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SUMMARY LETTER REPORT

ON

WORK ORDER NO. 9

TASK ORDER NO. 21

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#5

November 26, 1963



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February 13, 1964

Dear Sir:

This summary letter report describes the research conducted under Work Order No. 9, Task Order No. 21, during the period from June 27 through November 26, 1963. This work consisted of an investigation of the primary design factors related to a proposed method of penetrating overburden by a remote controlled, electrically powered "mole" that would tow a wire electrical conductor.

Introduction

Over the past several years, the Sponsor has been interested in tunnelling and boring by a variety of methods. We have conducted various research programs directed toward the study and development of equipment utilizing digging, drilling, pushing, and pulling to produce holes. The configurations of these equipments have been strongly influenced by the length and diameter of the desired holes, the amount and type of power available, and the conditions under which the operations were expected to take place.

Work Order No. 9, Task Order No. 21, was set up as a result of the need described by the Sponsor for a device to tow a wire conductor through overburden. A device that would be considered satisfactory would be remotely controlled and powered by indigenous electrical energy, probably 220-volt, single-phase, 50-cycle current. It would have a range of up to 50 ft and if possible, would be guided to within a 1-sq-ft area at the maximum range.

-2-

The hole formed immediately adjacent to the "mole" would be the minimum needed by the "mole" and could collapse or be filled in around the conductor following the passage of the "mole". The device, consisting of the "mole" and a control box, would be portable, having minimum weight and volume compatible with the desired performance.

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Summary and Conclusions

A review of commercially available equipment uncovered no device which could be utilized directly or could be easily modified for this purpose. It was also concluded that a device which operated in a substantially straight line and was not guided after once started would be most practical at present because of the lack of commercially available orientation-sensing and guidance devices.

A promising concept consisting of an auger powered by an external motor through rigid sectioned shafting was evolved. There are indications that this device would have sufficient accuracy to meet the mission objectives. It is strongly recommended, however, that the potential accuracy be the first item investigated in any further development work.

Engineering Activity

The engineering activity began with a limited review of the state of the art to determine what devices were commercially available and their limitations. After no applicable devices were found, a few preliminary experiments were performed to explore the amount of power which would be required for a "mole"-type unit. The results of these experiments and the

-3-

state-of-the-art review were the basis for the mid-project decision restricting the consideration to units which operated in a substantially straight line and were not subjected to additional guidance, in contrast to guided units. The remainder of the effort was then directed toward the evolution of concepts related to "straight line"-operating devices.

State-of-the-Art Review

Information was requested from about 46 companies, as listed in Table 1; even though many of these companies were not engaged in the manufacture of the type of equipment of interest, it was anticipated that they might be able to provide further leads. Information obtained previously from other companies in connection with similar projects for the Sponsor was also reviewed. Table 2 is a partial listing of the U. S. patents checked; many other patents not listed were reviewed by means of the "Patent Gazettes" in our library. Approximately 35 articles were also scanned for pertinent information.

In general, most of the information available pertained to pipe pushers, drills, trenchers, tunnelling machines, mining machines, and electric moles, none of which have the characteristics necessary for the application of interest.

A commercial device, the "Kret" pneumatic missile, was uncovered that is not considered applicable because of the operating noise level and air requirements; nonetheless, the information available on this device suggests that the accuracy obtainable with a pre-aimed nonguided unit may be acceptable for the application of interest. The "Kret" is a 4-1/4-ft long, 3-1/2-in.-diameter, 64-lb missile propelled by means of a piston ram

-4-

TABLE 1. COMPANIES CONTACTED FOR INFORMATION

Airdox-Cardox Products Co. 305 N. Michigan Avenue Chicago, Illinois	Foushee & Heckendorf Cedar Point, Kansas
American Kret Corporation 225 East 46th Street New York 17, New York	Earthworm Boring Machine, Inc. 1415 14th Street, P. O. Box 1100 Santa Monica, California
Baker Oil Tools Inc. P. O. Box 9274, Terminal Annex Los Angeles, California	George E. Failing Co. Enid, Oklahoma
Bell Telephone Laboratories Columbus, Ohio	Geo-Drill Co. P. O. Box 6-E Bridgeville, Pennsylvania
Bell Telephone Laboratories Murray Hill, New Jersey	Hardsocg Manufacturing Co. 800 West Samantha Ottumwa, Illinois
Bico, Inc. 3118 Valhalla Drive Burbank, California	Highway Trailer Company Edgerton, Wisconsin
Cavins Co. 2853 Cherry Avenue Long Beach, California	Houston Engineers, Inc. 1412 Ennis Houston, Texas
Central Mine Equipment Co. 6200 N. Broadway St. Louis, Missouri	Hydrauger Corp. Ltd. 681 Market San Francisco, California
Centromor Motokowska 49 Warsaw, Poland	Hyster Company 2905 N.E. Clockamas Portland, Oregon
Charles Machine Works, Inc. 603 Birch Street Perry, Oklahoma	Ingersoll-Rand 11 Broadway New York 4, New York
Chicago Pneumatic 8 East 44th Street New York 17, New York	International Manufacturing & Equipment Co., Inc. 52 Church New York, New York
Construction Machinery Co. Waterloo, Iowa	Joy Manufacturing Co. Dept. 8, Oliver Building Pittsburgh, Pennsylvania

-5-

TABLE 1. COMPANIES CONTACTED FOR INFORMATION (Continued)

KA-MO Tools, Inc. Cicero, Illinois	J. R. Prewitt & Sons, Inc. Pleasant Hill, Missouri
Kenco Manufacturing Co. Kenco Building 5212 Telegraph Road Los Angeles, California	Ranney Water Systems, Inc. Columbus, Ohio
Line Scale Co., Inc. 3757 N.W. 37th Oklahoma City, Oklahoma	Reichdrill Division Chicago Pneumatic Tool Co. Howard Street Franklin, Pennsylvania
Long Company Oak Hill, West Virginia	The Salem Tool Co. 767 South Ellsworth Avenue Salem, Ohio
Long-Airdox Co. 305 North Michigan Avenue Chicago, Illinois	Sprague & Henwood, Inc. Scranton 2, Pennsylvania
E. J. Longyear Co. 76 South 8th Street Minneapolis, Minnesota	Templeton Henly & Co. 2545 Gardner Road Broadview, Illinois
McCulloch Corp. 6103 W. Century Boulevard Los Angeles, California	Trainer Associates, Inc. 62 Young Avenue New Castle, Delaware
The Mine & Smelter Supply Co. Denver Division P. O. Box 9041, 3800 Race Street Denver 16, Colorado	Western Alloy Products Co. 348 North Avenue Grand Junction, Colorado
Mobile Drilling, Inc. 906 North Pennsylvania Avenue Indianapolis, Indiana	Wilcox Manufacturing Co. Raleigh, West Virginia
Peterson Engineering Co., Inc. 460 Kifer Road Santa Clara, California	Hugh B. Williams Manufacturing Co. 833 Lovett Street Dallas, Texas
Pitnam Industrial Products Co. 608 5th Avenue New York 20, New York	Young Engine Corporation P. O. Box 532 Canton 1, Ohio

-6-

TABLE 2. IDENTIFICATION OF SOME OF
U. S. PATENTS REVIEWED

1,210,925	2,153,680	2,531,909	2,721,059
1,285,712	2,165,666	2,588,068	2,726,064
1,295,969	2,182,477	2,619,340	2,733,057
1,310,274	2,196,260	2,623,387	2,742,264
1,311,142	2,197,019	2,625,375	2,742,265
1,311,143	2,207,505	2,625,376	2,743,085
1,326,480	2,211,223	2,633,334	2,745,648
1,388,545	2,234,451	2,639,931	2,747,839
1,462,997	2,271,005	2,646,962	2,749,101
1,511,957	2,274,431	2,647,726	2,750,154
1,532,243	2,292,098	2,656,148	2,750,175
1,639,219	2,300,016	2,664,273	2,750,176
1,650,103	2,319,512	2,665,117	2,751,203
1,699,936	2,325,565	2,670,180	2,753,154
1,812,719	2,338,351	2,675,213	2,756,020
1,835,191	2,380,156	2,684,834	2,756,036
1,865,853	2,384,397	2,688,465	2,756,037
1,923,015	2,397,070	2,692,754	2,758,825
1,932,068	2,400,853	2,693,345	2,765,154
1,943,103	2,404,605	2,698,169	2,776,824
1,948,733	2,435,934	2,699,328	2,783,037
1,993,366	2,466,709	2,712,920	2,783,971
2,027,063	2,492,794	2,715,524	2,790,968
2,083,834	2,495,073	2,715,526	2,798,707
2,128,240	2,529,246	2,720,391	2,798,710
2,136,152			
2,149,345			

-7-

driven by compressed air. The device pierces a continuous hole through subsoil by compressing the ground around the pointed missile head so as to form a pseudo-casing. It was reported that on a drive 109 ft long the missile emerged within 4 in. of the target point. This is approximately the same accuracy claimed for horizontal small-diameter drilling units.

Another important factor illustrated by the "Kret" literature is that the initial penetration level must be below a "critical depth" which varies with the type of soil; otherwise, the missile may tend to rise as it progresses and hence may break through the surface before reaching the target. This same philosophy can probably be applied to any "straight line"-operating device which functions by compressing the subsoil, as opposed to devices such as drills which remove the soil.

Exploration of Power Requirements

Since no commercial device which was considered applicable was uncovered, it was decided to explore the power requirements for the type of device of interest, in order to obtain some indication as to the feasibility of performing the mission with reasonably sized drive units, without overloading the power source. Accordingly, preliminary experiments were performed to obtain order-of-magnitude values for the forces involved in penetrating the subsoil and for the frictional drag resulting when a wire-conductor type of element was towed through the subsoil.

One experiment was directed toward exploring the compressive force involved in displacing and penetrating the soil by means of a pointed object. In this experiment, a 2-3/8-in.-diameter, 56-in.-long pipe was pushed into a hillside by means of a "Portapower" hydraulic jack; a conical nose cone,

-8-

machined to a 120° included angle, was mounted on the pipe prior to pushing. The force necessary to push the pipe increased steadily up to about 700 lb at a penetration distance of about 36 in. and stayed constant at this value until the rear-end cap on the pipe entered the soil. This force corresponds to a soil compressive pressure of 160 psi based on the projected area of the nose cone. Of course, the taper angle of the nose cone could have been varied to either increase or decrease this force within a reasonable range. A decrease in the included angle of the nose cone would have resulted in a decrease in the compressive load and an increase in the frictional drag. The interrelationship of these two factors was not investigated.

Another experiment was conducted to estimate the torque necessary to rotate an auger-type unit into the soil. In this experiment, a 2-3/4-in.-diameter spiral metal drill rotated by means of a torque wrench was drilled vertically into the ground. The soil in which this test was performed was about 3 ft from the edge of a river and hence was very moist; it consisted generally of dark clay and contained rocks up to 1/2 in. in diameter. Because of the moisture content, the soil packed very easily and adhered to the drill, thus resulting in torque values which were higher than would be expected in the application of interest.

The torque values obtained were generally as follows: The torque required to rotate the drill increased to about 20 ft-lb, at which time the drill was self supporting. The torque remained at the 20 ft-lb level until the drill flutes were filled with clay; then it increased to 30 to 35 ft-lb and remained at that level until the flutes were below the surface of the ground. The torque then increased to about 50 to 60 ft-lb and remained constant for the

-9-

rest of the test. On occasion a maximum torque value of 80 ft-lb was obtained; this was attributed to the rocky nature of the clay.

In a third experiment to explore the frictional drag, a 1/2-in.-diameter rubber hose, simulating the conductor cable, was pulled through a 44-in.-long box which contained an earth-gravel mixture including some stones as large as 3 to 4 in. in diameter. A spring scale was used to pull the hose through the mixture, and simultaneously to measure the frictional drag force. With a loose earth-gravel mixture, the force required was 18 lb or 4.9 lb/ft of buried cable. With the earth-gravel mixture packed by tamping with a shovel, the force increased to 25 lb or 6.8 lb/ft of buried cable.

The values would probably be higher if damp soil had been used. However, it is assumed that (1) the cable which would be used in the proposed application would be smaller than 1/2 in. in diameter, and (2) that the desired mole-type device would leave a hole which was open or filled with loose soil. Thus, for the proposed application, a frictional drag value of 6 to 7 lb/ft would be conservative and perhaps even ultraconservative.

In view of the relatively low values obtained for these forces and for the frictional drag, we consider that a "mole"-type device which would penetrate the soil and tow a conductor cable into position is feasible. Further, it appears that the power needed might be supplied by one man.

Mid-Project Decision

In the light of the foregoing results, consideration was given to the difficulties and high costs involved in the development and ultimate fabrication of a unit which would be guided, as had originally been specified, in contrast with one which would be aimed and then would travel in a

-10-

substantially straight line. The major pros and cons are summarized briefly in the following.

"Straight Line" Device. In the operation of a "straight line" device, if an obstacle such as a large rock were encountered, the device would have to be removed or retracted and another attempt made after moving to a new, slightly displaced starting point. In view of the fact that, in general, several attempts might be necessary to achieve a satisfactory emplacement, mission definition becomes a primary consideration.

As defined by the Sponsor, the mission would consist of a drive from Point "A" to Point "B", Point "A" being accessible for a period of 12 to 24 hr and Point "B" being continually accessible. During some cursory experiments with a dynamite auger as discussed later, the drive rate obtained was approximately 1 ft/min for six drives including the extraction time between drives. Thus, it appears that within a 12-hr period, several attempts to achieve a satisfactory emplacement could be made; for example, for distances of 50, 100, and 150 ft, the number of attempts possible would be approximately 14, 7, and 4, respectively.

The possible accuracy of a "straight line" device can only be estimated based on the reported performance of commercial devices. As discussed above, the "Kret" missile reportedly has been within 4 in. of the target on a 109-ft drive. Most of the horizontal-drill-unit manufacturers who were contacted stated that the accuracy of a horizontal drill unit depends on the skill and "feel" of the operators and on the drilling conditions such as type of drill bit, drilling fluid, and soil type. However, most of them indicated that an

-11-

accuracy similar to that reported for the "Kret" is attainable. It is reasonable to assume, therefore, that "straight line" devices could achieve a desirable accuracy.

The development and per unit costs for "straight line" devices can be expected to be relatively low because of the possibility of utilizing off-the-shelf components. The utilization of standard components would also increase the reliability of the "straight line" devices.

Guided Devices. A guided device might consist of two units:

(1) a boring unit, which would progress through the ground, and would contain sufficient instrumentation to sense its position and orientation relative to some fixed point and also a means for varying the boring direction; and (2) a control unit, which would provide a readout of the boring-unit position and orientation, and would include a set of controls to actuate the direction-changing mechanism in the boring unit.

Essentially, a guided device can be considered to be a "straight line" device to which has been added (1) position- and orientation-sensing equipment, and (2) direction-modification equipment. For the successful application of guided devices, these two types of equipment would have to be developed; this would be time consuming and expensive. Nothing is currently available that could be easily modified to perform these functions. In the oil-well drilling field, which is where most of the past pertinent improvements have occurred, the accepted practice is to drill a hole, remove the drill unit, and survey the hole by various means to determine its location. Wedging devices are then generally used to change the direction of drilling, if necessary. Because of the necessity of evolving

-12-

and developing both the sensing equipment and the directional-control equipment, the procurement costs of the first device would probably be higher by a factor of 10 or more than the cost of obtaining the first "straight line" unit.

After a detailed discussion of the above with the Sponsor, it was mutually agreed that the remaining effort should be directed toward the evolution of concepts for a "mole"-type unit, and that the effort should be concentrated on the "straight line" type of device. At the same time, the Sponsor indicated that a device with a range of 110 to 150 feet (as opposed to the originally indicated range of 50 ft) would be useful.

Preliminary Concepts Considered

Figures 1 through 4 illustrate schematically the major parts of four concepts evolved that are representative of the preliminary concepts considered for application as "straight line" devices. The "counter-rotating auger" as shown in Figure 1 would consist of two augers with opposite helix angles and a center nonrotating section. The two augers would be designed so that a single motor would drive both, thus balancing the rotational forces. The center section would have fixed guide vanes which would resist differences in the rotational forces. With such a unit, one major problem would be the difficulty of achieving rotation of the two augers under conditions where the soil texture varied significantly, i.e., was fairly heterogeneous.

The "bootstrap" concept, illustrated in Figure 2, would consist of concentric sliding cylinders propelled by means of a floating motor and ball screw arrangement which would extend and contract the cylinders. In the position shown in Figure 2, as the ball screw shaft extended to the left, the front pawls would close, the rear pawls would open and bear on the soil,

-13-

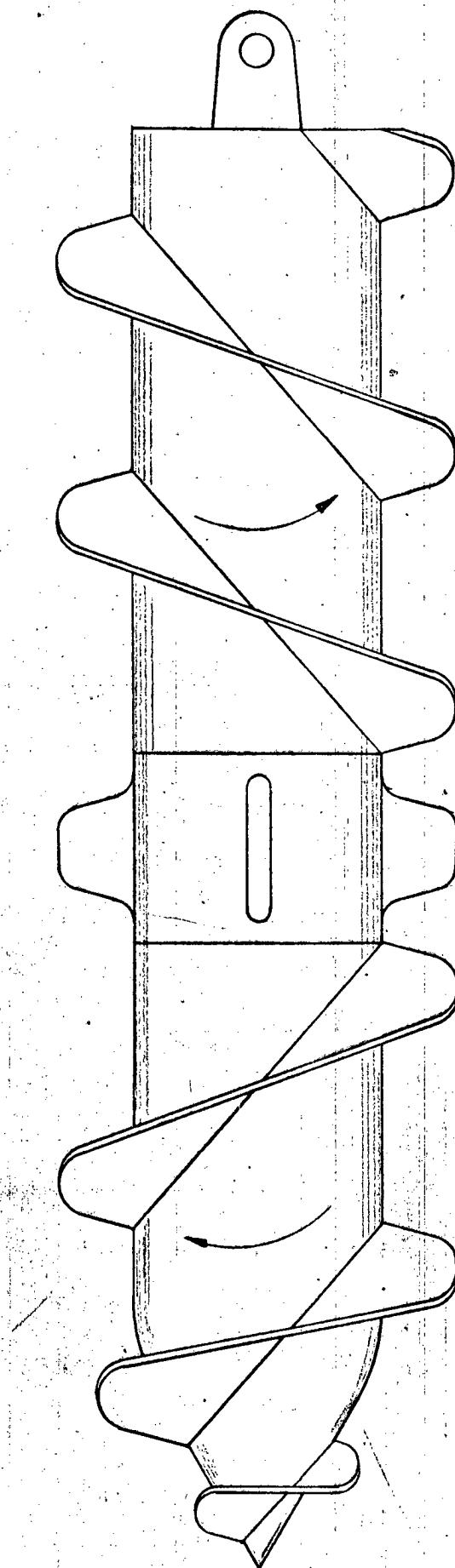


Figure 1. Concept Based on Counter-Rotating Auger

-14-

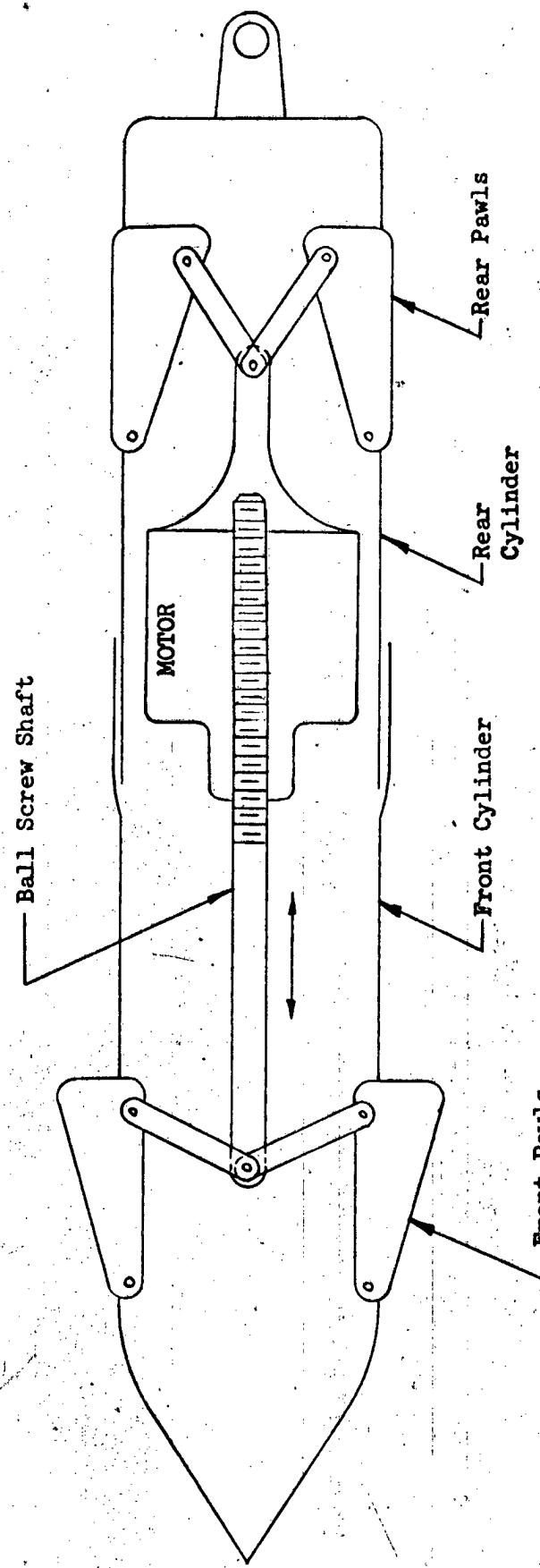


Figure 2. "Boot Strap" Concept

-15-

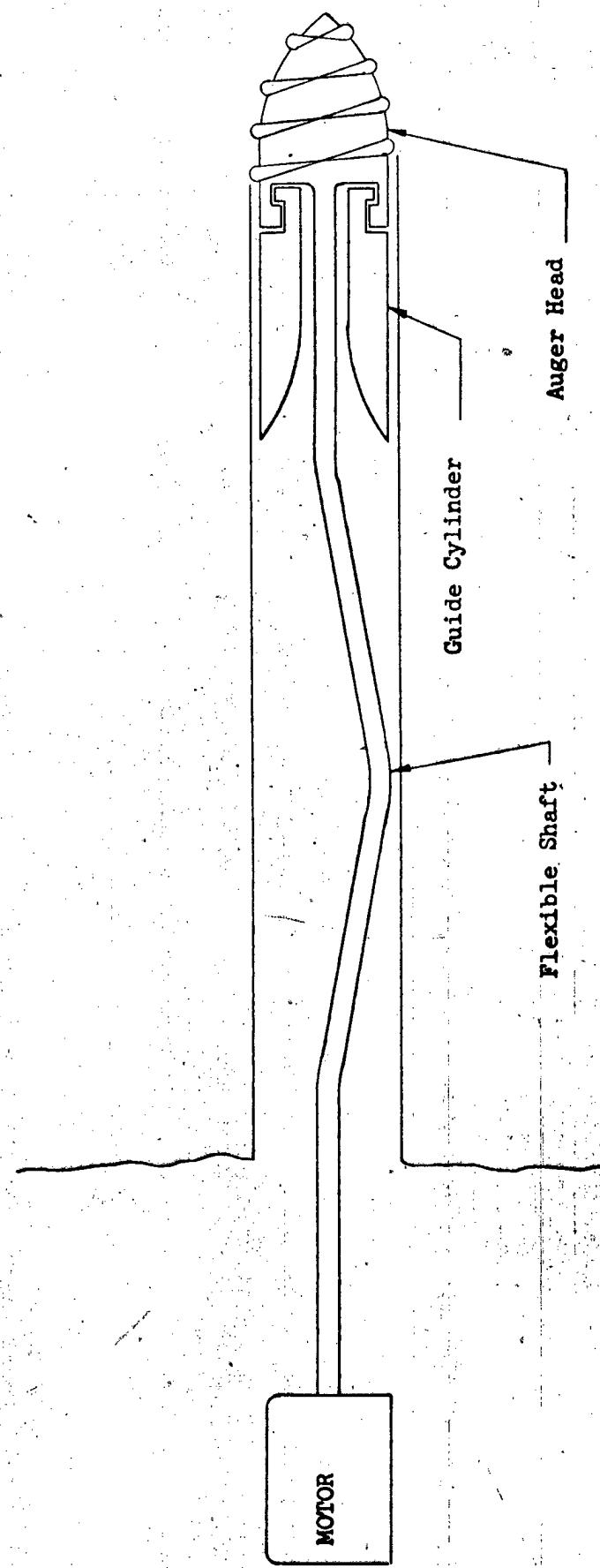
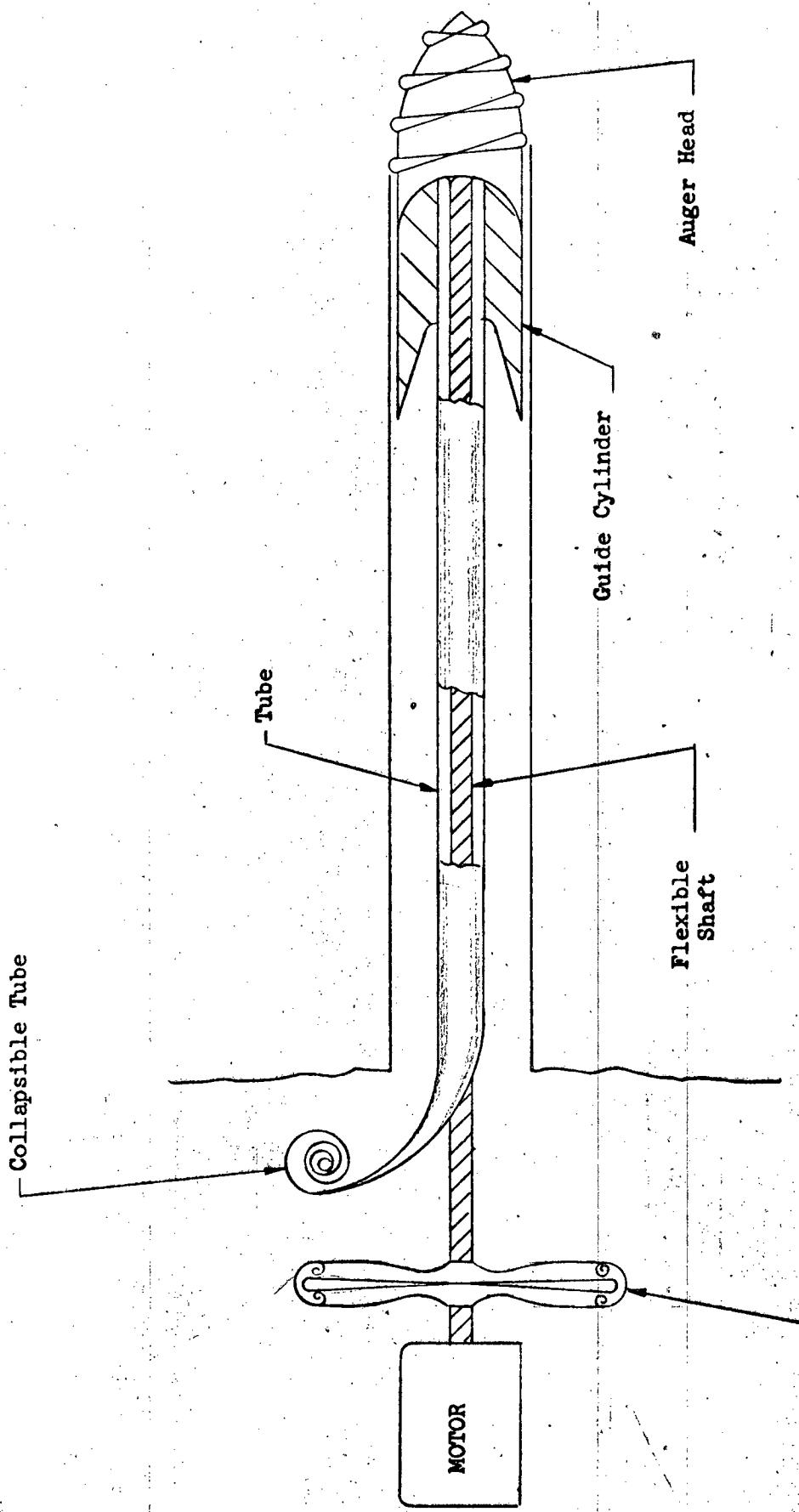


Figure 3. Concept Based on Disposable Auger Tip
and Flexible Shaft

-16-



Sewer-Cleaner Type of
Flexible Shaft Reel

Figure 4. Concept Based on Disposable Auger Tip
and Enclosed Flexible Shaft

-17-

and the front cylinder would be moved to the left. Reversal of the motor direction would cause the ball screw shaft to extend to the right; as a result, the front pawls would open and bear on the soil, the rear pawls would close, and the rear cylinder would be pulled to the left. This cycle would then be repeated. Although motors and motor components are available that might be modified for this application (Raco Machine Co., Bethel Park, Pennsylvania), the associated development work makes this concept less desirable than the recommended concept described below.

Figure 3 is a sketch of a concept consisting of an auger head driven by means of a flexible shaft. The guide cylinder would be long enough to guide the auger generally in a straight line. The auger tip and guide cylinder would be disposable, i.e., they would be driven into the final position and left there. The flexible shaft would unscrew from the auger tip when the motor was reversed. Figure 4 illustrates a similar concept, with the addition of two modifications. The flexible shaft would be contained on a reel such as is frequently used with sewer-cleaner systems. Further, the flexible shaft would be enclosed in a "STEM" (Storable Tubular Extendable Member) unit of the type developed by DeHavilland Aircraft of Canada for use as an extendable antenna for orbiting satellites; this would allow the use of a relatively small-diameter flexible shaft and would eliminate the tendency for the shaft to kink.

Recommended Concept

Analysis of the above-outlined four preliminary concepts resulted in a fifth concept, which appears to combine the better features of the above concepts. The equipment based on this concept, as illustrated in Figure 5, would consist of a motor drive unit coupled to short sections of hollow, rigid shaft, at the front end of which would be mounted a small-diameter

-18-

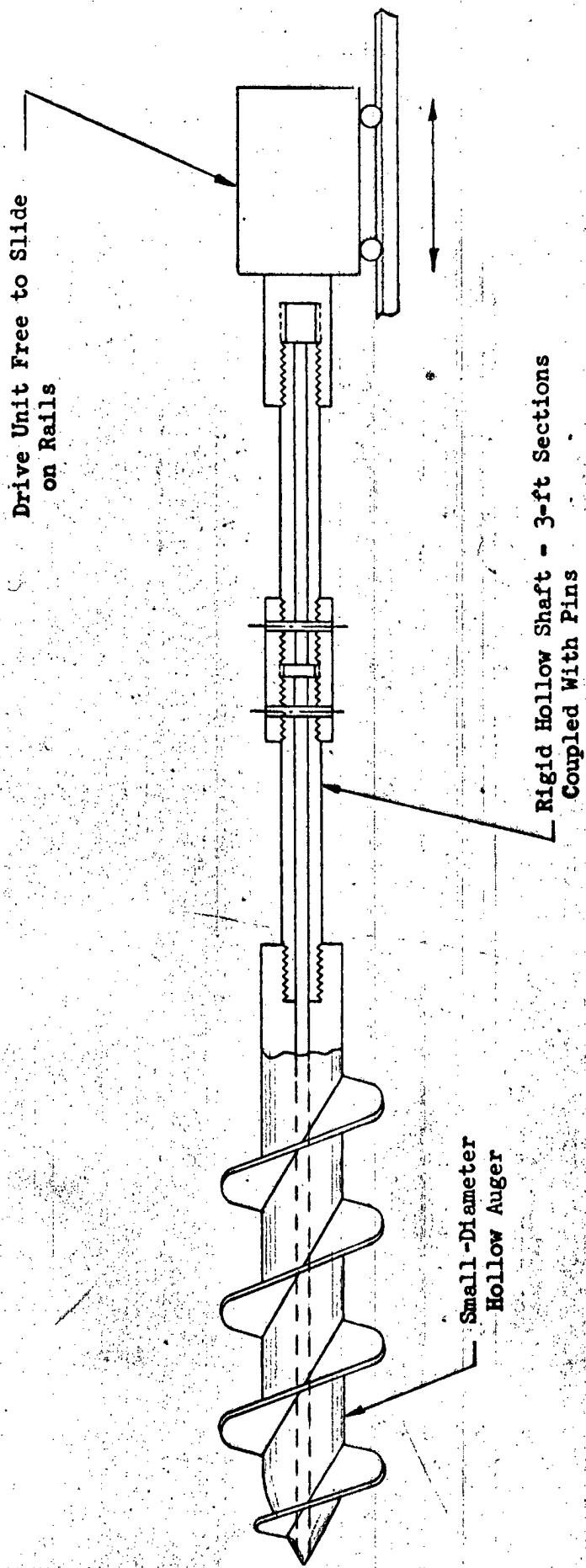


Figure 5. Recommended Concept, Based on Disposable Auger Tip and Rigid Sectional Shaft

-19-

hollow auger. The shaft sections would be added as the auger progressed through the soil. All joints would be pinned or locked to achieve assembly; accordingly, when the motor is reversed, the auger could be "screwed" out of the soil. The rotational speed of the auger would be chosen such that the auger would essentially progress forward through stationary earth rather than progressing by transferring earth from the front to the rear of the hole. The conductor cable would either be attached to the inside of the auger before starting the drive or would be pushed through the auger by means of a small stiff wire, after completion of the drive.

A number of preliminary experiments were subsequently performed with a 2-3/4-in.-diameter dynamite auger, shown in Figure 6, to explore the feasibility of a rigid shaft system. For these tests the auger was welded to a 12-ft-long 3/8-in.-diameter steel rod. The auger was then drilled into a rock-filled levee along the river. In view of the fact that the soil in the levee contained considerable large and small rocks, and other potential obstacles, it was not expected that long drives could be made.

For one experiment, a torque wrench was used to rotate the auger. Approximately 25 to 30 ft-lb of torque were required to rotate the auger until a solid obstacle was met, at a penetration distance of 6 ft. A torque of 60 ft-lb was insufficient to drive the unit further. A torque of 15 to 30 ft-lb was required to screw the auger out of the hole. About 10 to 15 minutes were involved in running the auger in and out with the torque wrench.

In a second experiment, a 3/4-in. electric drill motor was used to rotate the auger. The drill motor was powered through a Variac, to reduce the speed to approximately 150 rpm. At a 6-ft penetration distance, the motor stalled and a torque of 50 to 55 ft-lb was necessary to break it free.

-20-

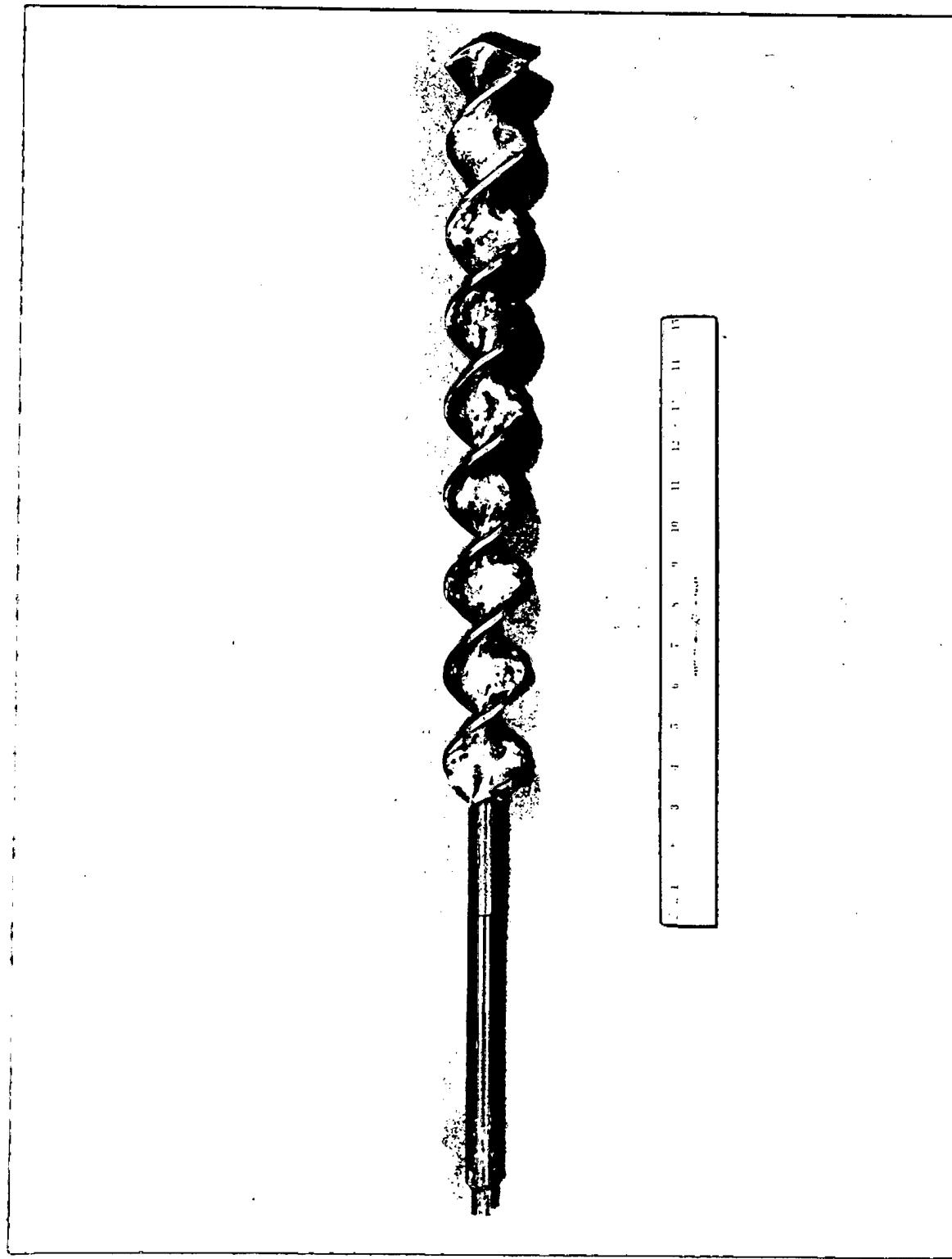


Figure 6. Dynamite Auger

-21-

The motor was then used to achieve a total penetration distance of 8 ft, at which point a solid obstacle was met, and the test was discontinued.

In a third experiment, the 3/4-in. electric drill motor was operated at its full speed of 250 rpm. A total penetration distance of 10 ft was attained on this drive. The motor stalled twice during the drive, but it was possible to break the auger loose with a torque of 45 to 55 ft-lb. It was not possible to back the auger out of the hole because, in view of the rotational speed used to drive the unit, the earth was packed "solidly" behind the auger in the hole. A 1-1/2-ton chain jack was used to extract the auger.

A series of six additional preliminary experiments, an electric impact wrench with a zero speed capacity of 80 ft-lb was used to drive the auger. The six tests achieved penetration distances of 3, 5, 1, 8, 5, and 10 ft. It was possible to remove the auger in five of the six drives merely by reversing the impact wrench. The total time used for the six drives, including the time for pulling out the auger at the end of one of the 5-ft drives with a 1-1/2-ton chain jack, was approximately 1-1/2 hr.

In view of the results of these ten preliminary experiments, it is considered feasible to use an auger at the end of a rigid shaft to penetrate the soil for considerable horizontal distances. Although the longest drive made was 10 ft, we believe that longer drives, for example, for distances of 100 to 150 ft, are feasible using this type of system. The soil drilled during these experiments was far from typical of what would probably be encountered under normal conditions, as outlined by the Sponsor. Also, the auger used in these experiments was of the type prescribed for removing dirt for dynamite holes, and was not designed for penetrating soil by a "screw in" action. It is considered that an auger could be designed specifically to provide the desired type of penetration.

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-22-

On the basis of this preliminary investigation, no major problems are envisioned in the successful development of a rigid-shaft auger system for the application of interest.

Future Work

It is recommended that further work be done to develop the rigid-shaft auger system into a practical, reliable tool. In this connection, efforts should be concentrated in four areas: (1) verification of the accuracy achievable in "hitting the target area", (2) selection and/or development of a proper auger, (3) design of the shafting and joints, and (4) selection of a drive unit. Probably the most expeditious development program would consist of the following: The initial work would involve a preliminary selection and assembly of commercially available components. This preliminary system would then be used to empirically verify the accuracy achievable and to better define the requirements for the auger, shaft and joints, and the drive unit. These results would be used as a basis for the selection of components and the subsequent development of an experimental system. Evaluation of this system would conclude this development effort.

We would appreciate any comments regarding our efforts under Work Order No. 9, and would be glad to arrange a meeting to discuss the further development of the recommended rigid-shaft auger system.

Sincerely,

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In Triplicate

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