DEEP DRILL STATUS REPORT

Mark A. Wumkes

Field Engineer

PICO
Polar Ice Coring Office

Polar Ice Coring Office
University of Alaska Fairbanks
Fairbanks, Alaska 99775-1710

PICO
TR-90-2

November 1990

* PICO is operated by the University of Alaska Fairbanks under contract to the National Science Foundation, Division of Polar Programs.

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PREFACE

The purpose of this report is to review the progress of the PICO Deep Drill development, as designed for the GISP2 project. It examines the concepts and procedures that were implemented in the 1990 GISP2 field season in central Greenland.

This report presents an evaluation of the drill's performance as well as providing a number of solutions to the problems that were identified. It describes the steps necessary to refine the design so that it will perform as expected in the 1991 drill season, as well as the test schedule that will be necessary to prove the effectiveness of these modifications.

John J. Kelley
Director

I. INTRODUCTION

The 1990 GISP2 drilling season began 11 June 1990 and ran until 7 September 1990. During this time the entire drill and drill handling system were constructed. (Fig. 1) This consisted of, among other things, a 33-meter high twin tower assembly, the carousel drill handling system, the drill fluids handling and recovery systems, the ventilation system, as well as the core-handling line where the core was extracted and initially logged. Also installed was 77-meters of 25-centimeters diameter drill casing. All of these components are housed inside a 17-meter diameter geodesic dome.

These construction tasks were completed in two stages. Stage 1 was aimed primarily at achieving the tasks necessary to put the drill into position producing dry core. Stage 2 was primarily for the purpose of preparing the drill for wet drilling.

Dry drilling began 6 July, ended 13 July, and produced core to a depth of 131.6 meters. Wet drilling began 2 August ended 25 August and produced core to a depth of 335.2 meters. The period of wet drilling also acted as a testing ground for the actual performance of butyl acetate as a drilling fluid. Butyl acetate was found to be a safe, workable drill fluid. Its levels in the dome and science trench were kept well below the threshold limit values as defined by OSHA. This is quite important in that it replaces the types of drilling fluids used in the past which have characteristically contained dilute solutions of PBBE (polybrominated biphenyl ether), a known carcinogen.

Although the depth reached in the 1990 drill season was not that which was expected, it can still be safely stated that the drill was a success. A number of minor problems plagued the drilling procedure. The problems themselves were not serious, but were not curable in the field. These will be discussed further as well as the solutions that will be implemented.

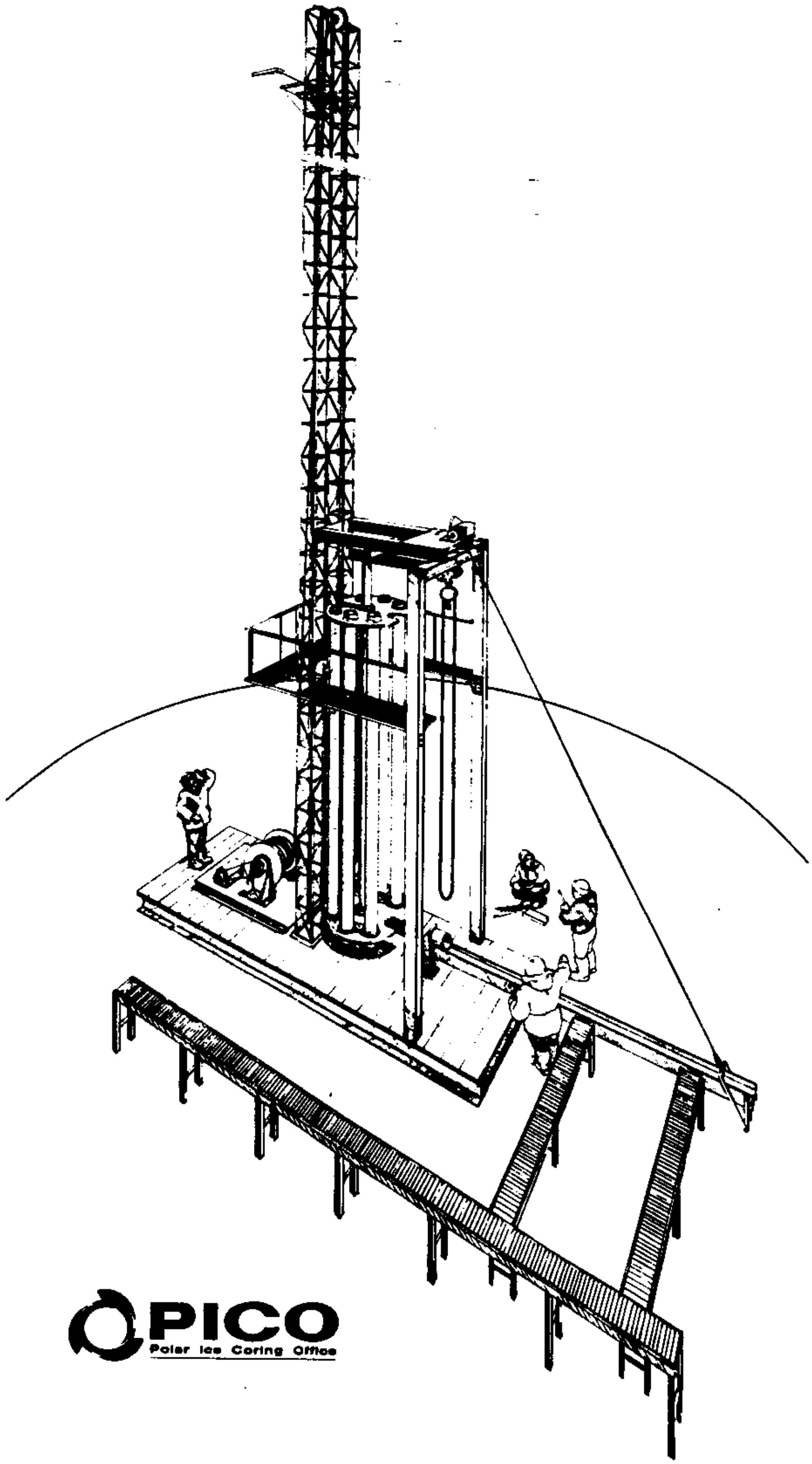

Figure 1. PICO 5.2 inch wet coring drill and handling system.

II. PROBLEMS ENCOUNTERED DURING 1990 GISP2 SEASON

There were three areas of the drill that caused the problems encountered in the 1990 drilling season. These were the anti-torque springs, the couplings, and the drill head itself. The solutions to these problems were evident while still in the field but, due to their nature, could not be dealt with there.

Probably the most important improvement that will be made to the drill string will be a redesigned anti-torque assembly. This keeps the drill from spinning in the borehole while core is being taken. It was the major limiting factor in core production. The drilling process was slowed down considerably in an effort to keep the antitorques from spinning. Once the antitorques had spun, the drill process was slowed even further due to the great care needed to drill past the section where the antitorques had spun and enlarged the borehole.

The anti-torque springs added another factor that made drilling rates difficult to control. They did not travel down the borehole in a smooth, steady manner; rather, they slid down in jerks. This resulted in a feedback mechanism that caused the drill to dig in when the anti-torques slid down unevenly. The drill would cut until it took enough core to weight the cable and overcome the vertical friction of the anti-torques. The drill string would then slip down the borehole and the cutters would grab, spinning the drill. This uneven downward travel was working in conjunction with another problem that made itself evident during the drilling season. The drill head itself was not tuned to match the penetration rates of drilling that the anti-torques were capable of holding.

The drill-head penetration shoes, which control the rate of cutting, were not matched to the anti-torques. The penetration shoes that we had were too aggressive and as a result the anti-torques could not hold the drill from spinning. In a normal drill operation, the penetration rate is controlled by the penetration shoes on the head, which limit the depth of cut that the drill makes. As a result, the penetration rate was controlled by the winch cable alone.

Only one type of cutter shoe was available this season. It had a penetration angle of 1.2 degrees. This caused too heavy a cut, which the anti-torques could not hold. With only one penetration shoe angle to choose from, the head could be tuned only by using shims to alter the clearances between the cutter and the penetration shoe. This proved to be awkward and did not offer a permanent solution. Different combinations testing the best angles to use were tried, but no combination was effective.

Another factor that contributed to the nature of the cutter geometry was the sharpening process of the cutters themselves. As material is removed from the cutter during sharpening, it decreases the clearance between the cutter and the penetration shoe, decreasing the penetration angle, thereby taking a lighter cut. This is an inherent design limitation that cannot be altered without changing the design of the head itself.

The third problem area discovered during the drill season was the restrictive chip path at the bottom of the screen sections. This caused problems with removal of the chips after every run. The chips were removed with a vibrator and a wash system. The wash system, using a series of nozzles spraying butyl acetate, proved ineffective. The vibrator proved to be effective when used by itself but, due to the slightly restrictive chip path, tended to clog at the bottom of the screen. This was solved in the field by removing the coupling from the screen section after every run and by turning on the vibrator. With a free chip path, the vibrator was effective in removing all the chips from the screen.

III. MODIFICATIONS TO THE 5.2 INCH WET DRILL

A. ANTI-TORQUE SYSTEM

The most important modification to the drill for the 1991 field season will be an improved anti-torque system. Several designs have been developed and approved for testing at the CRREL test facility between January and February 1991. All of the antitorque designs will be interchangeable with existing hardware (Fig. 2). This will allow several configurations in the field to adapt the drill to varying ice conditions.

The new antitorque designs will incorporate wheels and skates. This will allow the drill to travel more smoothly down the borehole and offer greater resistance to rotation. All designs will be tested at the UAF coldroom facility to determine their relative effectiveness before being tested at CRREL. All design and fabrication will be done at UAF so that PICO engineering can monitor progress and development.

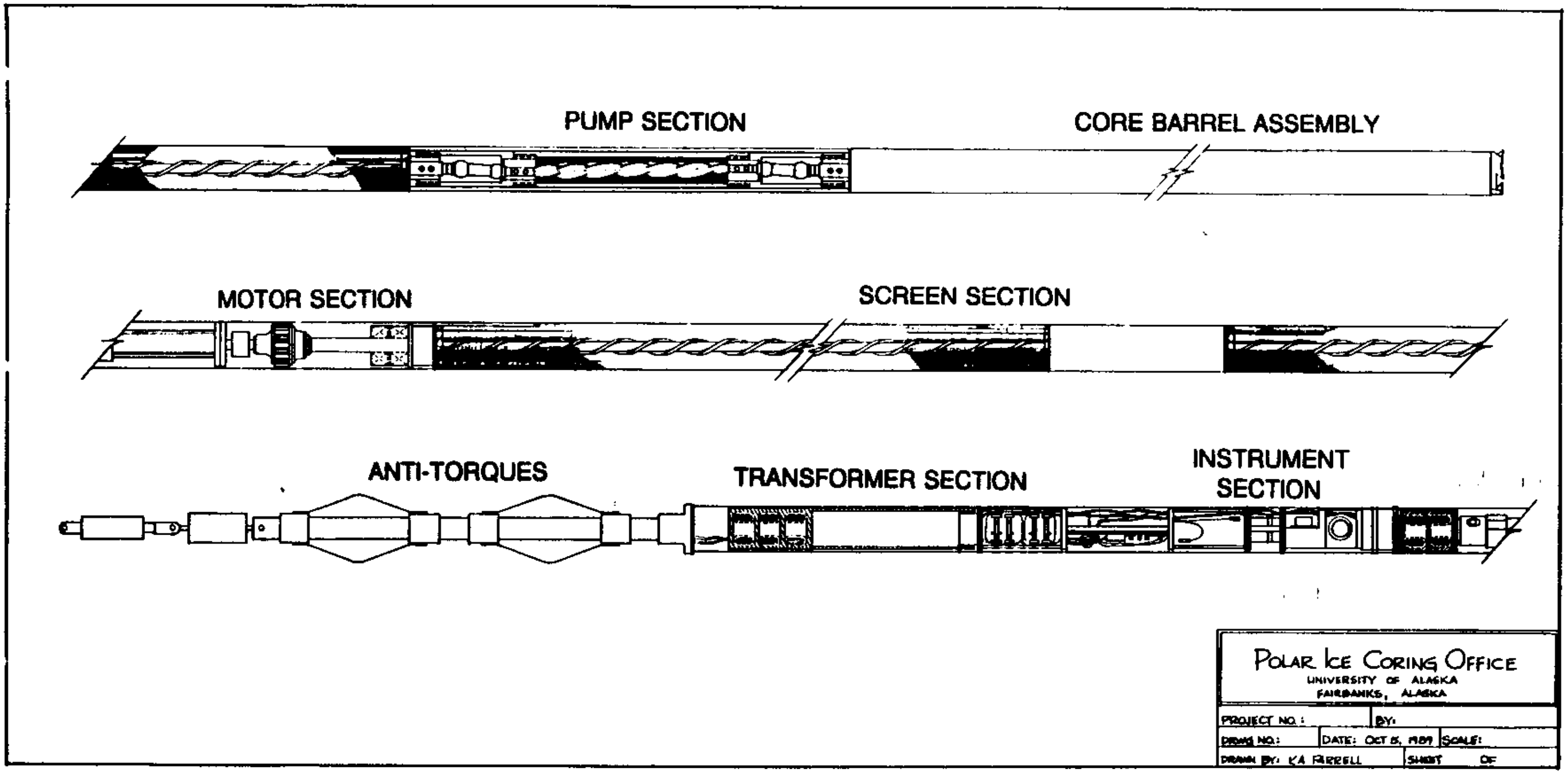

Figure 2. PICO 5.2 inch wet coring drill.

B. DRILL HEAD DESIGN

Although the current drill-head design produced good quality core, a number of limitations became evident as the season progressed. The current head design needs a greater latitude of tunability. We were limited to penetration shoes with a 1.2 degree lead angle. This proved to be too aggressive for the anti-torques to hold. For the 1991 season we plan on having a number of different-angled penetration shoes that will allow penetration rates to be changed without resorting to shims. This will allow the head to be tuned to the conditions encountered.

Some slight problems with core-dog springs were encountered but will be solved by making the springs out of a different material.

Along with the refinements of the existing head, we are also developing another design that will incorporate several features that are not part of the present head (Fig. 3). The idea of a pre-cutter arrangement that will cut a relief annulus to prevent imparting stresses on the core has been examined. A prototype incorporating this pre-cutter design will be built for testing at PICO and will be given a trial run at CRREL.

A feature incorporated into this new head design will be a combined cutter and penetration shoe assembl, which will have replaceable cutter inserts. This will reduce the cost of the cutters and allow to easy replacement in the field. Another benefit will be a cleaner surface on the penetration-limiting portion of the cutter assembly. This will eliminate the problems with accretion that occurred on the penetration shoes used in the field in 1990.

Another feature of the combined cutter–penetration shoe arrangement that will be approached is the self-tracking ability of the head. Various cutter profiles will be tried in an effort to determine the effects of cutting a pilot hole allowing a straighter, more vertical hole to be drilled.

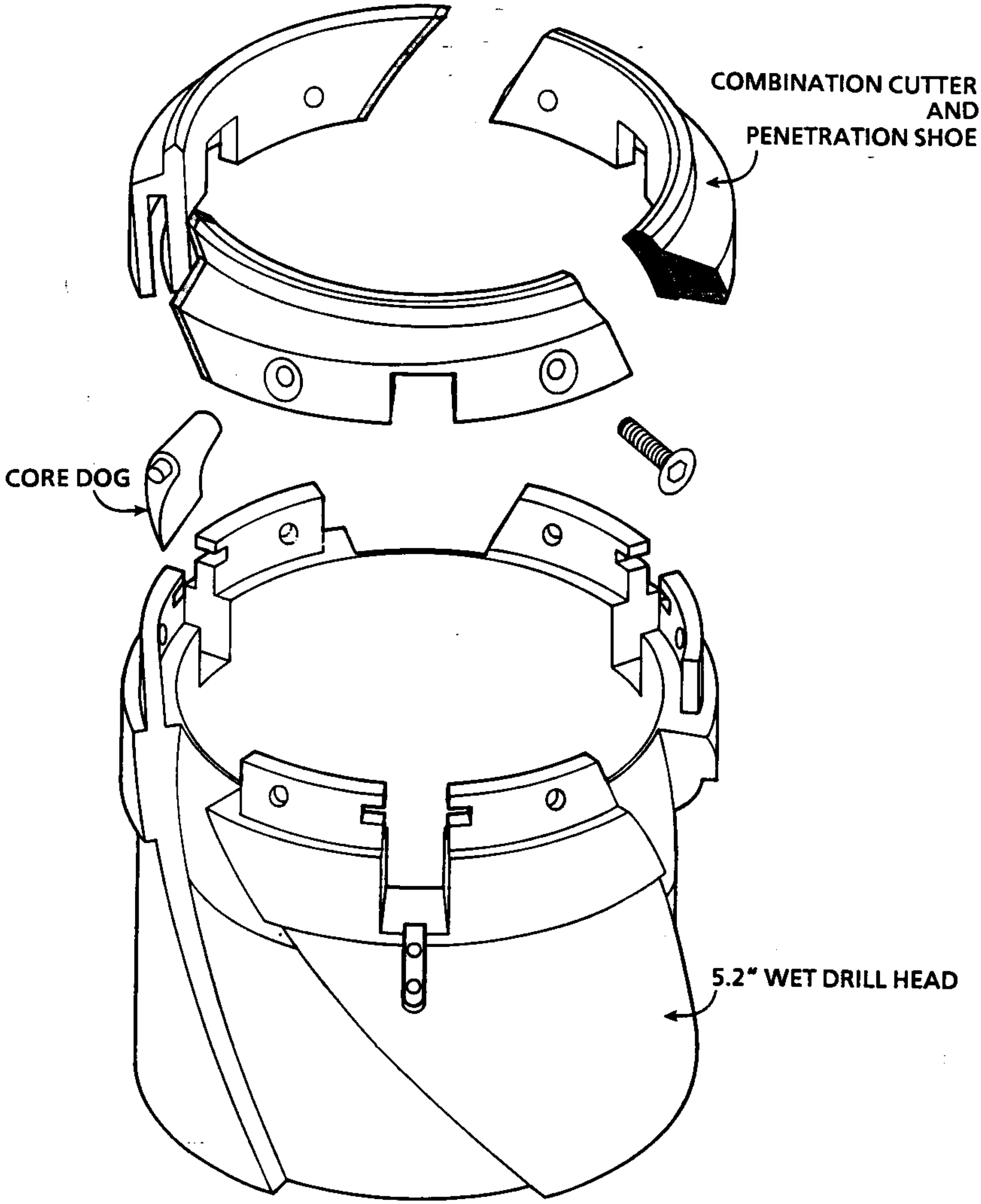

Figure 3. 5.2 inch wet coring head.

Other areas that will be examined are a cleaner chip path after the cutter assembly. Surface finish will also be examined to define its effect on chip transport. An accurate sharpening fixture will also be examined in an effort to produce more consistent results in the sharpening process.

The feasibility of incorporating a cutter ring that bolts directly to the inner core barrel is also being examined.

C. COUPLINGS

The restrictive chip path that caused difficulty in the screen-cleaning process has been corrected. A prototype was fabricated by the time we returned from the field and was displayed at the GISP2 meeting in Reno. It will be tested in Fairbanks and in the drill test at the CRREL drill test facility. The splined coupling shaft running through the screen has been modified. This has provided a clear chip path that allows the chips to empty the bottom.

The vibrator used to shake the screens was effective in getting the chips to move in the screen section. It was tuneable only in amplitude. This year's vibrator will be both amplitude- and frequency-tuneable. This will allow us to find the most effective combination for chip removal.

Core barrels used in the 1990 season represented a success in the use of carbon graphite/epoxy composites. Clearances between the inner and outer core barrels will be reduced slightly in an effort to keep the drill tracking as straight as possible. Also, Centering buttons located on the outer perimeter of the outer core barrels will be incorporated for the same reason.

D. INSTRUMENT PACKAGE

The instrument package was effective and serviceable. It performed well the entire season with only minor technical problems that were solved in the field. A number of modifications will be incorporated to provide more data to be used for hole logging and maintenance. The power package will be changed from a 560-volt AC supply to 1120-volt. This will minimize power losses in the longer 4000-meter cable. An hour meter will be added to the control panel so that accurate records of component life can be noted and integrated into a service schedule. This time record along with drilling parameters will be recorded on a computer so that further study of the effect of modifications on drill performance can be conducted.

E. RETRIEVAL TOOLS

Due to the very real possibility of dropping a foreign object downhole, a broader selection of retrieval tools will be on hand. A borehole television camera is being investigated so that the object can be identified and the proper method of retrieval can be used. Most fasteners used in the drill are currently made of stainless steel. All of these will be replaced with grade-8 steel fasteners, so a magnet will be used for their removal. A number of other retrieval tools from the oil industry are currently being examined.

F. TELEVISION MONITOR

A television monitor mounted on the carousel will be used to provide the drill operator with a better view of the coupling procedure. This will remove the blind spot and offer a much safer coupling and decoupling process which has the most potential for bodily injury.

G. TILT TABLE AND CORE HANDLING TABLE

A new tilt table for laying the core barrel in a horizontal position will be designed and built. This will speed up the core-handling process in the dome. It will also streamline the core-extraction process and provide a more gentle handling of the core. This is particularly important this coming season because of the problems with the brittle ice zone. This tilt table will also consist of a matching core-removal table which will reduce the amount of handling of the core.

IV. FIELD PLAN FOR 1991 DRILL SEASON

With the benefit of experience gained during the 1990 field season, it was felt that a goal of 100 days of drilling would be needed. As a result, the flight periods and put-in flights have been arranged to accommodate this as much as possible. An overall season goal for 1991 was discussed at the GISP2 planning meeting in Reno and a figure of 2000 meters was chosen. This goal seems reasonable in light of the 100-day drilling season. A number of factors will work in our favor, such as the increased winch speed when bringing the drill to the surface. The 1000-meter winch used in 1990 had a speed of 30 meters per minute,. while the new 4000-meter winch has a retrieval speed of 150 meters per minute.

Drilling personnel will be increased for 1991. Additional drillers will be hired and trained so that two 10-hour shifts can be implemented. This will allow 20 hours of drilling per day and allow a 4-hour maintenance and repair period. This 4-hour period will allow for scheduled repairs and maintenance to take place without interfering with core production.

A revised organizational plan for the field season has been developed. The field is the primary focus for prioritization and decision making. Field operations will be directed by a triumvirate consisting of the Chief Scientist, Camp Manager and Chief Driller. Weekly reports will be filed and distributed to the SMO and PICO-UAF.

V. CONCLUSION

The 1990 GISP2 field season offered a test of the potential of the PICO deep drill. Although the total depth achieved was not as expected, PICO believes that it was a successful season.

A number a theories have been proven in field conditions. The use of butyl acetate as a drilling fluid has proven to be a success. PICO has led the way in finding safe, workable solutions to the health risks that have plagued drilling programs in the past. PICO has proven that drill fluids containing carcinogens are no longer necessary or acceptable.

Total depth achieved was not as great as expected but this must not cloud our view of the overall project. We feel confident that the goals of the GISP2 program will be realized and that a continuous high quality core will be produced.

A very important but often unacknowledged issue is safety. No core is worth the jeopardizing human life. This season represented a large undertaking in constructing a drill of this complexity. PICO is proud of the fact that drilling and all its support systems were carried out in the field without a single injury.

APPENDIX 1

GISP2 1990 DRILLING REPORT

The 1990 GISP2 drilling season began on 11 June 1990, and ended 7 September 1990. This included two construction periods and two modes of drilling, one period of dry drilling from 6 July to 13 July and one period of wet drilling from 2 August to 25August. Initial field deployment was delayed from the initial put-in of 25 May due to a number of factors, including last minute problems with vendor deliveries.

The first task of the field drill crew was to construct the drill tower and associated drill-handling components. This initial construction period began 14 June and lasted until dry drilling commenced on 6 July. This proved to be more time- and labor-consuming than planned. Among the tasks completed during this time were construction of the drill base, erection of the twin 100-foot towers, anchors and guys, installation of the 1000-meter winch and controls, construction of the carousel handling system, a catwalk working platform, and the reaming existing hole and installation of 77 of the 25-centimeter diameter casing.

Dry drilling began on 6 July with the drilling out of the casing seal which consisted of an ice plug at the bottom of the casing. The hole was first reamed to a diameter of 33 centimeters at a depth of 85.4 meters. Seventy-seven meters of the 25-centimeter diameter casing was then assembled and suspended in the reamed hole. Approximately one cubic meter of snow was then shoveled down the inside of the casing, followed by 1000-liters of water. This was to form an ice plug at the bottom of the casing to act as a seal to prevent the loss of butyl acetate from the borehole. After shoveling in the snow the depth measured 73.3 m and after the water was added and had frozen the depth measured 68.1 m. It was discovered that after the casing was frozen it was no longer straight. This caused some problems when drilling began. After several runs it was noticed that we were drilling into the casing wall and rapidly ruining cutters. A TV camera was lowered down the borehole and we could see that the drill was indeed hitting the side of the casing. This was caused by the casing buckling during the freezing-in process. 120 liters of water were put down the hole to fill the void where the core had been removed. A centering device was fabricated and installed on the end of the outer core barrel in order for the drill to track down the center of the casing without hitting the sides.

This proved successful and we drilled through the ice plug and into the ice sheet without any further problems. Dry drilling was continued to a depth of 131.6 m, which was reached on 19July.

A second construction period began after the July flight period. At this time the various systems for handling the wet drilling using butyl acetate were built. Among the construction tasks completed at this time were the auger system for handling the butyl/chip slurry, the ventilation system, the butyl recovery system, the screen washing system and all the pumps, valving and handling system for butyl acetate. This construction period lasted until the commencement of wet drilling on 2 August. Other minor construction and modifications continued during wet drilling.

The use of butyl acetate as a drilling fluid was one of the successes that came from the 1990 drill season. There were many questions concerning the use of butyl acetate, especially its flammability and health risks. In the field these concerns proved easy to deal with. The safety gear proved to be very workable and effective even in the cold conditions. The ventilation system was effective in keeping the butyl levels at an acceptable level. The drilling equipment withstood the effects of being immersed in butyl acetate without any major effects except for the DC drill motor. A report describing the effects of butyl acetate on the motor is attached.

The deep-coring wet drill used for the 1990 field season was a departure from systems used in the past in that the drill components were handled with a revolving carousel system (Fi. 1). Due to the length of the core barrels (3 and 6 meters long) and the screen sections (6 and 12 meters long), the drill quite long (15 meters using a

3-meter core barrel and 24 meters using a 6-meter core barrel). As a result, the tower from which the drill was suspended was 100 feet in height. A revolving carousel was designed to handle the components in a vertical mode. Extra stations were used to enable the carousel to hold the replaceable sections of the drill so that as the drill was taken apart at the surface to release the core barrel and screen sections, fresh core barrels and screens would be ready to reconfigure the drill and start the next run. This kept to a minimum the time that the drill was at the surface.

After the drill was reconfigured and sent down for another run, the core barrel and screen could be dealt with at the surface without affecting the drilling process. This system proved effective and workable. Only a few minor changes of the carousel are in order for the 1991 drill season. No mechanical problems arose with the carousel during the drill season and it was both durable and easy to handle. One drawback was the time taken for its construction.

Design changes for a more streamlined, light-weight, portable carousel system have been noted for future field seasons. Also, television camera will be installed to allow the drill operator a better view of the coupling procedure, thus, making this much safer procedure.

To handle the core barrel after it was removed from the drill, a tilting table was used to lower the core barrel from a vertical position to a horizontal one. This was a simple table made of an aluminum H-beam that was raised and lowered with a winch. It was designed to handle either a 3-meter or a 6-meter core barrel. It proved simple and effective although a little slow. Because of floor space restraints, it had to be relocated so that it tilted into the throat of the carousel core barrel station without introducing shock to the core. We propose solving this problem by designing a new tilt table that allows a more streamlined procedure for laying the core barrel and for extracting both the inner core barrel and the core. The new tilt table will align with a core-handling table that will make core extraction and cutting the core to length easier and also gentler on the fragile core.

The chip slurry that was produced by emptying the screen sections was caught in a drip pan that was located under the carousel. A 6-inch U-trough auger then transported this slurry outside the dome where the butyl acetate was separated from the chips by draining and by centrifuge. This proved a workable arrangement. With a few minor refinements this system will work even better for the 1991 season. Twenty-two drums of butyl acetate were recovered this season using this system, and at a cost of $1000 per drum this is a significant savings. Because it requires a person assigned to operating the butyl farm for most of a drill shift the projected staffing for 1991 has been increased.

The carousel and related system was a success. With only a few minor changes we will be able to efficiently handle the drill components per our proposed design.

The drill string performed relatively well during the season, although plagued with a few minor problems that could not be easily solved in the field. One of the most visible and frustrating problems was the couplings between drill component sections. Due to a restricted chip path, the chip slurry mixture did not readily empty from the screens. We had in the field both a washing system and a vibrating system to clean the chips from the screen. Washing was to be done with a spray ring and 12 wash nozzles spraying butyl acetate onto the screen section. This proved ineffective. The vibration system worked well for transporting the chips out the bottom of the screen but due to the restricted chip path the chips piled up at this restriction. The only other field option available to us was to remove the coupling from the screen section each time the screen needed cleaning. This was both time consuming and frustrating, but did not seriously affect the trip time. This situation was aggravated by the minimal number of screens that we had on hand. Larry Kozycki helped design a solution to the chip path problem in the coupling, and. by the time M. Wumkes had returned from the field, L. Kozycki had already incorporated these changes into the new coupling and had constructed a prototype. Although this coupling has yet to be tested, we are confident that the problem has been solved. As for the performance of the coupling in making and breaking the connections between drill components, it proved both simple and strong. It lent itself to ease of handling, which was an important consideration in that it was easy to handle while wearing all of the protective gear.

Another area of improvement to be tested is antitorques. The main limiting factor for drilling this year was that the anti-torques could not hold the drill from spinning at the penetration rates defined by the penetration shoes on the head. The anti-torques did not slide down the borehole smoothly; rather, they moved down in cycles. This is a result of a number of factors. Hysteresis of the cable and the frictional characteristic of the antitorque design and an over-aggressive penetration shoe led to a feedback mechanism that caused the drill to cut until the weight of the drill overcame the friction of the antitorques.

The drill would slip until sitting on the penetration shoes, which would allow not only too big a cut to be taken but also the drill to grab, thus spinning the antitorques. A number of options must be exercised in order to address this problem. The cutter penetration rate must be more closely matched with the cable-feed rate while using an anti-torque system that moves freely up and down the borehole while also having greater rotational resistance. A number of designs have been examined and will be fabricated and tested before the upcoming field season.

The drill head performed relatively well for the field season both for wet and dry drilling. There are a number of modifications that need to be incorporated in future head designs. One problem was that we had only a limited number of cutters for the field season. This did not hamper drilling because of the abbreviated drilling season but must be addressed before deployment for the 1991 field season. Because of the problems encountered when drilling through the casing along with the presence of foreign objects in the borehole, we found ourselves with an inadequate cutter supply.

The design of the cutter and shoe configuration also led to a problem when the cutters are sharpened. The material removed during the sharpening process changes the clearances between the cutter and the penetration shoe, thus changing the penetration angle and allowing a less aggressive cut. Shimming the penetration shoes becomes necessary as the cutters were sharpened and ice conditions change. Also the open, tapped holes in the shoes led to ice build up which reduced the penetration rate. The self-tracking characteristic of the cutter profile also needs to be examined. There is evidence that the self tracking of the drillhead might be inadequate and contribute to a fracturing of the core during the drilling process.

The core dogs in the drill head performed well, though a minor change in geometry might lead to easier core breaks. It was found that the core brakes easier if only 2 core-dogs were used. Some core-dog spring breakage occurred also and would be solved by making them out of spring steel rather than beryllium copper.

Chip paths of the head need some slight field modification. These chip paths will be streamlined and smoothed in the 1991 version.

The carbon graphite/epoxy inner core barrels worked very well both in dry and wet drilling. They are effective in transporting the chips when dry drilling.

The graphite inner barrels performed well all season without any major repairs being needed.

The outer core barrels also performed well. Two outer core barrels were used for the entire duration of the 1990 season, requiring only minor repairs or modifications. The shear strips welded to the inside of the outer core barrel became loose and detached, causing minor damage to one of the inner core barrels. This was easily repaired with an epoxy repair kit. The first 15 centimeters of the strips were removed, which prevented any further problems. An effort was made to re-attach the strips in one of the outer core barrels, which caused the end of the core barrel to be slightly out of round.

As only 3-meter core barrels were available in the field, a more extensive inventory of core barrels would have been beneficial.

A variable-amplitude vibrator suspended by the utility winch was coupled to the screen section during the cleaning process. This was effective in getting the chips to move down the screen section, but an improvement for 1991 would be a tunable amplitude and tunable frequency vibrator. Other improvements would include a swivel attachment both to the utility winch cable and to a load cell so that it could be determined when the screen was completely clean by noting the weight of the empty screen instead of decoupling the vibrator each time.

The utility winch used for handling the vibrator worked without fail the entire season. It would be helpful, however, to mount another control panel at the bottom of the carousel so that the winch could be operated from either work station. This would streamline the screen cleaning and handling process.

The instrument package designed and built by Walt Hancock of the University of Nebraska - Lincoln worked very well. It provided all the parameters necessary for efficient drill control. Early in the wet drilling process one of the transformers failed, but it was easily repaired and did not result in excessive down time. On several occasions the instrument section locked and as a result communication with the control panel at the surface was not possible. On one occasion the microprocessor in the instrument package failed; it was replaced and a minor design change was incorporated to prevent a recurrence of this problem. The instrument section worked flawlessly the remainder of the season.

During windy periods it became difficult to make the connection between drill components because the drill was displaced off center nearly 30 centimeters. A wind shield of CIBA pipe may be necessary next season to prevent high winds from affecting drill operations. This could be incorporated into a modified tower bracing system.

During the course of the drilling season it appeared that there might be foreign debris downhole. Various methods were used in an effort to remove this debris. A varied compliment of retrieval tools will be required to deal with this problem. Particularly useful would be a borehole television camera to inspect the borehole for the presence and type of debris so the proper tool could be utilized for its removal.

Drilling personnel for the 1990 field season were hard-working and capable. They performed their tasks without fail despite hazars and severe weather conditions. They accomplished a major construction project with limited resources. The drilling process, because of its use of butyl acetate as a drilling fluid, was particularly awkward drillers had to be fully clothed in butyl rubber suits, boots, respirators, goggles, gloves and hardhatsand still work in cold temperatures. Their attitude was cheerful despite the pressures and frustrations. Without them the 1990 field season would have been much less productive.

Core quality throughout the wet drilling portion was generally good. A number of operating parameters had to be continually adjusted to match the characteristics of the cutters and penetration shoes. The drill log describes the modifications and adjustments we initiated in order to produce the high quality core we recovered.

At the onset of wet drilling the fluid levels were kept to a minimum in an effort to keep the slip ring assembly and instrument package from being immersed too deeply in the butyl acetate. This was done to test the system's operation before introducing the drill to the higher pressures caused by deeper immersion in butyl acetate.

Tuning of the drill head had the greatest effect on core quality. Core runs were typically 2.6 - 2.9 meters in length with 70 - 80 centimeter pieces. After various efforts at tuning, the head core segments became longer and a 2.26-meter continuous piece of core was produced. Elsewhere in this report the details of head parameters will be discussed.

APPENDIX 2

DC DRILL MOTOR SERVICE EVALUATION

A DC motor was used in the motor section of the 1990 GISP2 wet drill. After an estimated running time of between 80 and 100 hours, sudden and violent current surges indicated problems with the motor and it was replaced with one of the three spares on hand. Upon return from the field it was dismantled and inspected with the following observations:

Corrosion of the external case was evident and was attributed to the shipping conditions encountered when retrograded from the field.

BEARINGS – All the bearing seals were intact with no obvious breakdown of seal material. All lubrication had been washed out of the bearings and, as a result, the bearings failed: they were not frozen but felt rough when turned by hand.

ARMATURE – The varnish insulation on the armature was inspected closely and found to have broken down in the area where two wires were in close proximity to each other, causing bare spots on the wire and bubbling of the varnish. Also visible were several wear spots on the armature laminations where it had struck the magnets. This was attributed to the bearing failure that created misalignment of the armature in the magnet housing.

BRUSHES – The brushes were well worn and had little useful life left. An inspection of these brushes took place a short time before the motor failed and were found to have very little wear at that time.

COMMUTATOR – Inspection of the commutator revealed arcing and over-current conditions. The commutator was well worn where the brushes made contact. Some carbon dust was imbedded between commutator segments.

MAGNETS – The adhesive used to secure the magnets to the motor housing had deteriorated and thus several magnets were loose.

SOLUTION – To solve the problems associated with the motor running while submerged in butyl acetate, we will seal the motor section of the drill so that it can be filled with a light oil. This will preclude seepage of the butyl acetate and extend the service life of both the motor and the gear reducer.