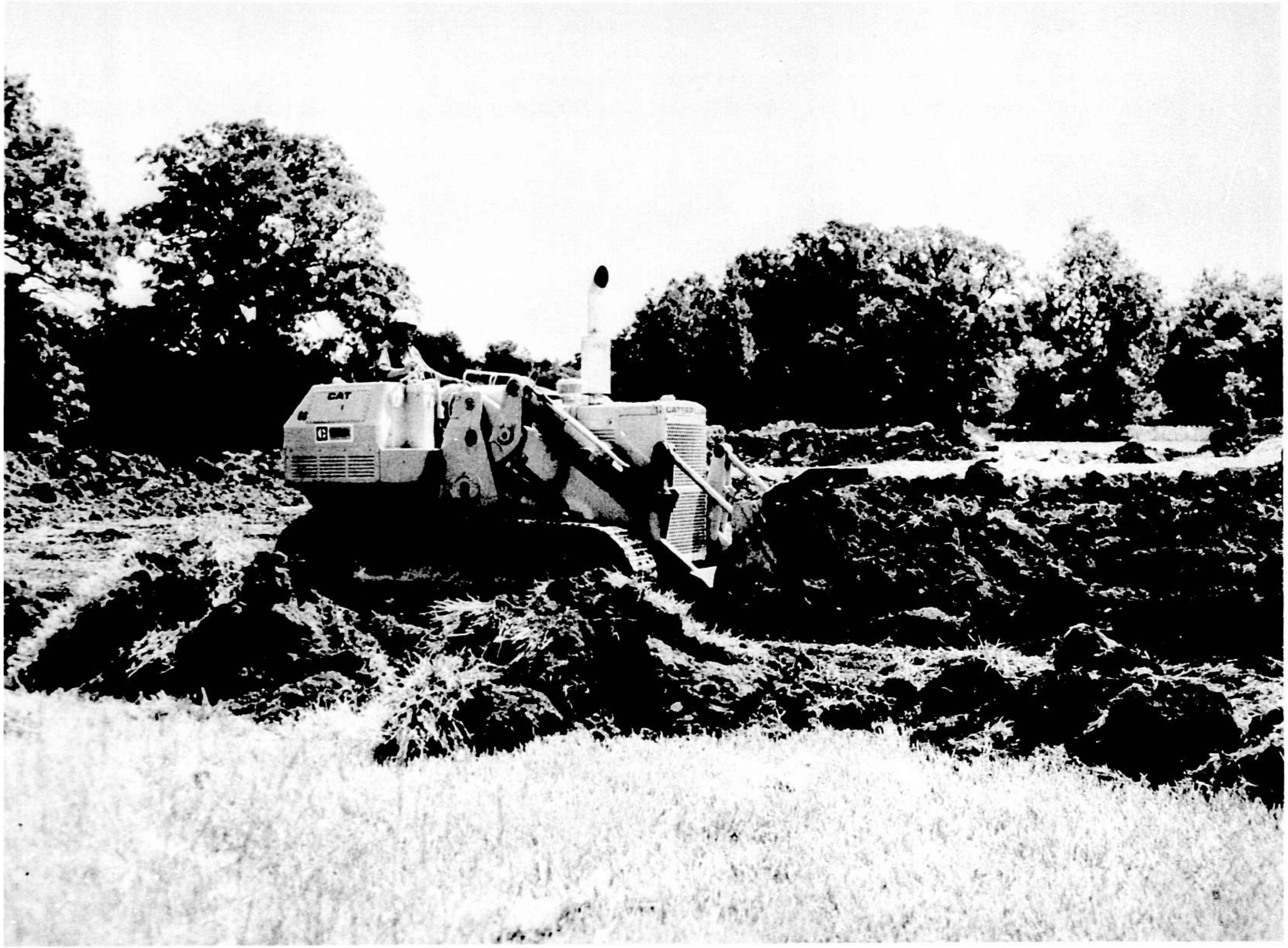


Fig. 6. Excavation Began, Front-end Loader at Work

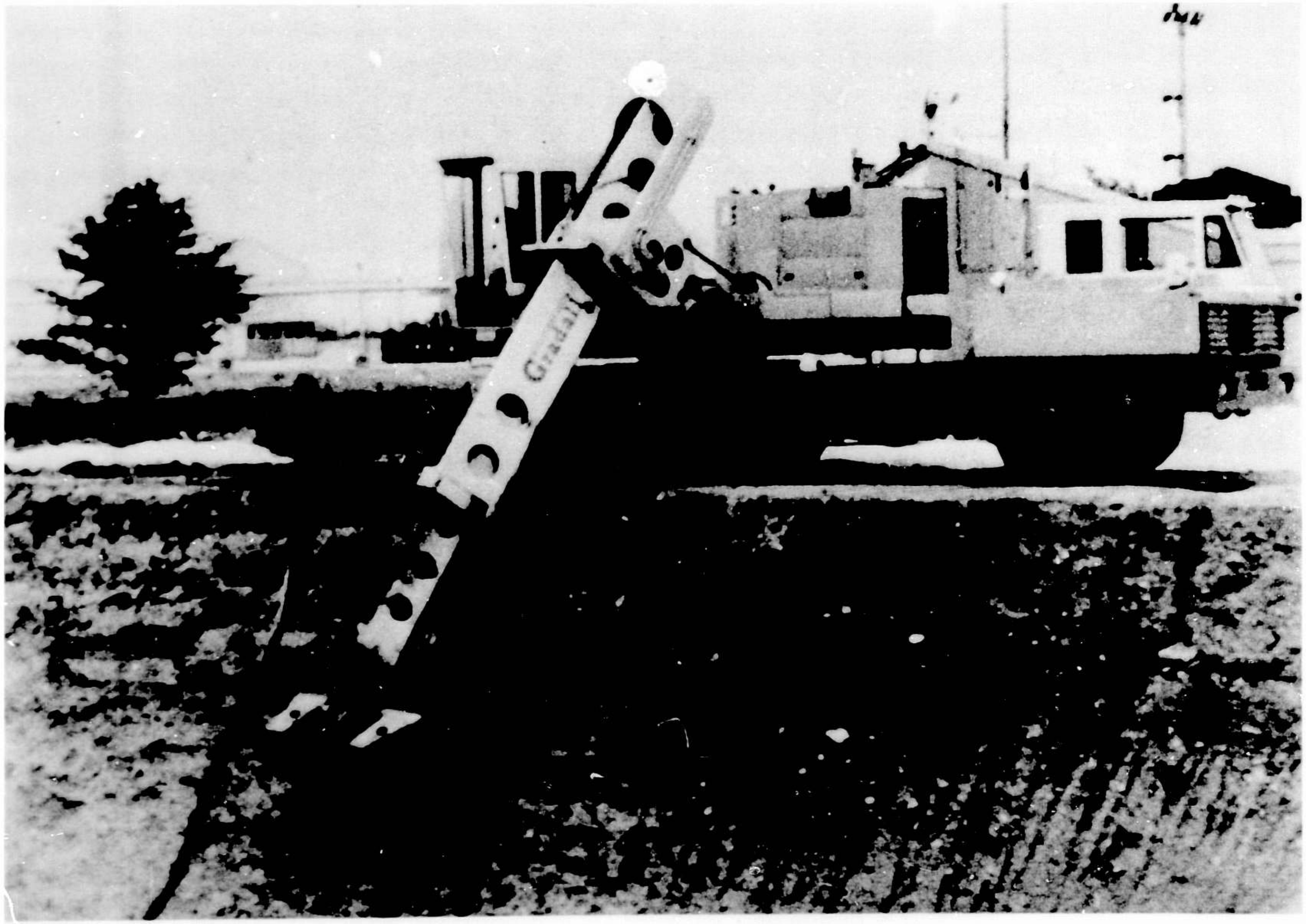


Fig. 7. Back-hoe Working on the Slope

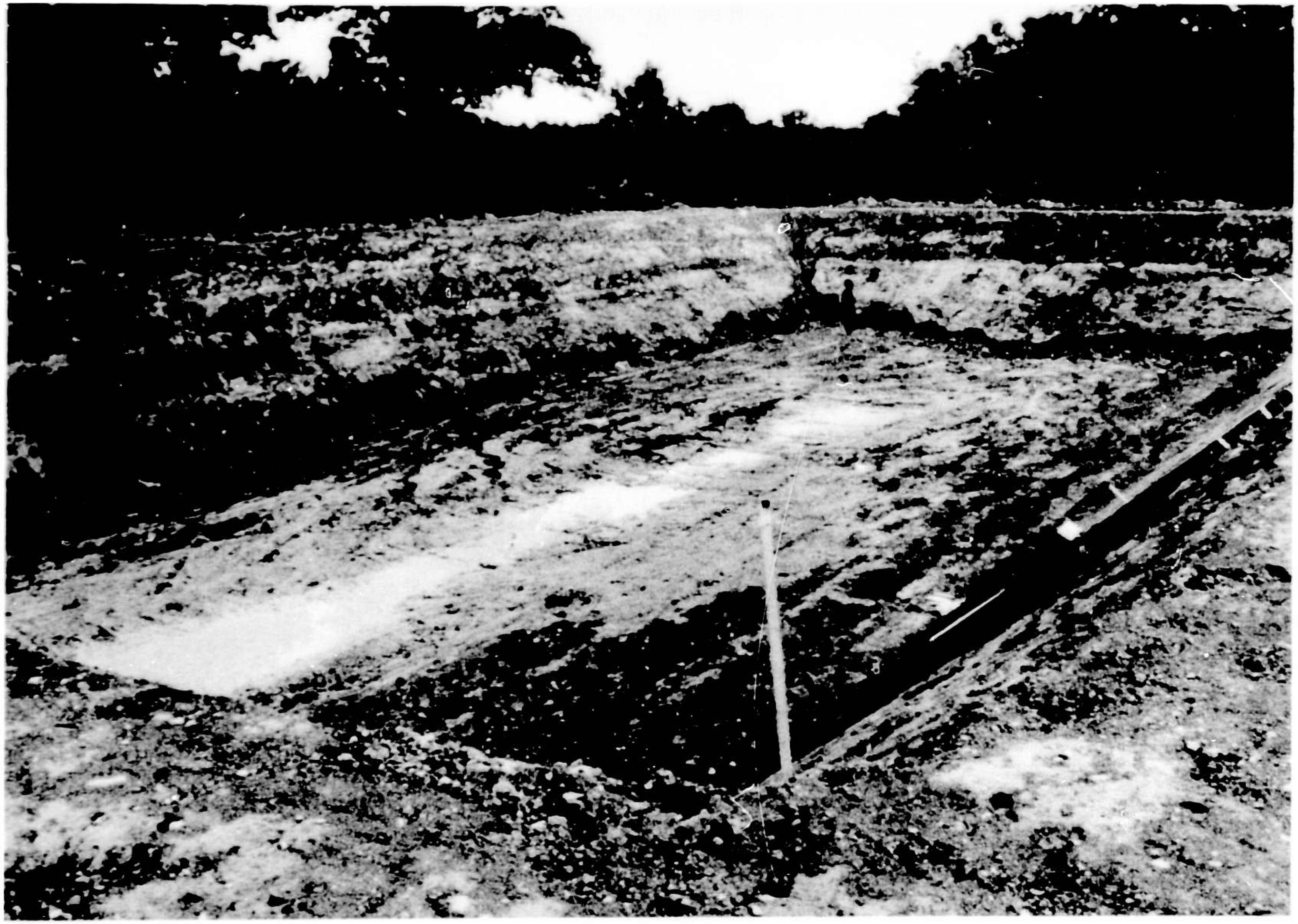


Fig. 8. Excavation Completed

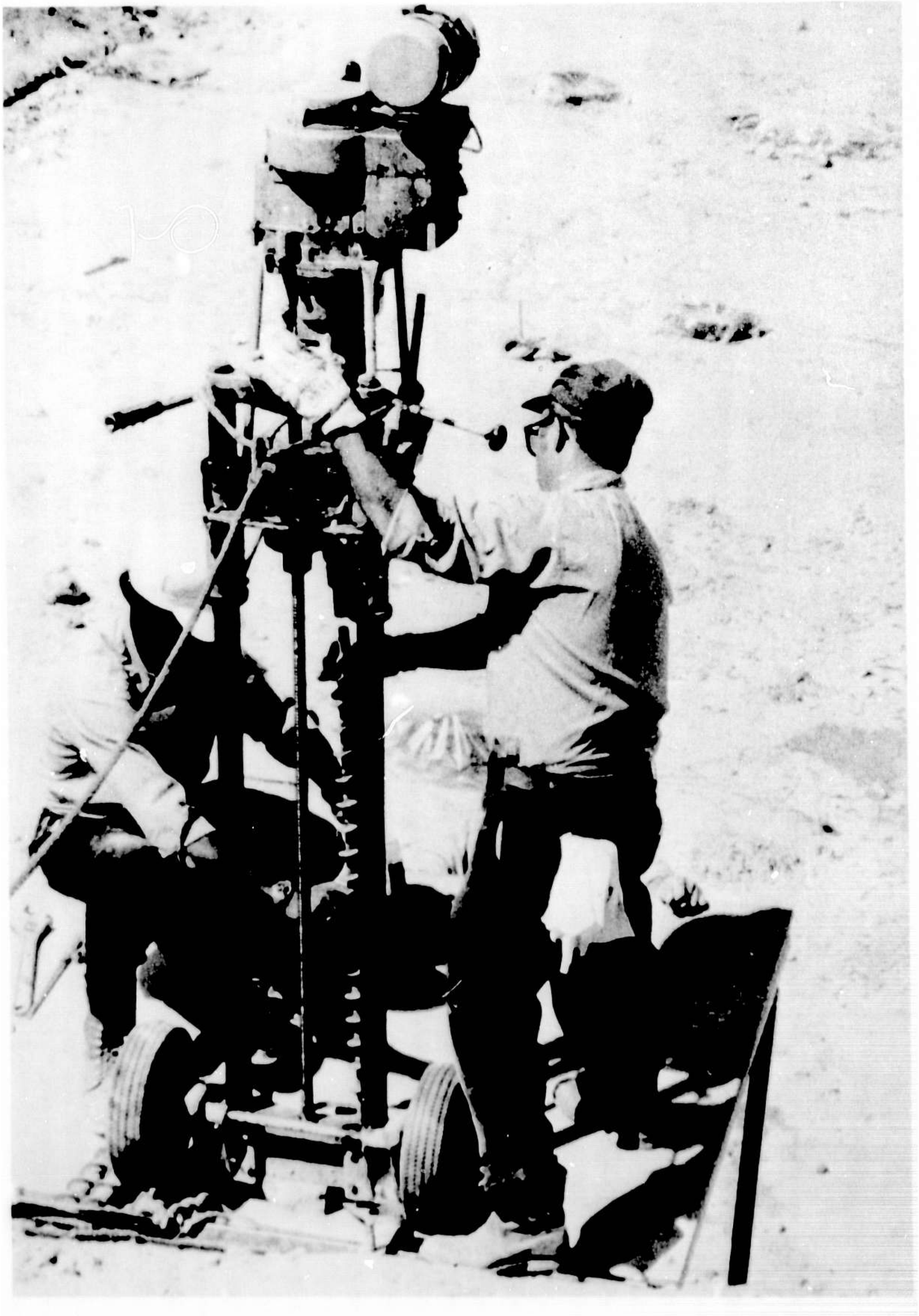


Fig. 9. Drilling on the Bottom of the Pond for Underground Thermocouples

Fig. 10. Drilling on the Slope of the Pond for Underground Thermocouples

Fig. 11. Plastic Sheets on the Slopes of the Pond to Prevent Rain Erosion during Construction

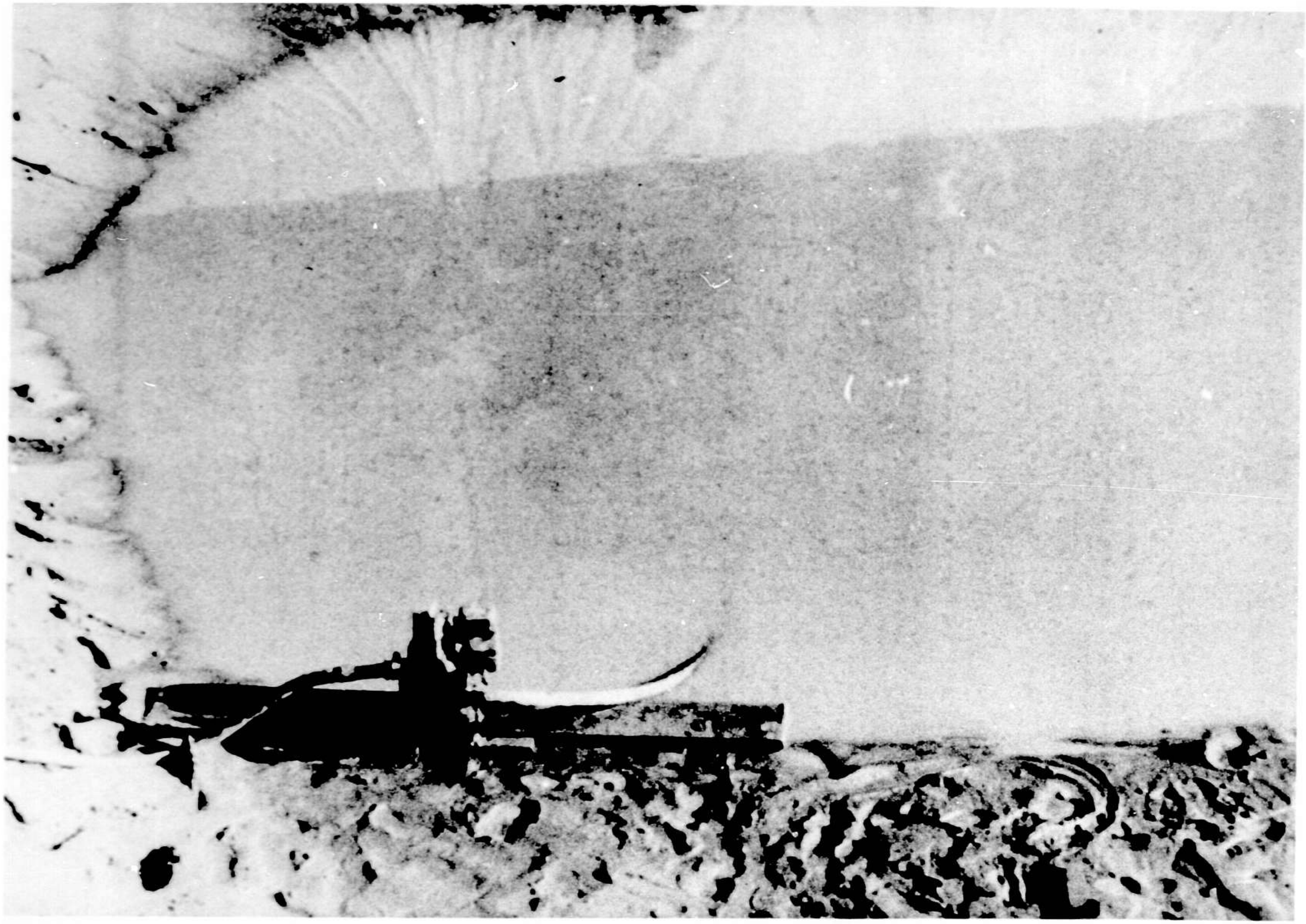


Fig. 12. Sump Pump and Accumulated Water at the Bottom of the Pond during Construction

Fig. 13. Removing Rocks and Roots from the Slopes of the Pond

Fig. 14. Sand Application at the Bottom of the Pond

Fig. 15. Unfolding the Liner on the West Bank of the Pond

Fig. 16. Liner Ready to Be Unfolded Across the Pond

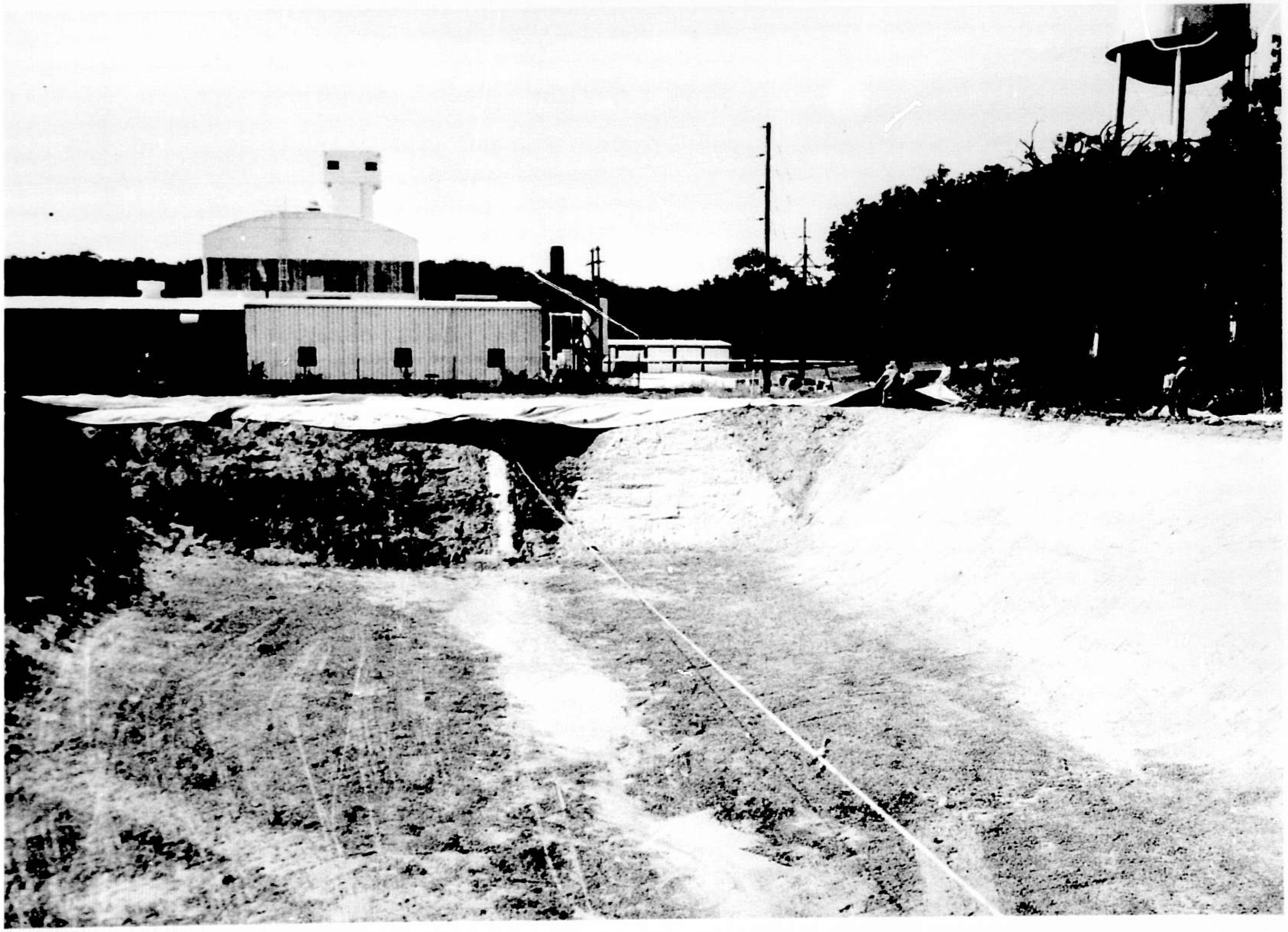


Fig. 17. Front-end Loader Beginning to Pull the Liner Across the Pond

Fig. 18. Another View of Liner Unfolding

Fig. 19. Two-thirds of the Pond Covered with the Liner

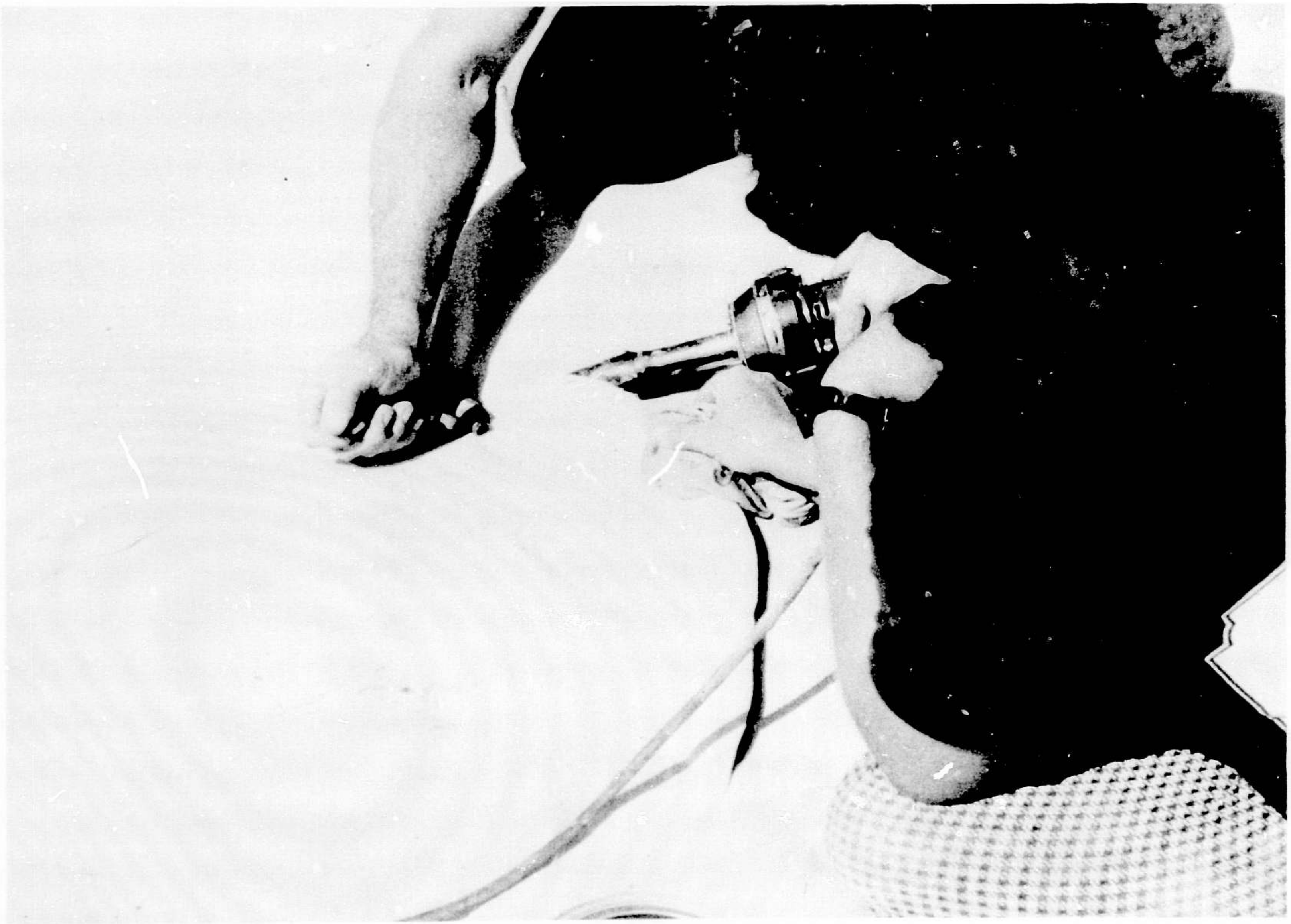


Fig. 20. Performing Field-Seam (Thermal) for the Center Cut

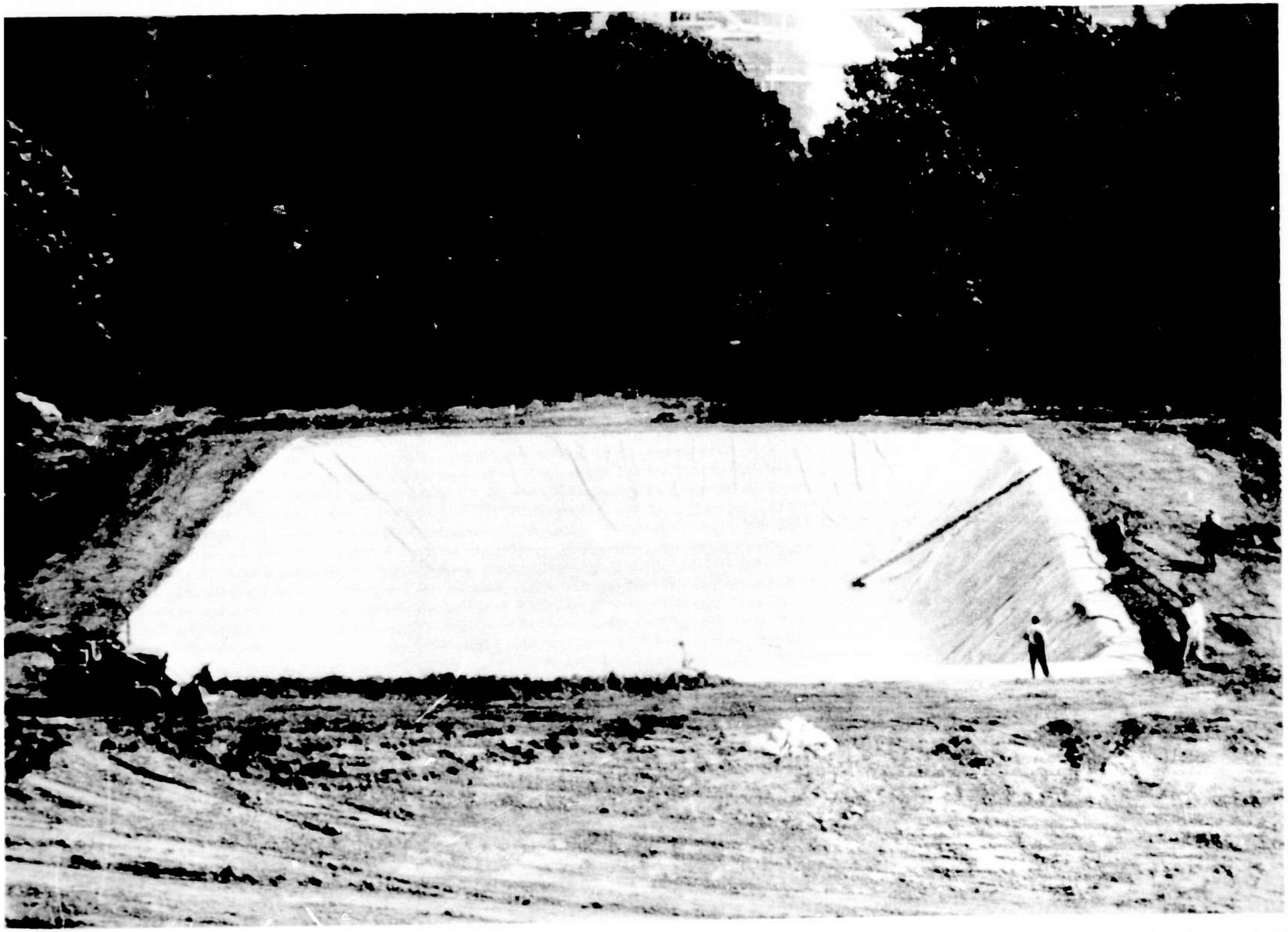


Fig. 21. Liner Completely in Place

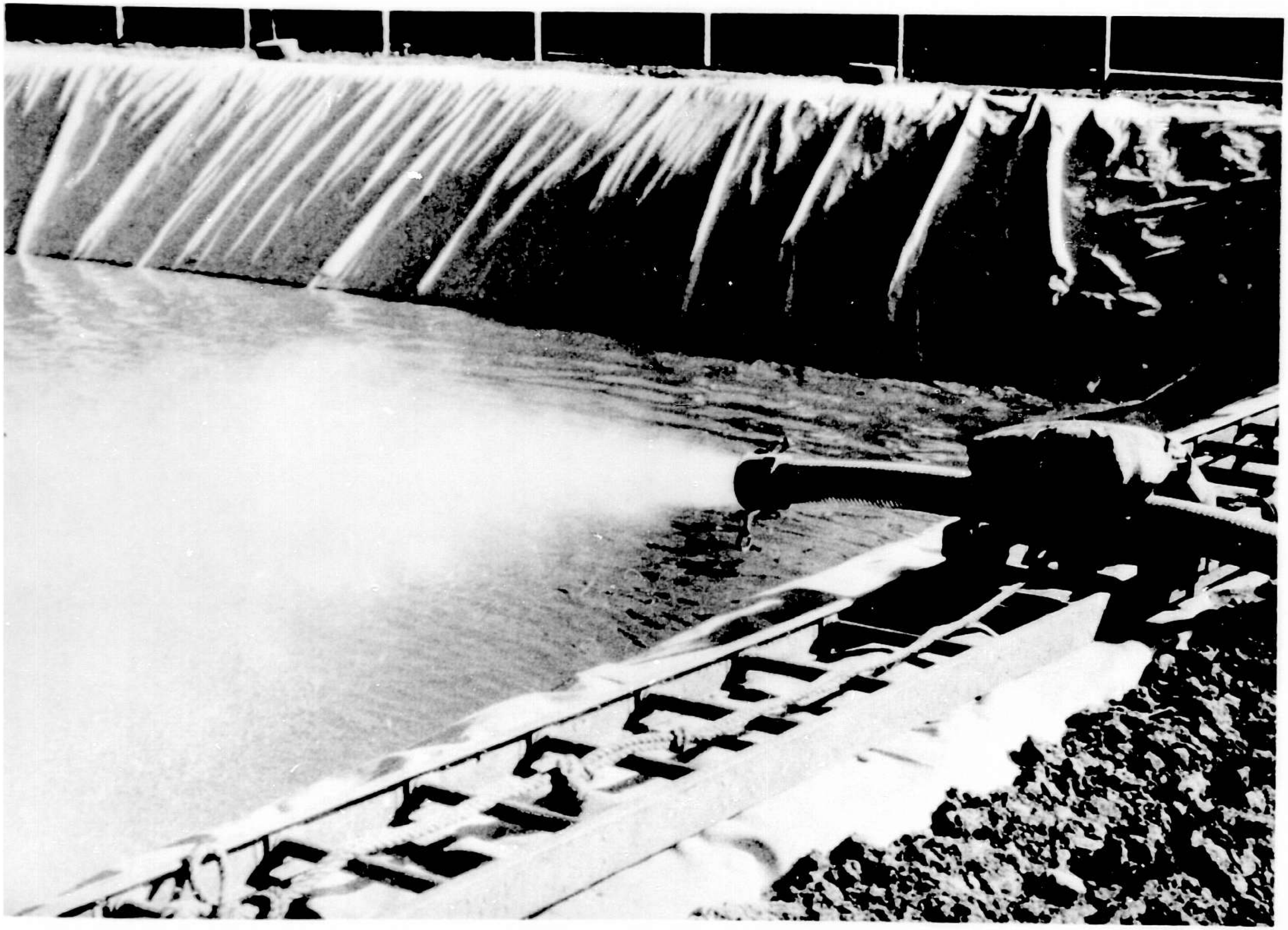


Fig. 22. Salt Injection Using the Air-Hose System

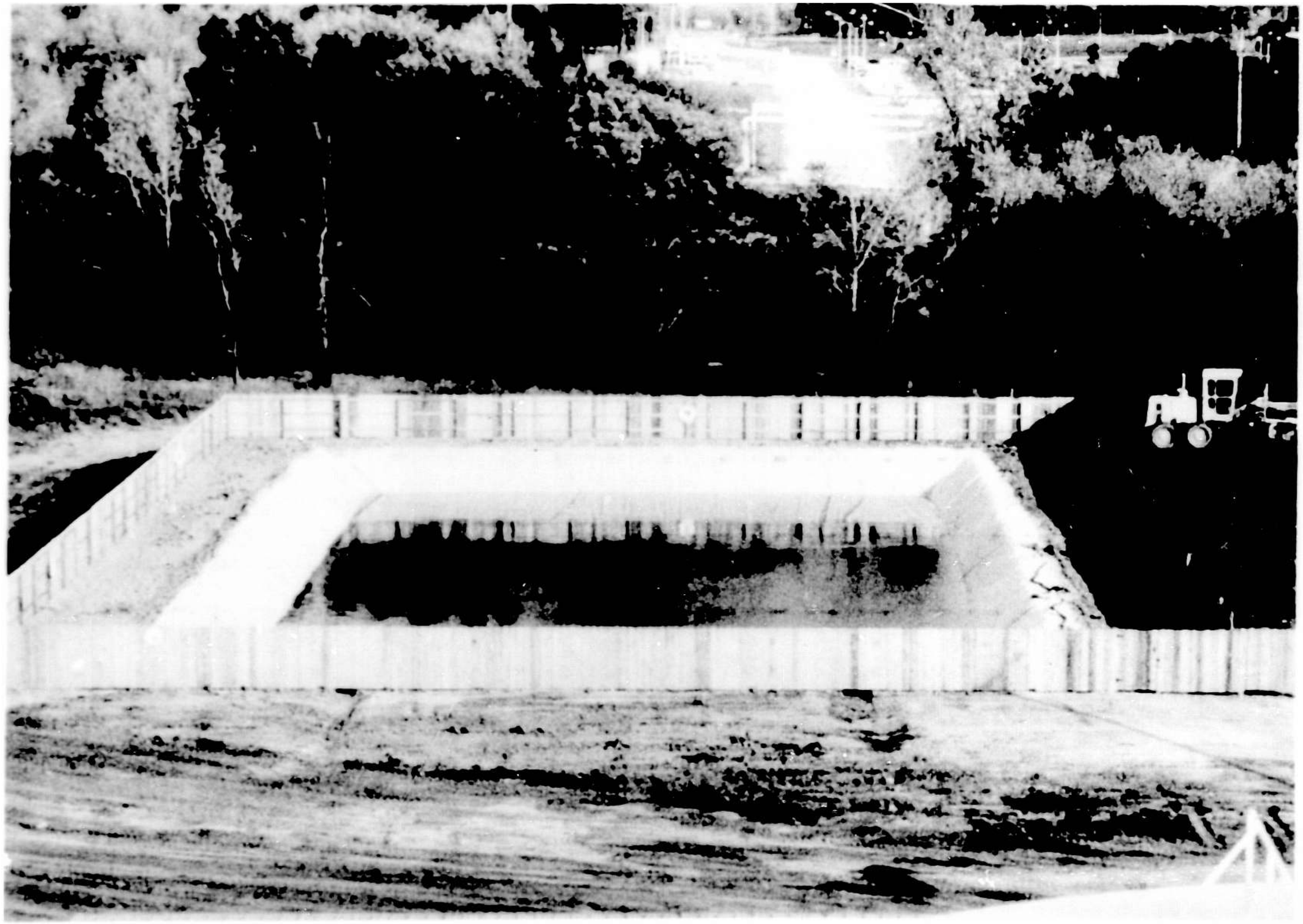


Fig. 23. An Entire View of the ANL-RSGSP

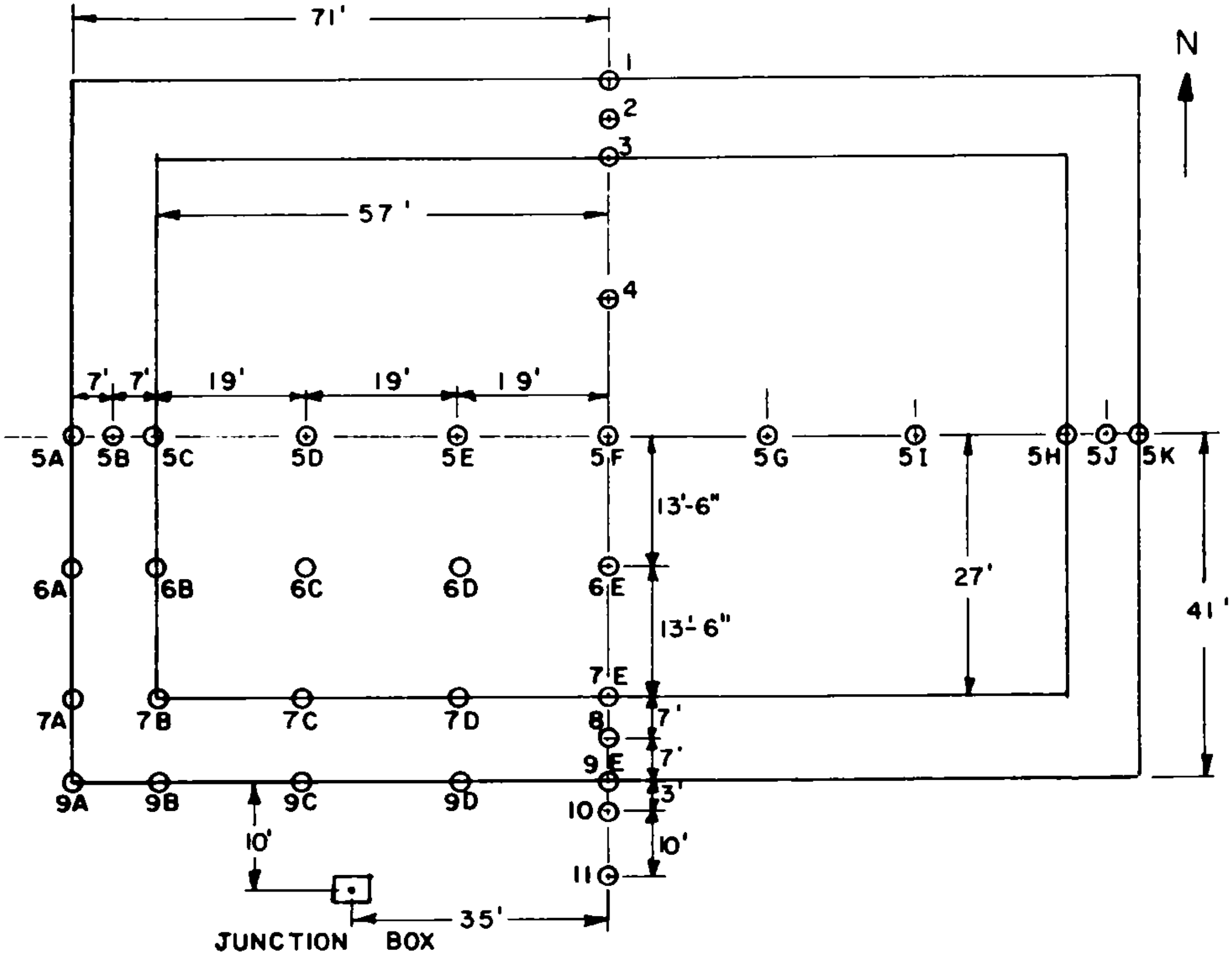


Fig. 24. Locations of the Underground Thermocouples of the ANL-RSGSP

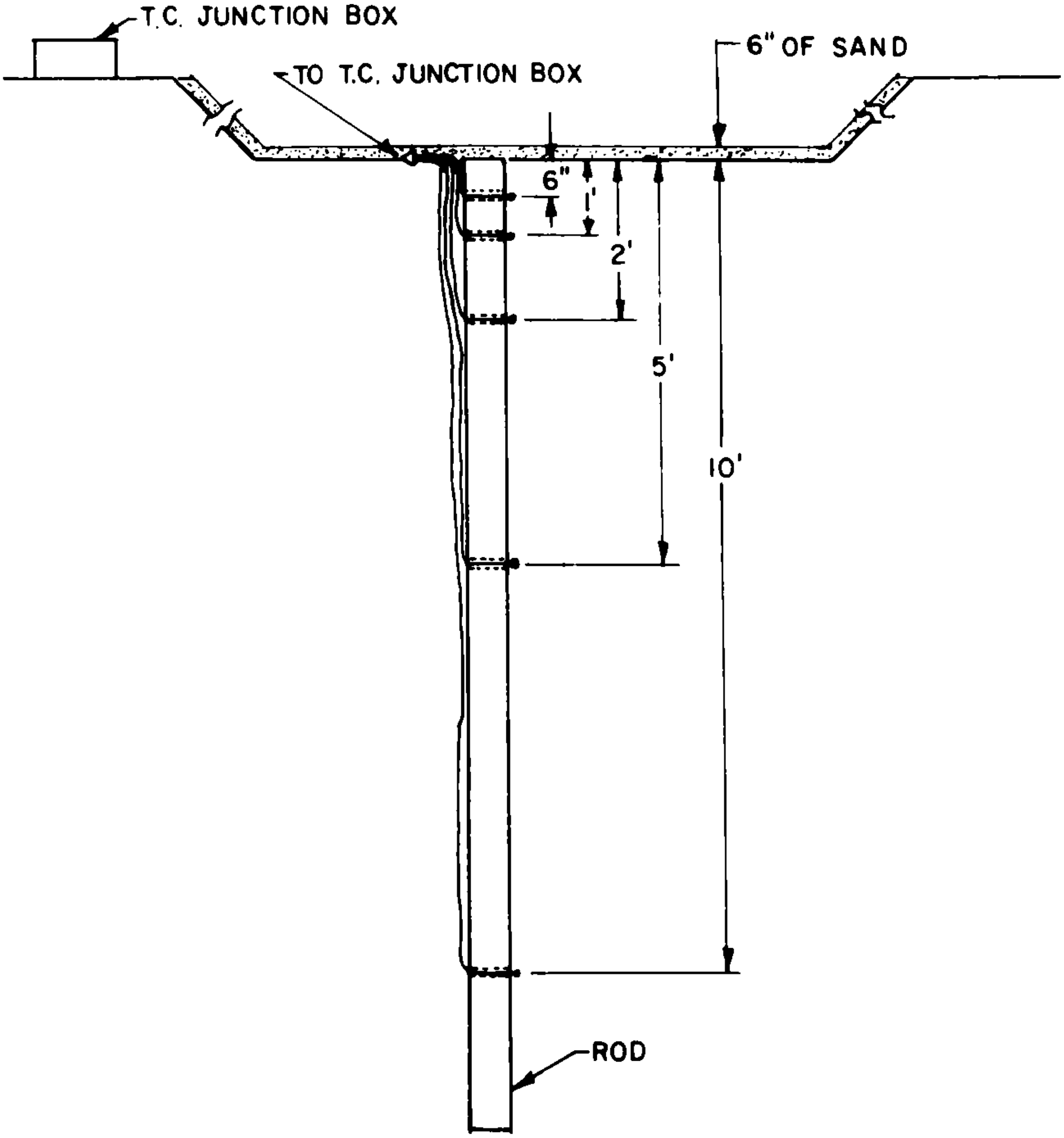


Fig. 25. Vertical Spaces Among Underground Thermocouples (Typical for Each Location Shown in Fig. 24)

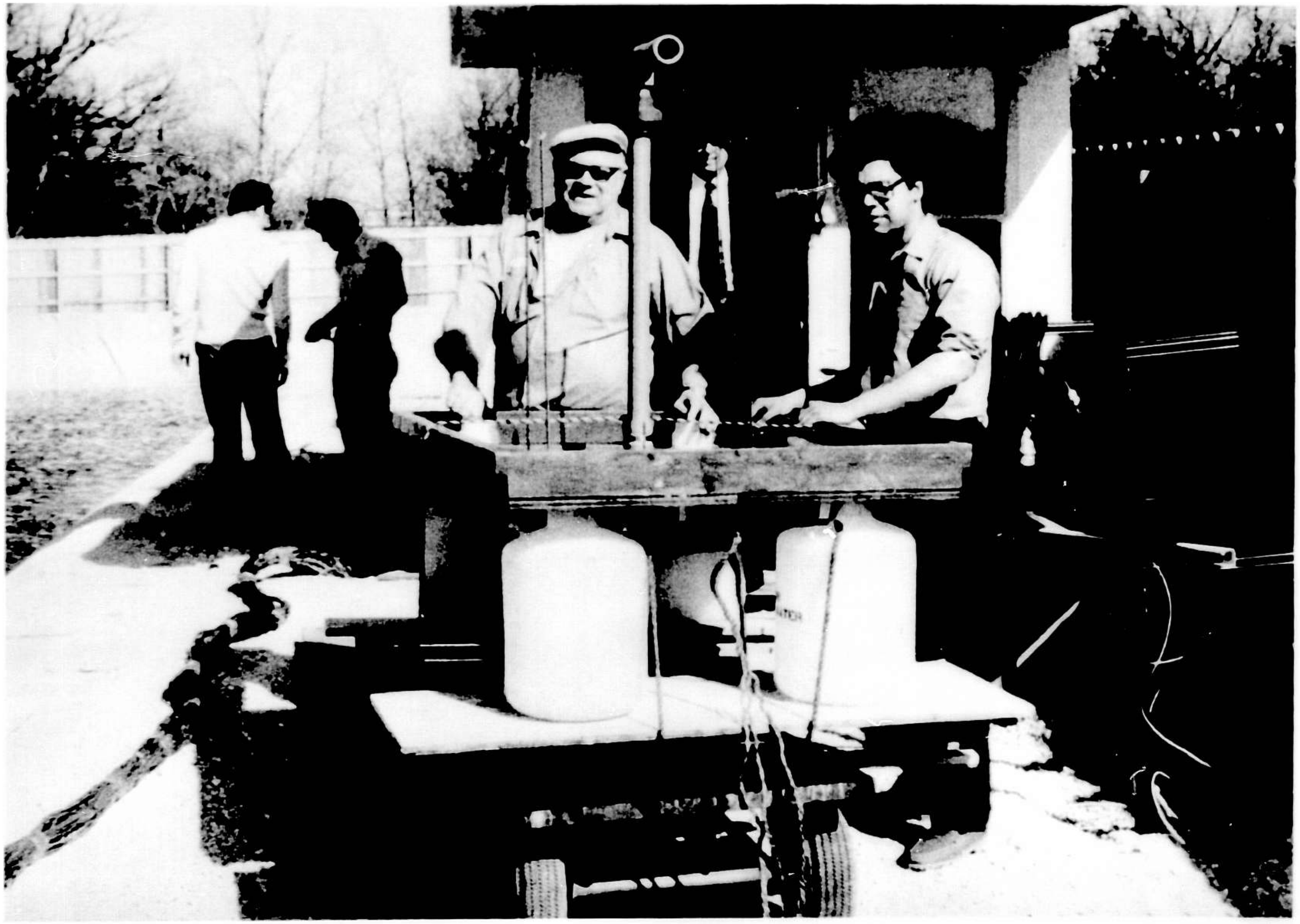


Fig. 26. Diffuser Assembly

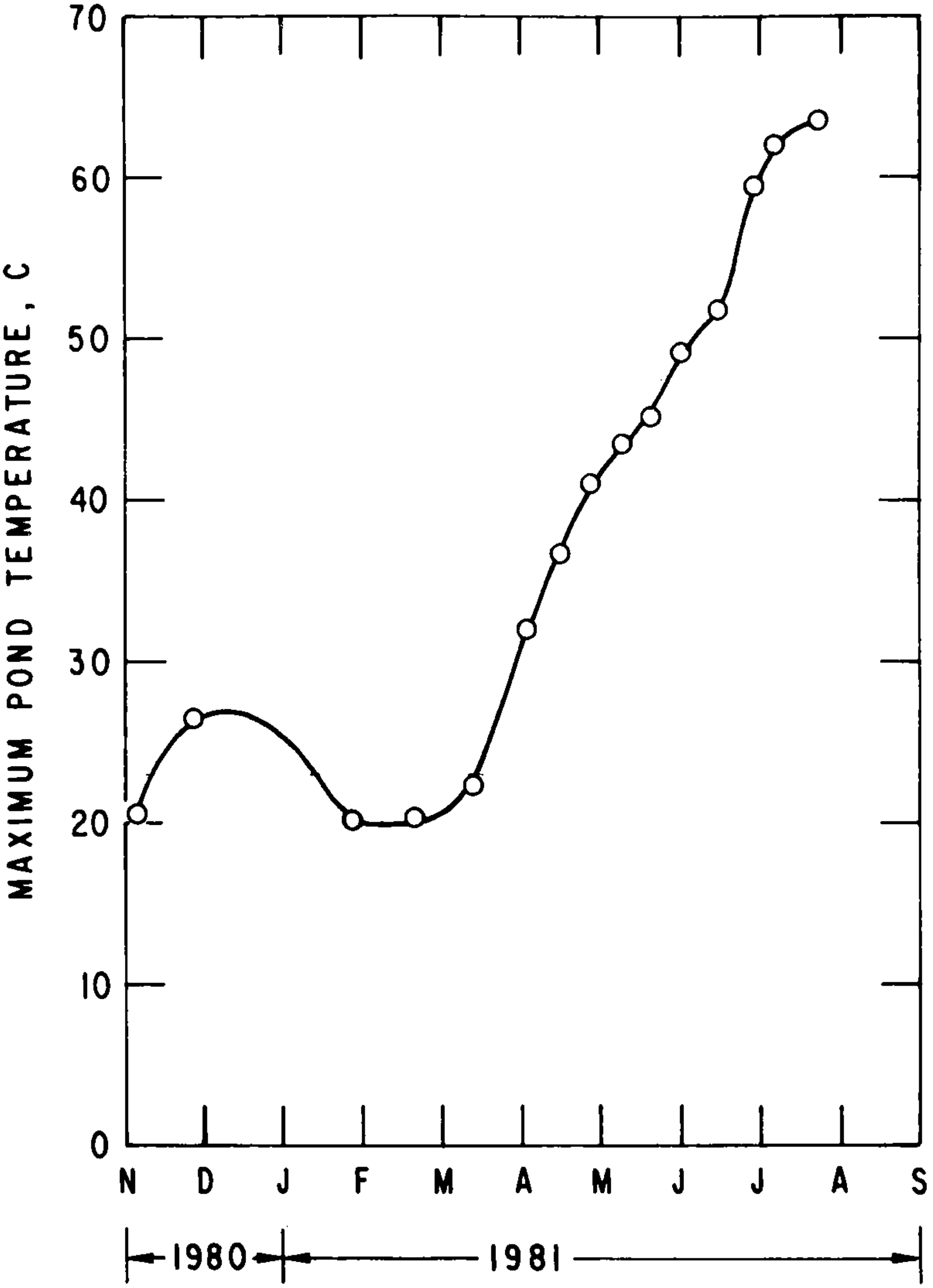


Fig. 27. Variations of Maximum Pond Temperature during 1980-1981

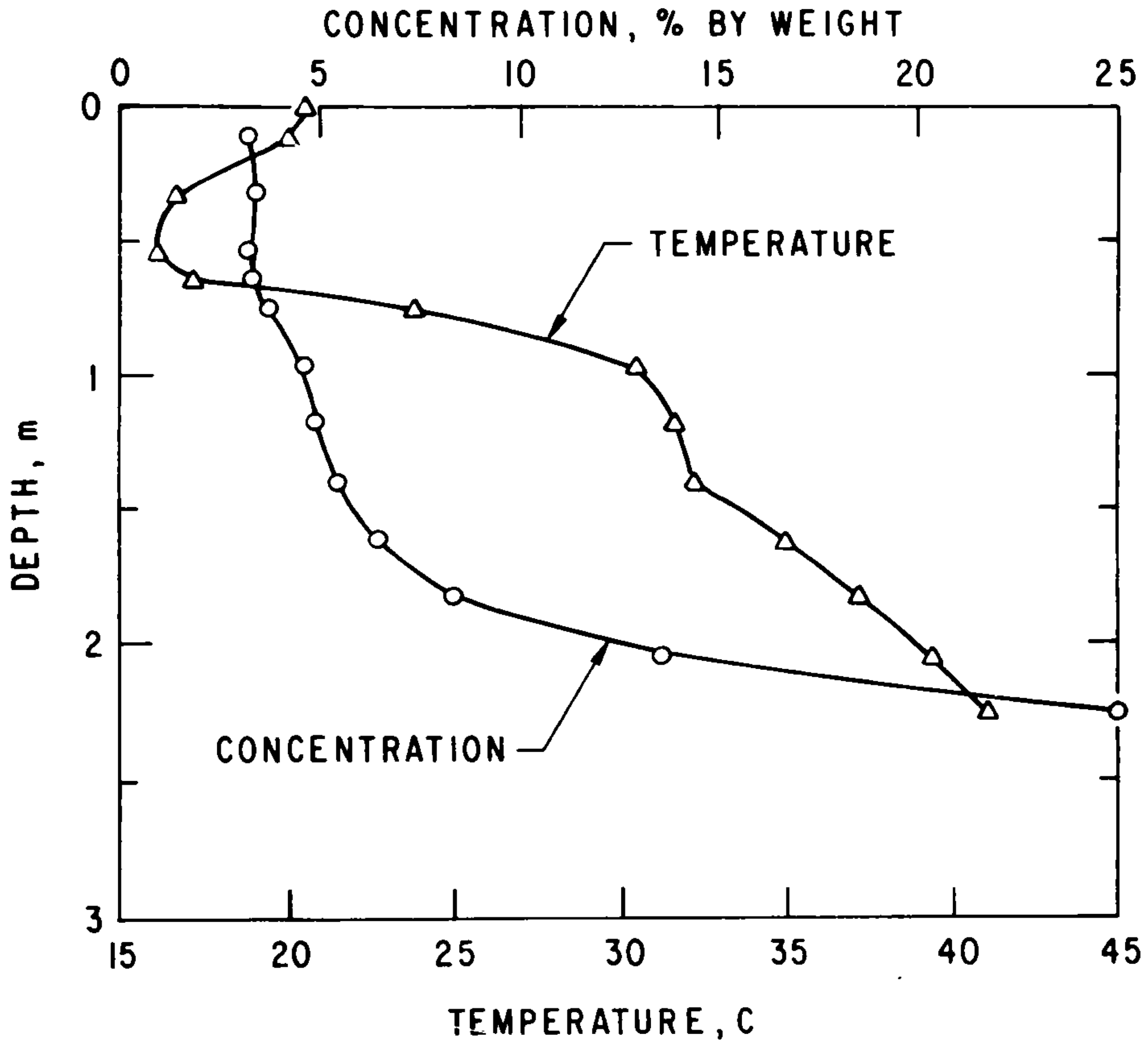


Fig. 28. Vertical Temperature and Concentration Profiles of the ANL-RSGSP on April 27, 1981

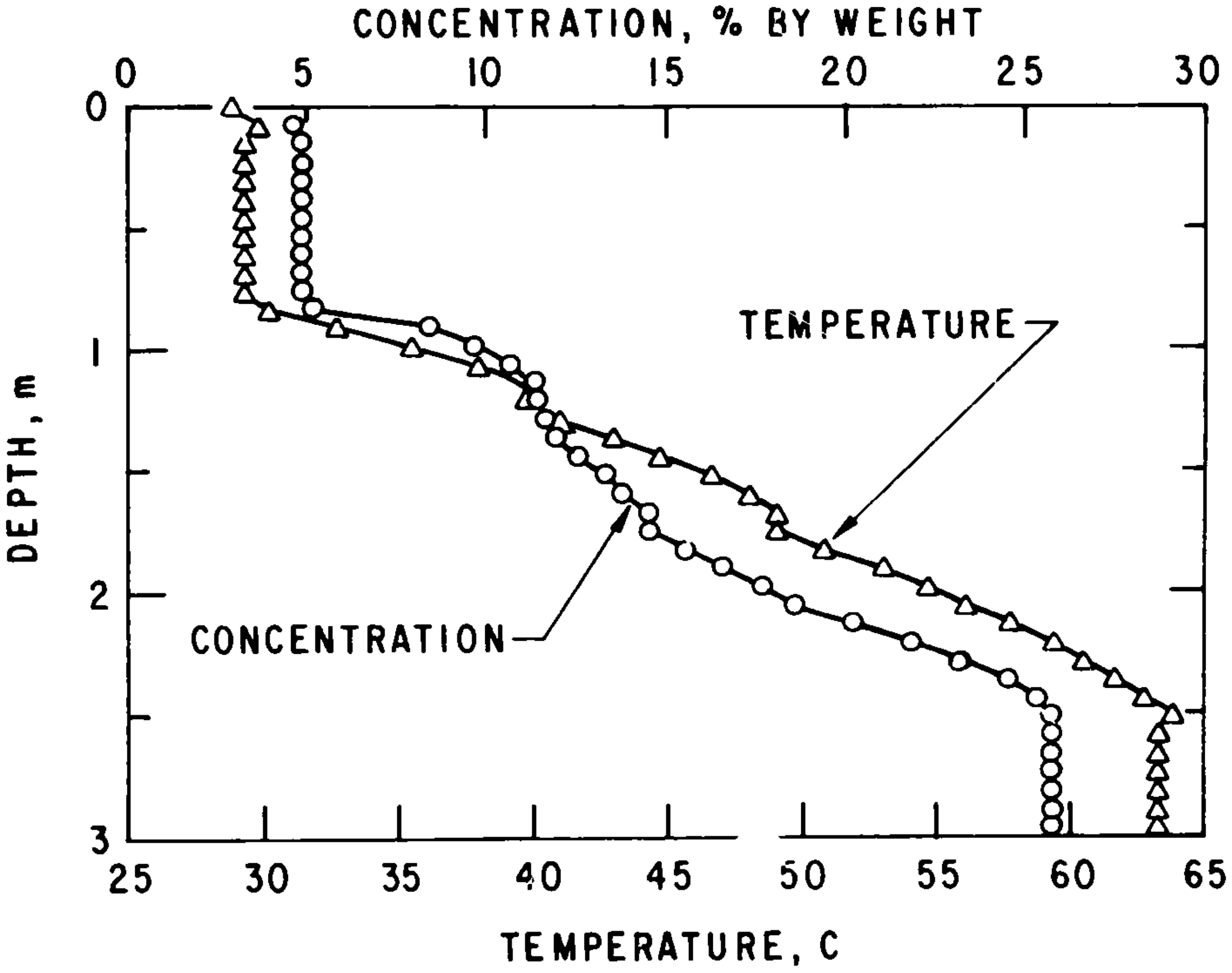


Fig. 29. Vertical Temperature and Concentration Profiles of the ANL-RSGSP on July 20, 1981