A minerals research contract report
December 1980

RETRACTABLE BIT SYSTEM

Contract H0272004
Longyear Co.

EAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR
Minerals Resources Technology

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16. Abstract

The prototype retractable bit system developed under this contract consists of a one-piece replaceable diamond set bit, a modified core barrel, bit changing tools, and surface components which allow activation of the system. Drilling with the retractable bit system is conducted in the same manner as present core drilling, except when the bit becomes worn the bit is changed with the drill string left in the hole. The operations in changing the bit are similar to those required in changing inner core tube assemblies with the wireline cable.

A total of 1,575 feet (480 m) of system drilling was completed with the deepest bit change accomplished at 1,294 feet (394 m). Bit penetration rates and bit life were comparable to present wireline bits. These field trials were conducted on contract drill sites under production conditions.

The prototype testing indicates that this retractable bit system is feasible. It has shown reasonable reliability, but an extensive research program will be required to determine if sufficient reliability and increased productivity can be achieved to justify development of the system as a commercial product.

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FOREWORD

This report was prepared by Longyear Company, Minneapolis, Minnesota, and Doerfer, a Division of CCA (subcontractor), Cedar Falls, Iowa, under USBM Contract number H0272004. The contract was initiated under the Mineral Resources Technology Program. It was administered under the technical direction of the Twin Cities Mining Research Center with William C. Larson acting as Technical Project Officer. Michael Lechuga was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period June 20, 1977, to December 20, 1980. This report was submitted by the authors on December 20, 1980.

The following groups allowed the system to be field tested on their properties:

AMAX, Inc., Denver, Colorado

American Smelting and Refining Company (ASARCO, Inc.), New York, New York

Consolidation Coal Co., Pittsburgh, Pennsylvania

Exxon Mineral Company, USA, Denver, Colorado

Gulf Resources & Chemical Corporation, Houston, Texas

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1.0 SUMMARY

The prototype retractable bit system developed under this contract consists of a one-piece replaceable diamond set bit, a modified core barrel, bit changing tools, and surface components which allow activation of the system. Drilling with the retractable bit system is conducted in the same manner as present core drilling, except when the bit becomes worn the bit is changed with the drill string left in the hole. The operations in changing the bit are similar to those required in changing inner core tube assemblies with the wireline cable.

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2.0 INTRODUCTION

Core drilling is the art of extracting from the earth a physical sample of what material lies under the surface, with the location of the sample referenced to the surface. It is an important prerequisite to mining and construction projects. It is also relatively expensive.

Where mining is concerned, no method of obtaining underground information yields more positive information as a basis for establishing development decisions.

The core drilling operation is basically simple in principle, but can be complicated in practice. It involves a hollow bit, which is rotated and pushed through the earth, cutting a "core" as it progresses. As conditions indicate, this core is brought to the surface by removing all the drill equipment from the hole, and coring is resumed when the tools have been reinserted into the hole. This simple principle was put to practical use when the diamond was successfully applied as the cutting element, thus making a tool which would cut through the hardest rock.

The original equipment was, understandably, quite simple. The core entered what was essentially a pipe. A circular spring device just above the bit broke the core as the rod string was pulled up out of the hole.

Drilling in softer, fractured or otherwise difficult and unpredictable conditions encouraged the development of more complicated designs of equipment at the bottom of the hole - the bit and the core barrel. An inner tube which received the core was introduced to protect it. Thus, the double tube core barrel appeared. A swivel bearing was incorporated to allow the inner tube to remain stationary while the outer tube and bit rotated. This evolved into the double tube swivel core barrel.

These, and countless other variations provided the driller with equipment suited for the specialized and exceptional conditions encountered. Two important objectives were the procurement of continuous representative core and the maximization of uninterrupted drilling time.

While developments in the improvement of core barrel and bit design progressed, it was the accepted practice to pull the rods and tools out of the hole to recover core, and, of course to reverse the procedure before continuing to drill. The time and money involved in doing such unproductive work was evident. It became of greater significance as the hole went deeper. Of equal importance in many cases was the damage inflicted on the hole wall by the frequent removal and reinsertion of the drill string.

About twenty-five years ago, a wireline system of core drilling was developed which allowed core to be brought to the surface with the rods left in place until the bit itself required replacement.

With this system, all the advantages of leaving the rods in the hole were realized. Cost was reduced. Core recovery was improved, and the hole was preserved.

With the worldwide acceptance of the wireline system, the economic advantages of a retractable bit became obvious to all in the core drilling industry. Thought turned to the possibility of retrieving and replacing the bit itself. This was seen as the ultimate in rod handling cost reduction, hole preservation, and convenient bit inspection.

The obvious potential value of bit retractability encouraged the start of a number of projects to develop it as a commercial product. Patents were granted for several project concepts. However, none of the attempts produced a commercially available product. In general, failure could be attributed to the inherent cost of such a project, its complexity, and the lack of a variety of technical skills to be applied to the problem.

Bureau of Mines Contract

The U. S. Bureau of Mines and Longyear Company, both recognizing the savings potential of a retractable bit system, joined in a cost sharing contract to develop a successful retractable bit. The Bureau of Mines sponsors research projects into mining related technology areas of concept and hardware development which individual companies find too financially risky to pursue alone. The Bureau of Mines-Longyear team brought together the needed technical experience, expertise, research and development management, and capital for a well-defined and well-executed project. Doerfer, a division of Container Corporation of America, subcontractor to Longyear and third member of the team, provided its engineering concept and design services and prototype fabrication facilities.

In order to retain all the previously achieved advantages in minimizing rod handling costs and to make all elements of the existing system as interchangeable as possible with any newly developed retractable bit system, the team decided to make the project an extension of the wireline system.

3.0 OBJECTIVES

3.1 Project Objective

The objective of the project was to develop a commercially available retractable drilling bit system for use in the mineral exploration industry.

3.2 Phase Objectives

The project was divided into 4 phases.

Phase I - State-of-the Art Investigation - 8 Months

The objectives of Phase I were to review, compile and evaluate past efforts; to search for literature and patents; and to discuss the project with research and drilling personnel. Parametric values and design criteria were to be identified and developed for use in the remaining phases of the project.

Phase II - Concept and Design - 8 Months

The objective of Phase II was to conceive and design a retractable bit system for fabrication and testing in Phase III.

Phase III - Prototype and Test - 8 Months

The objective of Phase III was to fabricate, laboratory test, and evaluate the initial prototype of the retractable bit system so that final system fabrication and field testing could occur in Phase IV.

Phase IV - Final Fabrication and Field Test - 18 Months

The objective of Phase IV was to fabricate, field test, and evaluate the entire retractable bit system and to report the results, conclusions, and recommendations of the project.

4.0 DEVELOPMENT OF THE RETRACTABLE BIT SYSTEM

4.1 Past Approaches to a Retractable Bit

Previous approaches to designing, and fabricating a retractable bit system have evolved around two general categories:

1. Totally collapsible bits, and

2. Pilot bits with expandable reamers.

Domestic patents on both types of concepts go back to the late 1800's and illustrate the long-time desire to reduce the nonproductive drilling time associated with pulling the rods out of the hole to change the bit. (Phase I of the project was directed toward a complete review of all known data regarding previous attempts, and a brief discussion of the more recent attempts at developing a retractable bit is presented.)

Totally Collapsible Bit

The totally collapsible bit concept is composed of several segments that join to make a single bit. These segments travel through the drill string in a cluster or in a line, one above the other. Mechanically the segments unfold or track into place forming the core bit. Retraction is achieved by reversing the insertion process by collapsing and withdrawing the bit.

Three research projects using the collapsible bit concept have been conducted within the past 15 years. The U. S. Government, through the National Science Foundation and the National Aeronautics and Space Administration (NASA), sponsored two of the projects (1, 2). The other project was funded by private industry, a joint effort of Christensen Diamond Products, Longyear Company, and Boart International (3).

Project Mohole, National Science Foundation funded, required a retractable bit able to drill into the earth's mantle to a depth of 31,500 ft. (9600m) below sea level. Project funding was discontinued before testing could begin. Design and approximately 65% fabrication of the parts were completed before project termination.

The Mohole bit, consisting of three segments (Figure 1), was designed to drill a 9.875 in. (251mm) diameter hole with a 2.000 in. (51mm) diameter core. The segments sequentially retained by the inner tube were locked into the drill string by lowering the inner tube assembly into place. The segments were oriented by an arrangement of carriers, cams, rollers and ramps (1, 4, 5, 6).

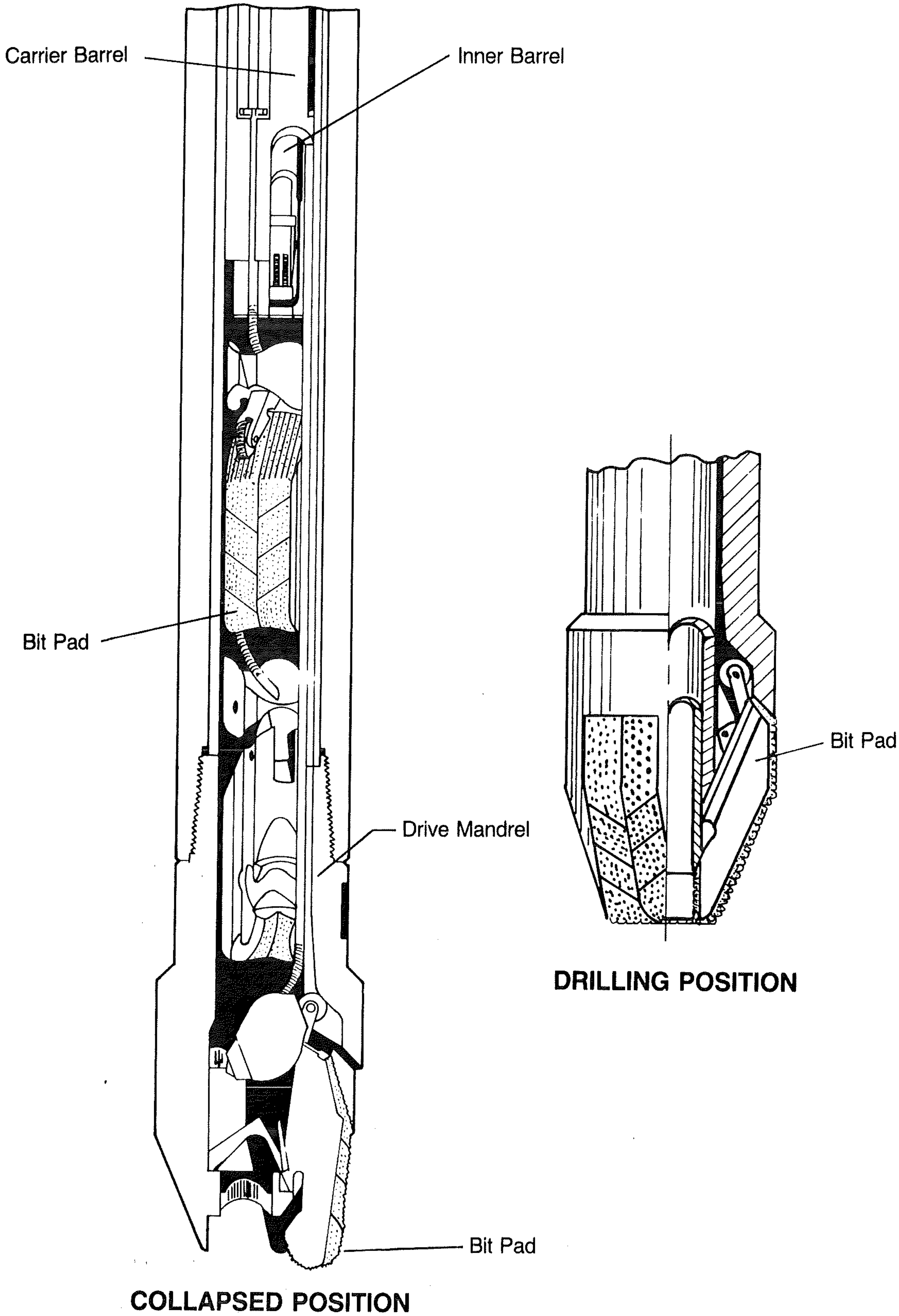


FIGURE 1 - Project Mohole Retractable Bit

The joint private industry effort envisioned the development of a commercial retractable bit suitable for diamond core drilling; whereas, the Mohole bit was found to have too small a core-to-hole ratio to be practical for most core drilling. For example, one core drilling company's N-size core equipment produces a 1.875 in. (48mm) core from a 2.980 in. (76mm) hole, a 0.63 core to hole ratio compared to 0.20 ratio for the Mohole bit.

The joint effort system consisted of more bit segments (Figure 2), 6 segments compared to 3, but eliminated many of the rollers, cams, and ramps found in the Mohole concept. The two sets of 3 segments or wedges formed the bit. During the short test program four holes were drilled for a total of 192 ft. (58.5m) with 121 ft. (36.9m) of core recovered. The system had 69 successful bit changes out of 103 attempts (3).

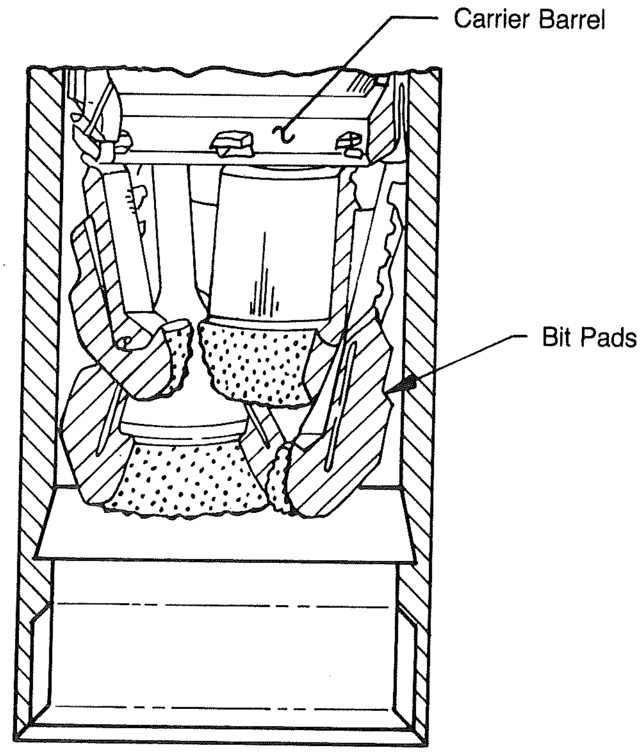
The joint venture was discontinued at this point. The retraction components were many, not rugged, and were complicated to manufacture. These factors and the low reliability caused the abandonment of the project (3). Patents were granted and are referenced in this report (7, 8).

The NASA system was not taken beyond the conceptual stage. A patent was granted (9). This bit was similar to the joint effort concept in that it consisted of wedging bit segments. One difference was that the bit segment carrier was not attached to the inner tube (2). The concept had the drawback of a multiplicity of parts which could not be made rugged and still maintain acceptable core-to-hole ratios.

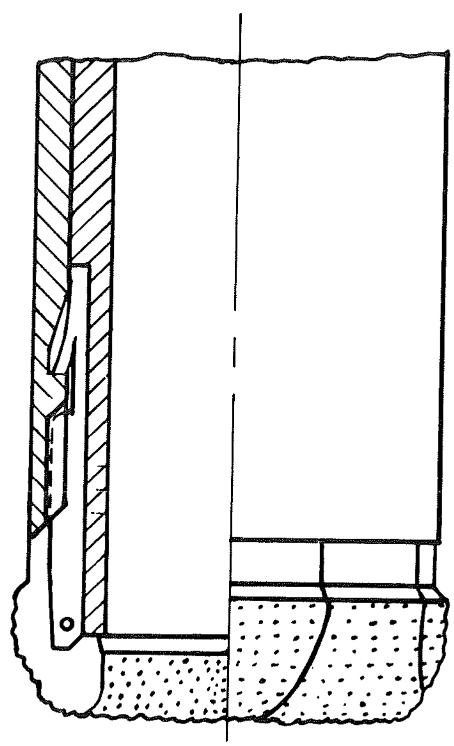
Pilot Bit with Expandable Reamers

The pilot bit with expandable reamers consists of a core barrel that cuts the hole from the core diameter to slightly less than the inside diameter of the drill string. Expandable reamers enlarge the hole providing clearance for the drill string (Figure 3).

Two companies are known to have developed pilot bits with expandable reamers. Sumitomo Company of Japan (10,11) and Mindrill Company of Australia (3) both developed such a system. The nesting tubes included the drill string, the outer tube assembly and the inner tube assembly. The outside diameter of the outer tube was smaller than the inside diameter of the drill string. The pilot bit was attached to the outer tube and the reamers were deployed from the outer tube assembly. The reamers on the Sumitomo concept were located in the core barrel above the pilot bit resulting in a smaller core, while the Mindrill reamers were above the core barrel providing a larger core. The Sumitomo system was fabricated, but no record of actual drilling tests or results was available.



COLLAPSED POSITION



DRILLING POSITION

FIGURE 2 - Totally Collapsible Bit

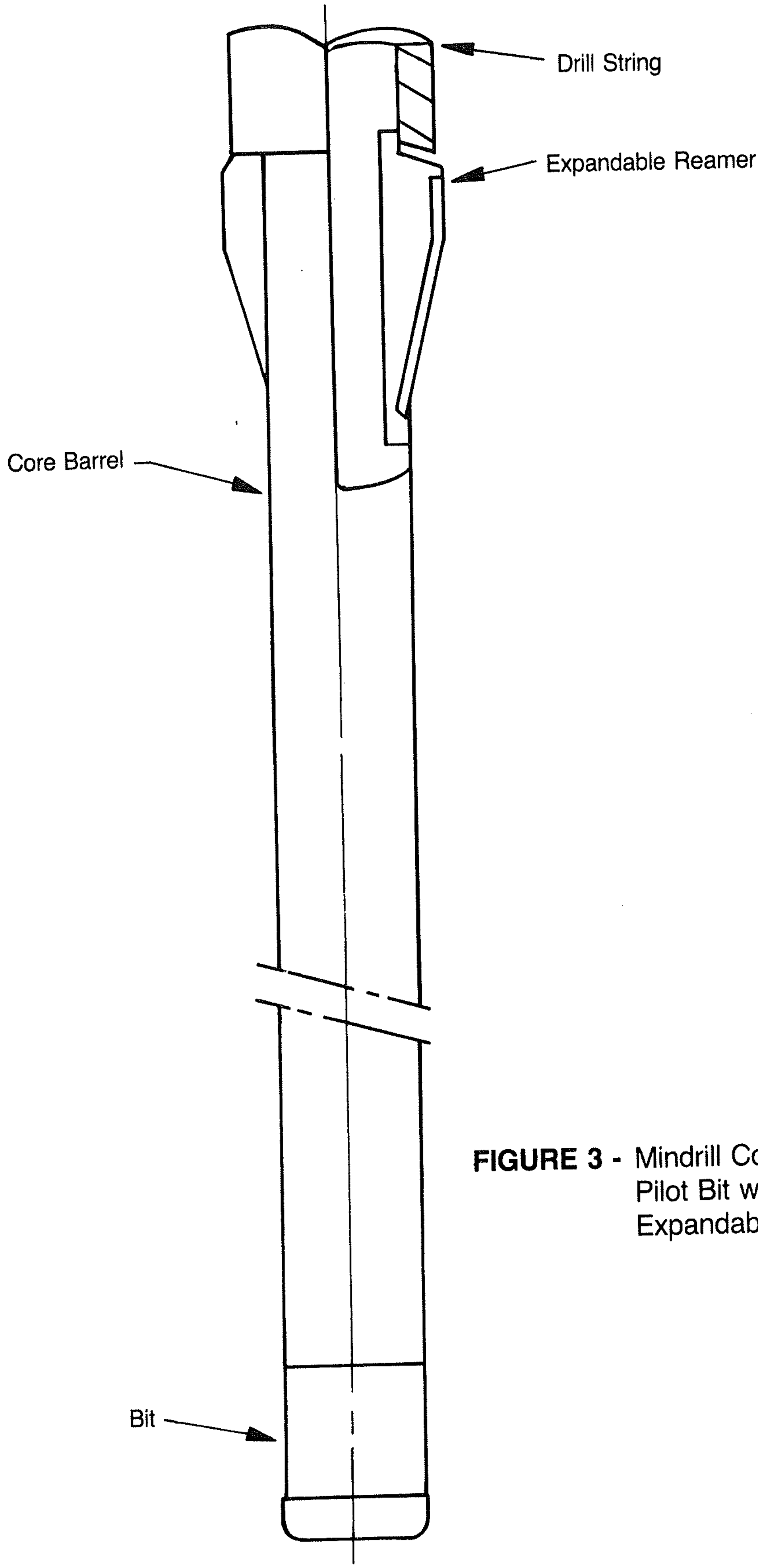


FIGURE 3 - Mindrill Co.
Pilot Bit with
Expandable Reamers

Mindrill began work on its system in 1972 and drilled 5,600 ft. (1710m) before discontinuing the project. Cancellation was caused by the economic infeasibility of solving the problems encountered, including; severe rod vibration, pilot bit/reamer misalignment, binding of the retraction mechanism, water leakage, insufficient structural integrity, and doubtful manufacturability of the reamers (3).

Evaluation of Previous Approaches

The previous approaches, the totally collapsible bit and the pilot bit with expandable reamers, generally had three shortcomings. First, the cutting elements were retracted each time the inner core tube assembly was pulled whether the bit was worn or not. An extremely reliable system was necessary to achieve good system efficiency when subjected to these frequent bit changes. Second, the bit, the consumable system component, was complicated, which led to machining and operating difficulties. Third, the bit and the retraction mechanisms were not rugged enough to endure the rigors of normal drilling. These observations and other information were used in establishing design criteria and in evaluating concepts and designs.

4.2 Design Criteria and Parametric Values

As a result of the state-of-the-art investigation, Phase I of the project, and consideration of provisions and restraints imposed by project definition, the following design criteria were established.

1. The system should operate in a hole of 3 inch (76mm) diameter.

2. The system should conform to standards set forth by the Diamond Core Drill Manufacturers Association (DCDMA) (12).

3. The system should perform at drilling rates and produce core quality equal to present wireline core drilling systems.

4. The system should be operated by competent drill personnel with a minimum of training and without requiring extensive changes in current drilling operations and procedures.

5. The system should be compatible with the present wireline system and include the following wireline characteristics:

   a. Bit and tools should be capable of being raised and lowered on the wireline cable.

   b. System should be as rugged, reliable, and safe as the wireline system.

c. System should break, retain, and extract core as efficiently as the wireline system.

6. The system should be capable of operating under extreme environmental conditions.

7. The system should have interchangeability of replacement parts.

8. The system should employ high-wear components which are easy and economical to replace.

9. The system should maintain I.D. and O.D. gauge, core and hole diameters.

10. The bit, whatever its configuration, must lock rigidly into place and be rugged, with few, if any moving parts.

11. The design of the retractable bit should allow the use of various diamond sizes, bit profiles, and matrix material.

12. The system should provide a signal to indicate that the bit and associated elements are locked into the proper position.

13. The retractable bit should be as economical as possible and designed for ease of fabrication.

14. The system should utilize standard, commercially available components where possible.

15. The system should have fluid clearances equal to those of current wireline systems and allow for the use of drill muds.

4.3 Concept Selection

Eleven distinct concepts were brought to an illustration status, all based on design criteria. Of these, four were considered worthy of further investigation, and three were eventually represented by steel models. The four concepts are shown in Figure 4 - A, B, C, and D, and the three steel models are in Figure 5 - A, B, and C.

The design shown in Figure 4 C, and Figure 5 B was finally adopted as the basis for the system. In addition to meeting the selected criteria above, it alone provided the following advantages:

1. The diamond set portion of the bit could be completely withdrawn.

2. One-piece bit construction gave greater strength and rigidity.

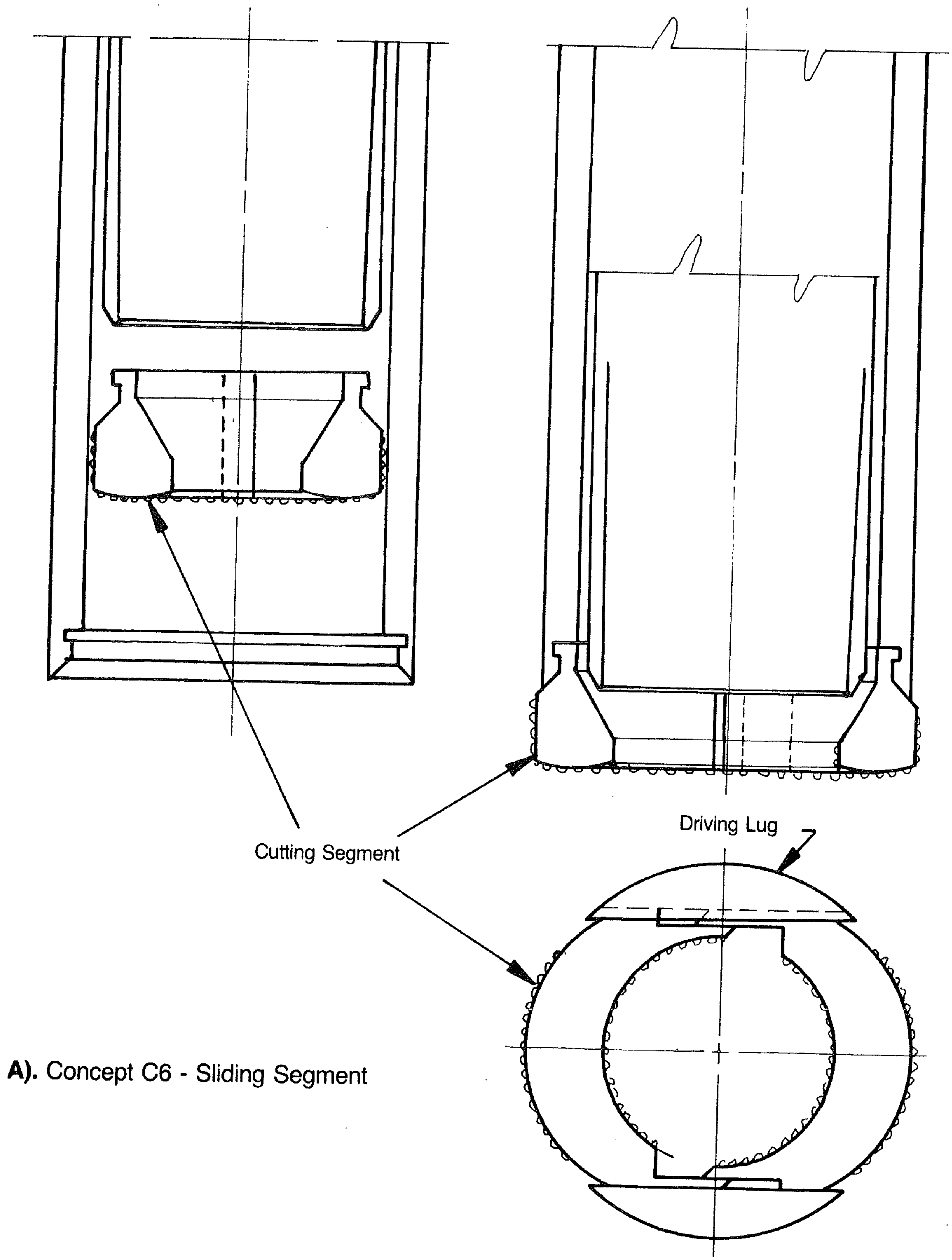
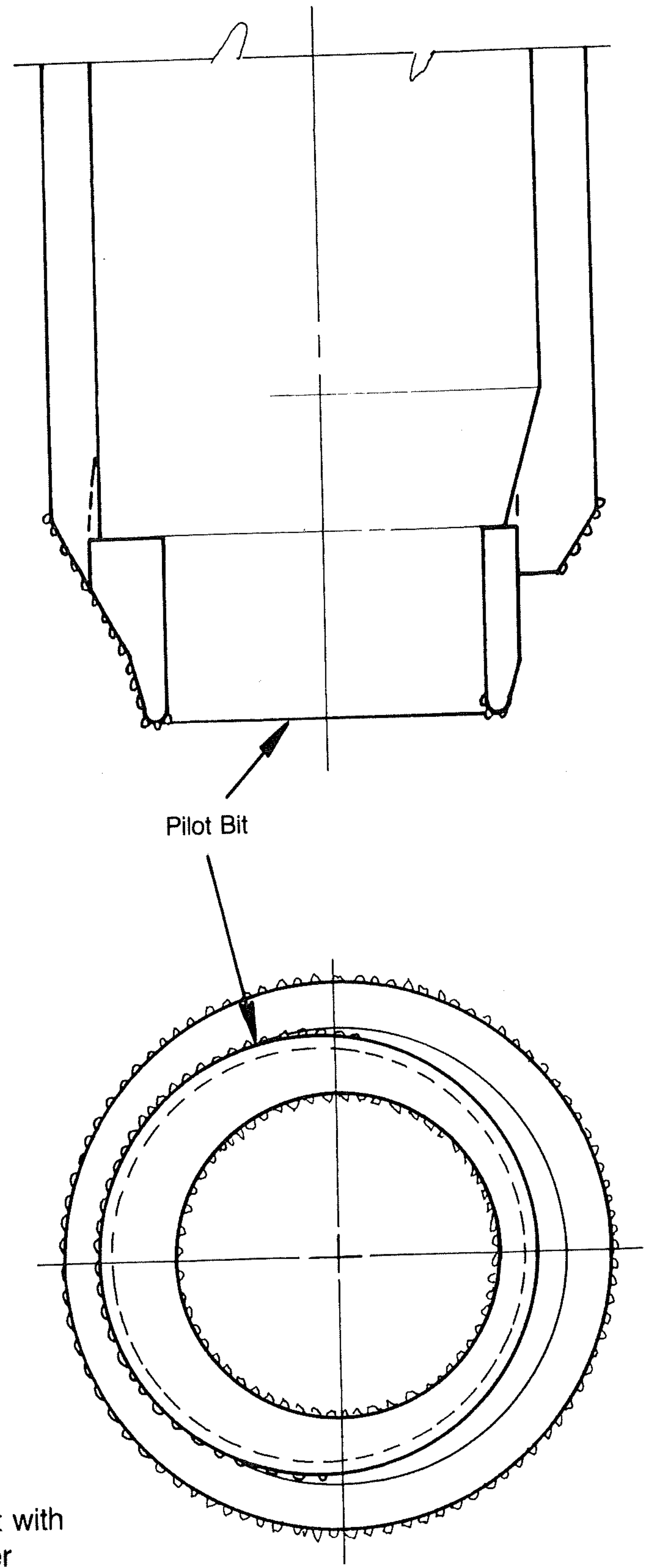
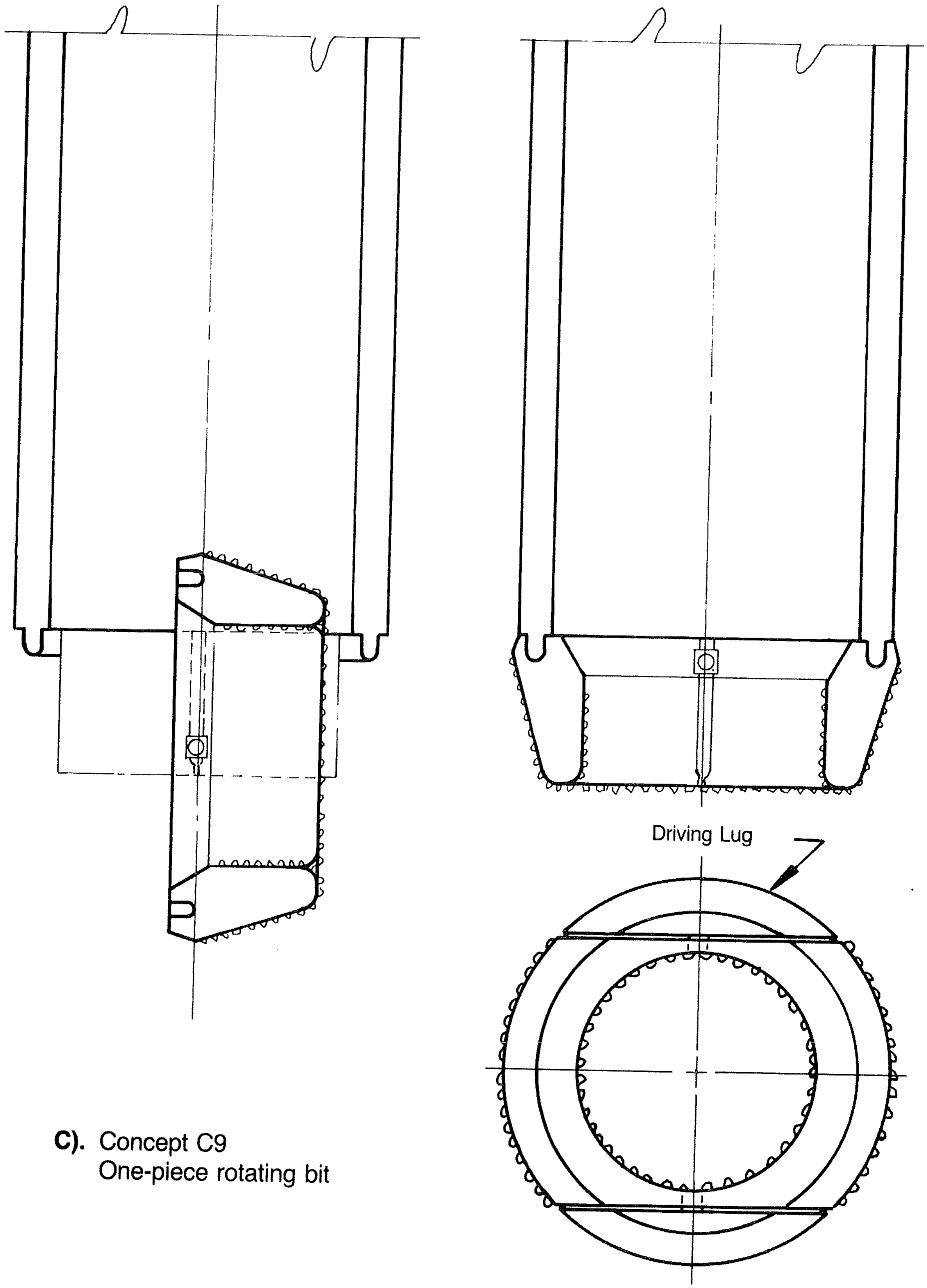


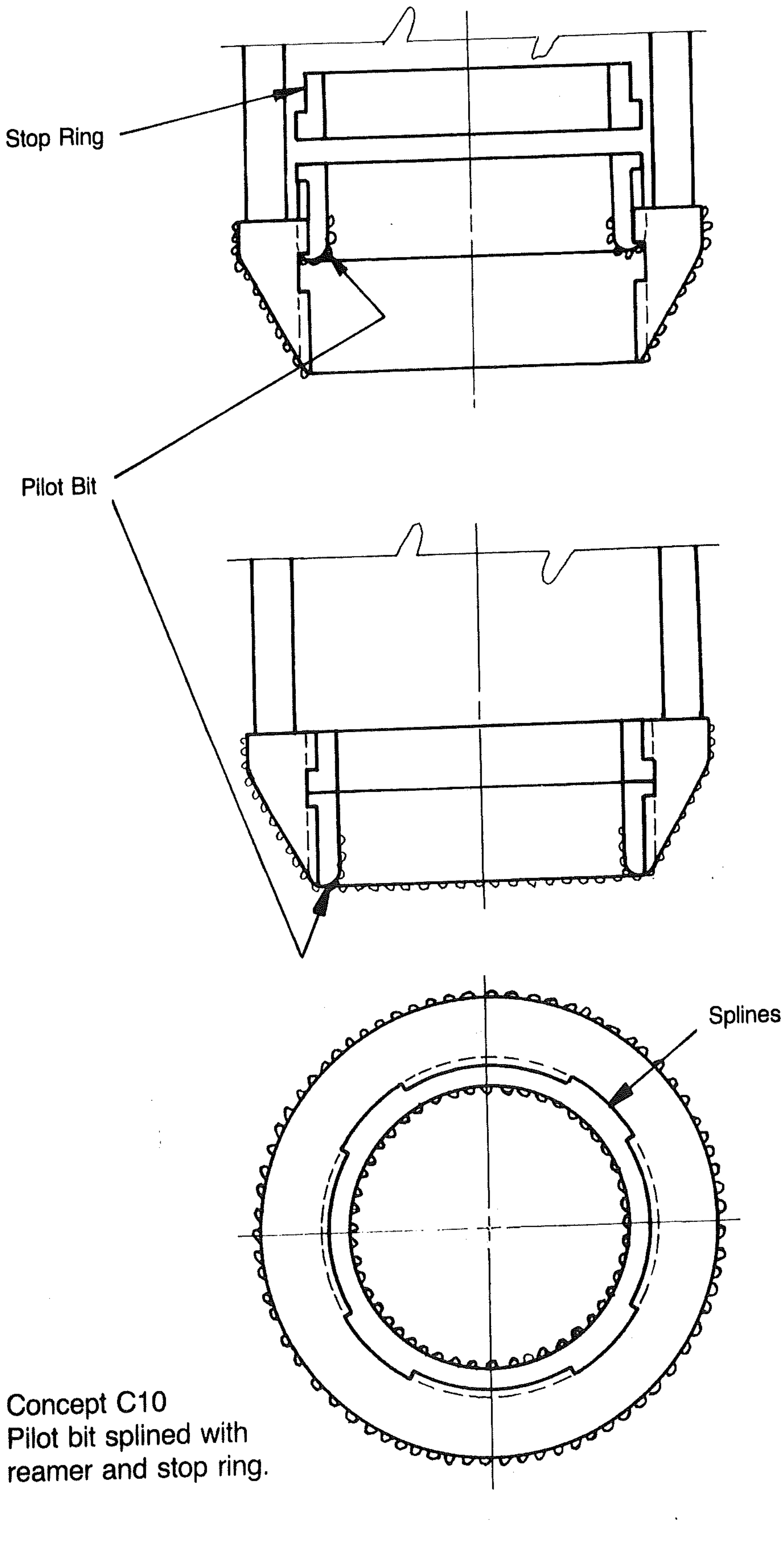
FIGURE 4 - (A-D) - Preliminary Retractable Bit Concepts.



B). Concept C7
Bi-Center pilot with
splined reamer

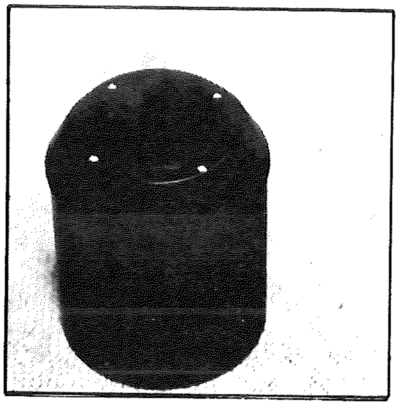


C). Concept C9
One-piece rotating bit

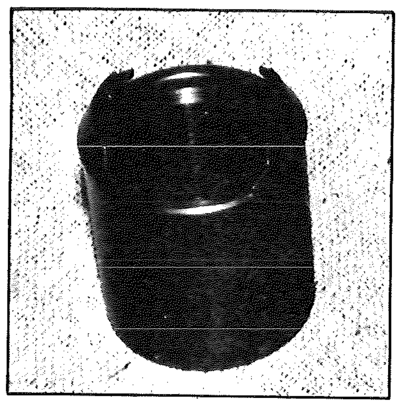


D). Concept C10
Pilot bit splined with
reamer and stop ring.

A). Concept C6-Sliding Segment



Retractable Bit Assembly



Outer
Tube with
Driving Lugs

3-Piece Cutting Element

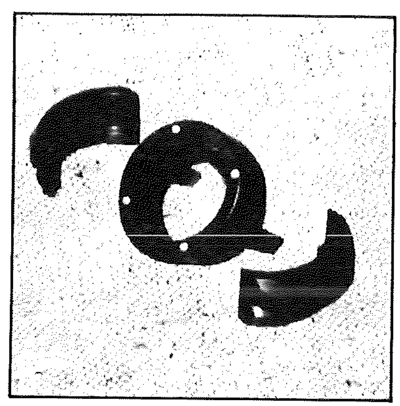
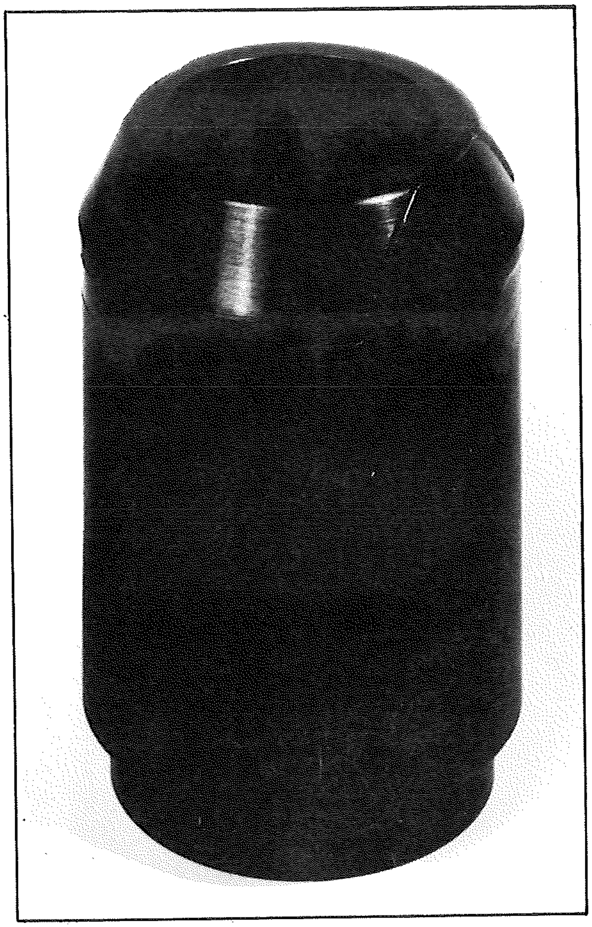
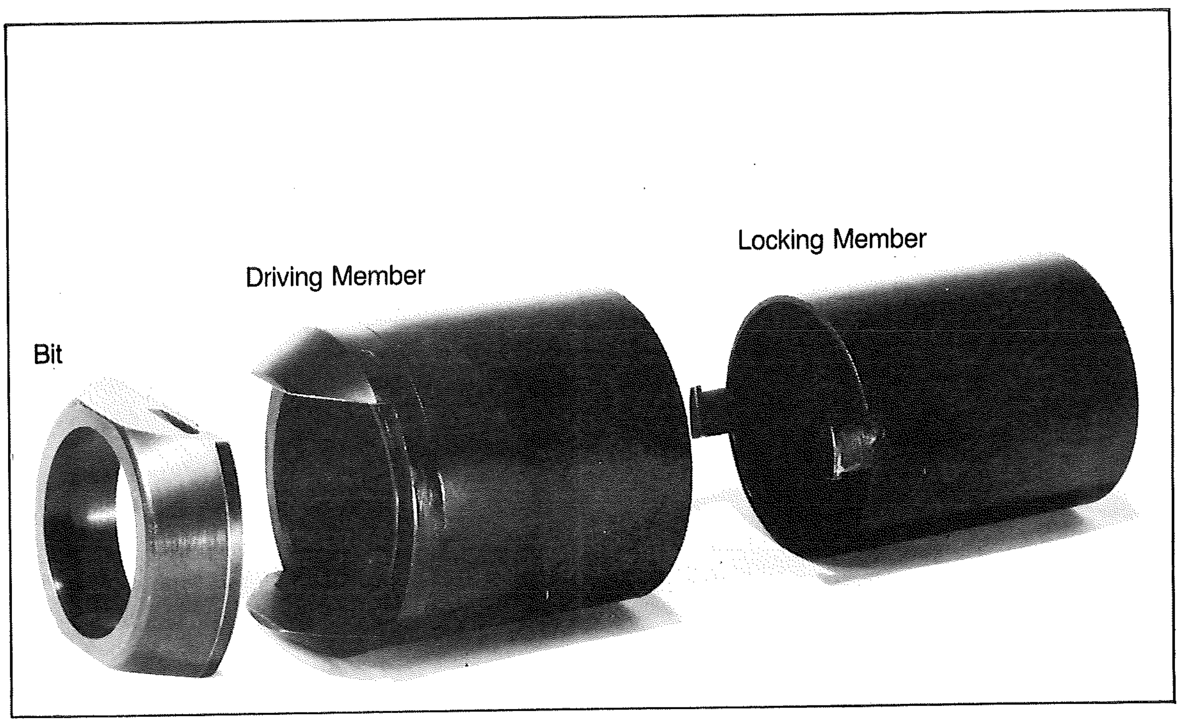


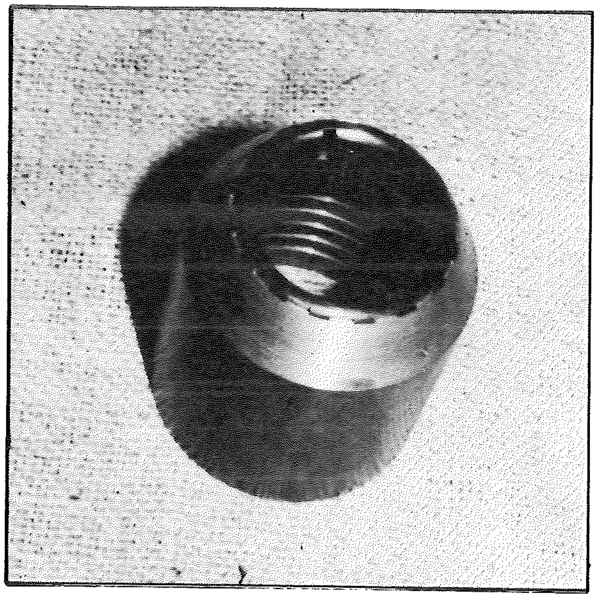
FIGURE 5 - (A,B,C) - Steel models of three of the retractable bit concepts.



B). Concept C9-One-Piece Bit

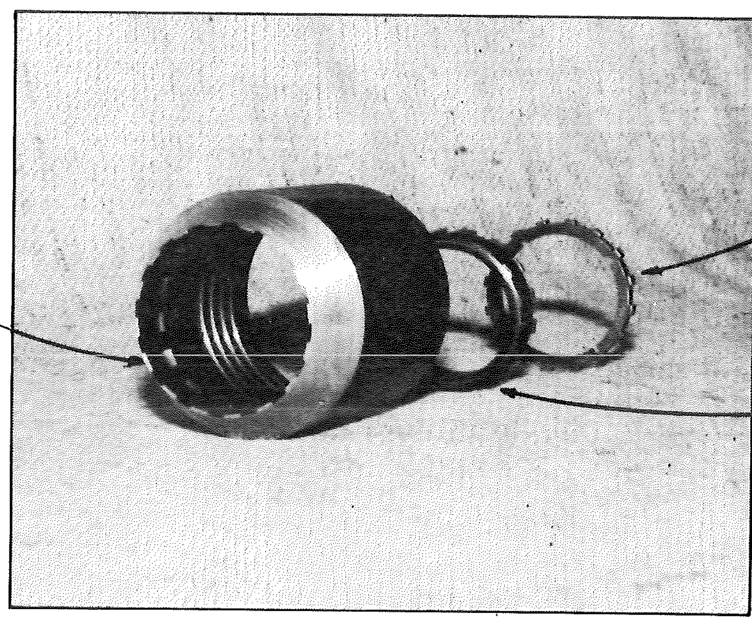
Retractable Bit Assembly





C.) Concept C10-Pilot Bit Splined with Reamer and Stop Ring

Retractable Bit Assembly



3. Simplicity of the bit assured greater reliability.

4. A reduction in diamond content compared to wireline bits was possible in the tapered portion of the bit profile, which is least subject to damage and wear.

5. The bit profile could accommodate a variety of bit configurations.

6. The bit face, which is normally subjected to more wear than the tapered portion of the bit, was equally as rugged as that of present wireline bits.

7. The one-piece bit had fewer mating surfaces making it easier to seal against fluid losses and consequent damaging washing action.

8. The one-piece bit could more consistently hold inside and outside gauge.

9. The one-piece bit avoided the adverse loading on related parts caused by the wedging action inherent in segmented bits.

None of the three discarded concepts had all these advantages. They were more complicated and expensive, and they were considered to be potentially less reliable, structurally weaker, and less rigid.

Previous attempts to develop a retractable bit system involved a design which brought the bit or some part of it to the surface each time the inner tube assembly was withdrawn. The bit had to be put in position each time the inner tube was lowered. Essentially, the number of bit retraction and insertion operations would be equal to the number of coring runs and not related to bit life. This multiplicity of operations spread over bit life (the real determinant of replacement) led to limiting consideration of concepts to those which allowed bit replacement only when the bit needed replacement. A simple example of the difference between the two approaches follows.

The system, which retrieves the bit each time the inner tube assembly is pulled, could be expected to malfunction one out of 10 core runs, if reliability was 90%. However, if the retractable bit were independent of the inner tube assembly (assuming equal reliability), the driller would only have to pull the rods out of the hole once every ten times that the bit was pulled for inspection. This would result in 900 feet of drilling compared to 90 feet for the other system before the rods had to be pulled to change the bit, assuming 100 foot bit life and 10 foot core runs.

Further, the concept of the one-piece bit adopted for this project had potentially greater reliability than did the much more complicated design resulting from the system which attaches the bit to the inner tube assembly.

For these reasons, it was decided to employ the one-piece bit concept, actuated by separate tools for bit retraction and insertion. With this system, changes to the already successful wireline core barrel assembly were minimized. The problems of reliability of the system could be limited to design and operation of the tools, whose operation would be less affected by the drilling conditions encountered.

4.4 General Description of the System Design

The retractable bit system (Figure 6) is made up of:

a. The replaceable bit.

b. A modified wireline core barrel fitted with a bit holder mechanism.

c. Wireline drill rods.

d. A conventional core drill with rod hoisting mechanism and wireline hoist.

e. A packer for the top of the drill string.

f. A conventional core drill pump.

g. A mast and wire rope.

h. A bit retraction tool.

i. A bit insertion tool.

j. Specialized hand tools to service the features involved with bit replacement.

All these elements are in conformity with the concepts described previously, and the concept conforms to the established design criteria.

Items c., d., f., and g. are currently available commercial products and require no special explanation. They also represent the major portion of capital investment for system equipment.

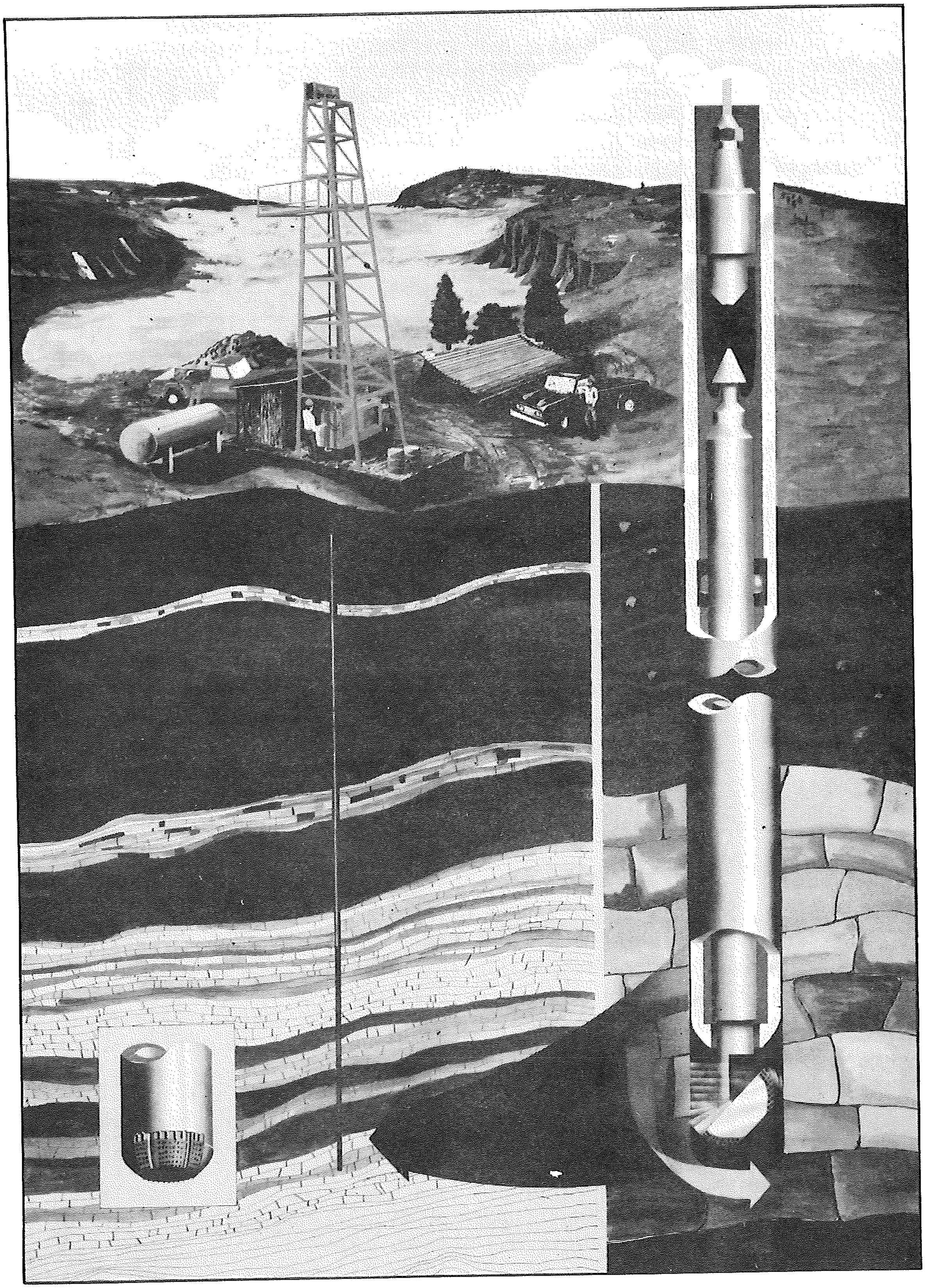


FIGURE 6 - The Retractable Bit System

The system functions as a wireline system in all aspects until it becomes necessary or desirable to change the bit. To change the bit, the inner tube assembly is removed from the core barrel assembly by the wireline system. The retraction tool is lowered through the open drill string by means of the wireline cable. It contacts the core barrel outer tube assembly at which time the top of the drill string is sealed off and fluid pressure is applied above the tool. This locks the tool in place for the retraction operation.

A pull on the wireline cable, which remains attached to the tool, causes it to go through motions which, first, grasps the bit, second, pushes it clear of the bit holder, third, rotates it into position for passing through the drill string and finally releases the tool from the outer tube assembly (Figure 7 A-F).

The tool, with the retracted bit, is hoisted to the surface where the bit is removed. The tool which replaces the bit is provided with a new bit held in place at its lower end. It is lowered through the drill string, and the operations described above are repeated. The insertion tool functions to put the bit in place, duplicating in reverse order the motions of the retraction tool. The inner tube assembly is then returned to its operating position, and drilling is resumed.

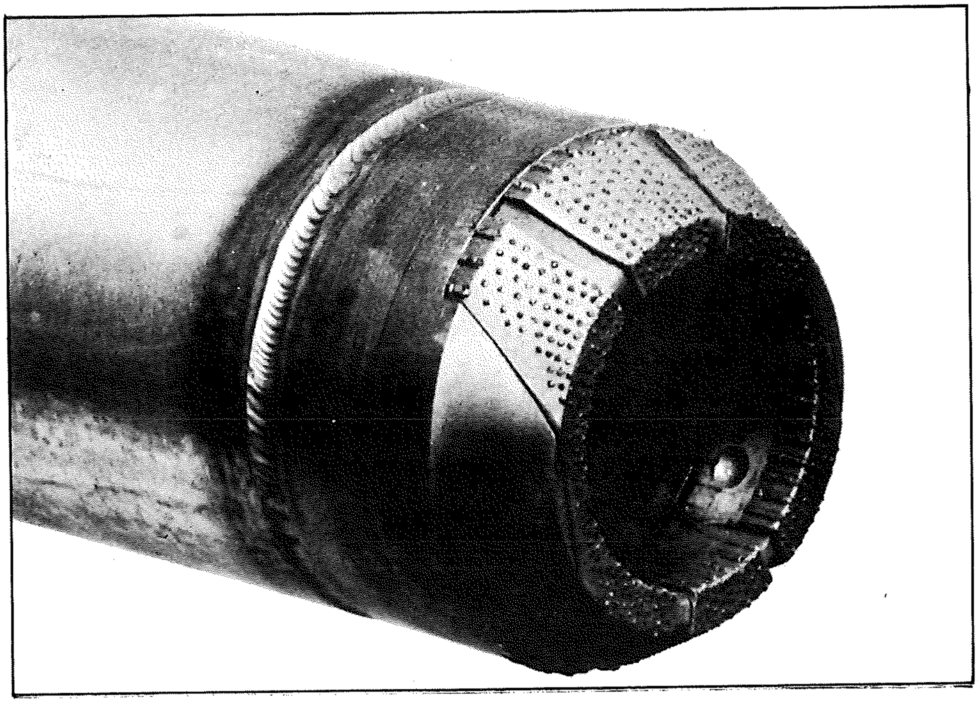
Both tools are alike in appearance, size, and internal construction. The only difference is in the drive mechanism which transforms the upward pull of the wireline cable into the variety of motions imposed upon the bit, to either remove it in one case or replace it in the other.

4.5 System Components

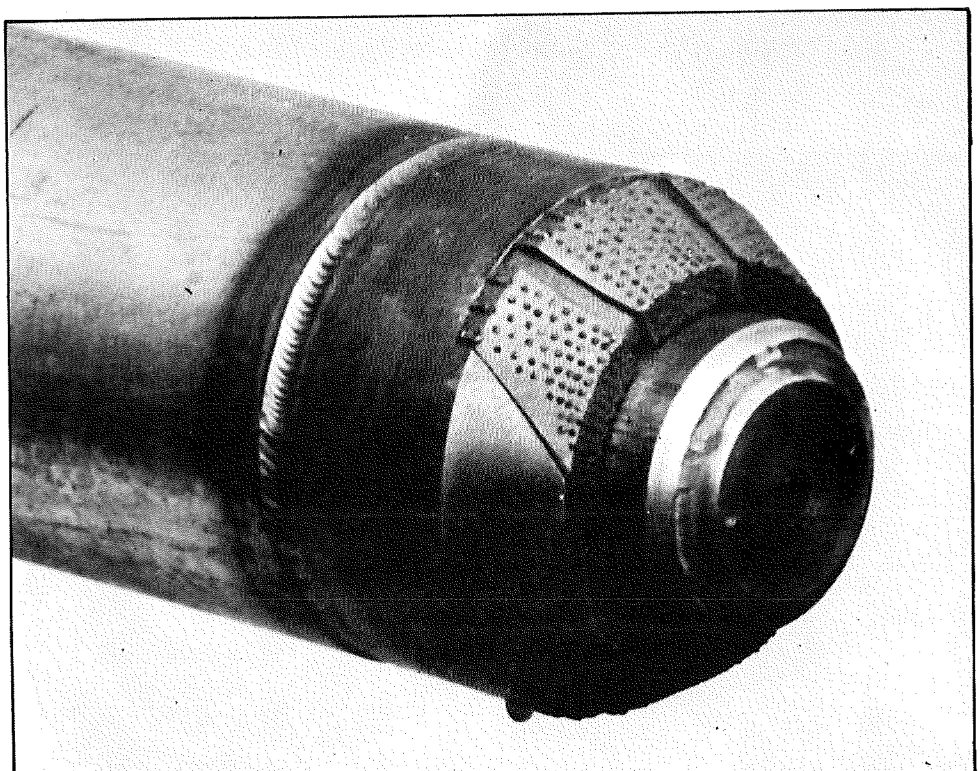
a. The Replaceable Bit

The bit is a one-piece diamond set element (Figure 8) positioned for drilling by two steel lugs and held by a locking device incorporated within the bit holder of the outer tube assembly of the wireline core barrel. Its external configuration is similar to that of a wireline bit (Figure 9) except for omission of two portions which provide the interface with the driving lugs.

The design allows for a multiplicity of external configurations, diamond settings, etc. just as with the wireline bit. The two basic differences between it and the wireline bit are in the manner of fastening to the core barrel outer tube assembly and in the omission of part of the circumferential surface in the area which abuts the driving lugs.

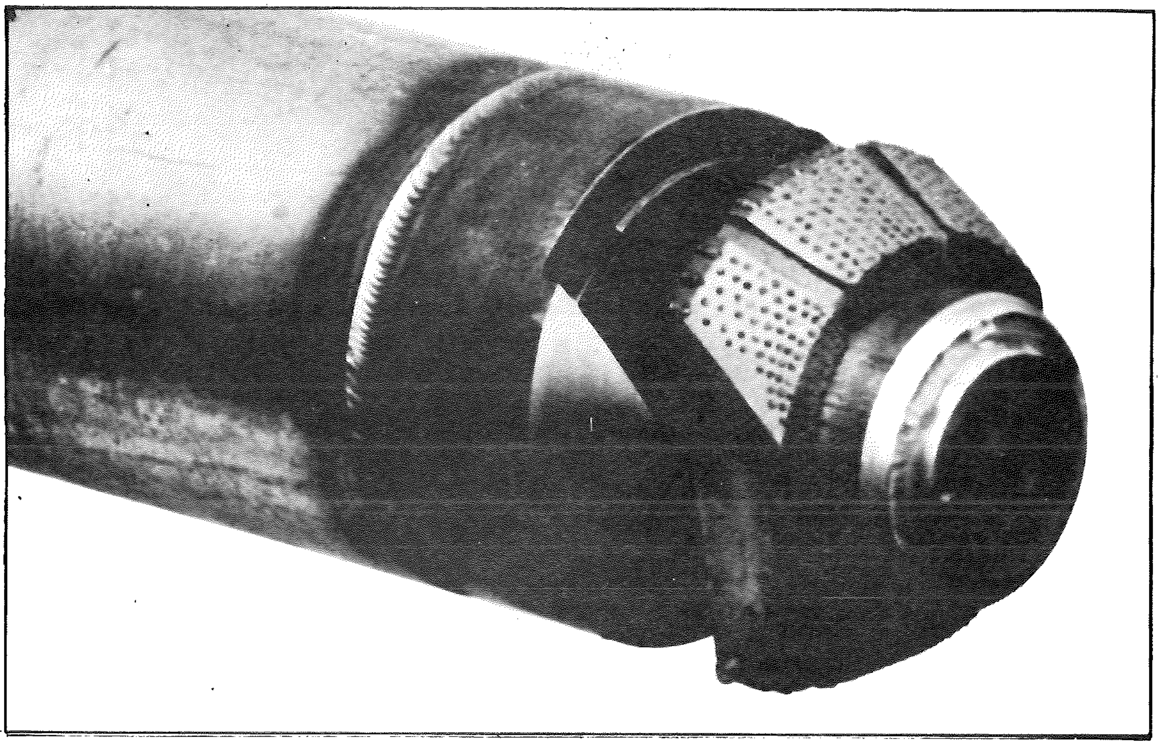


A). Retractable bit after drilling.

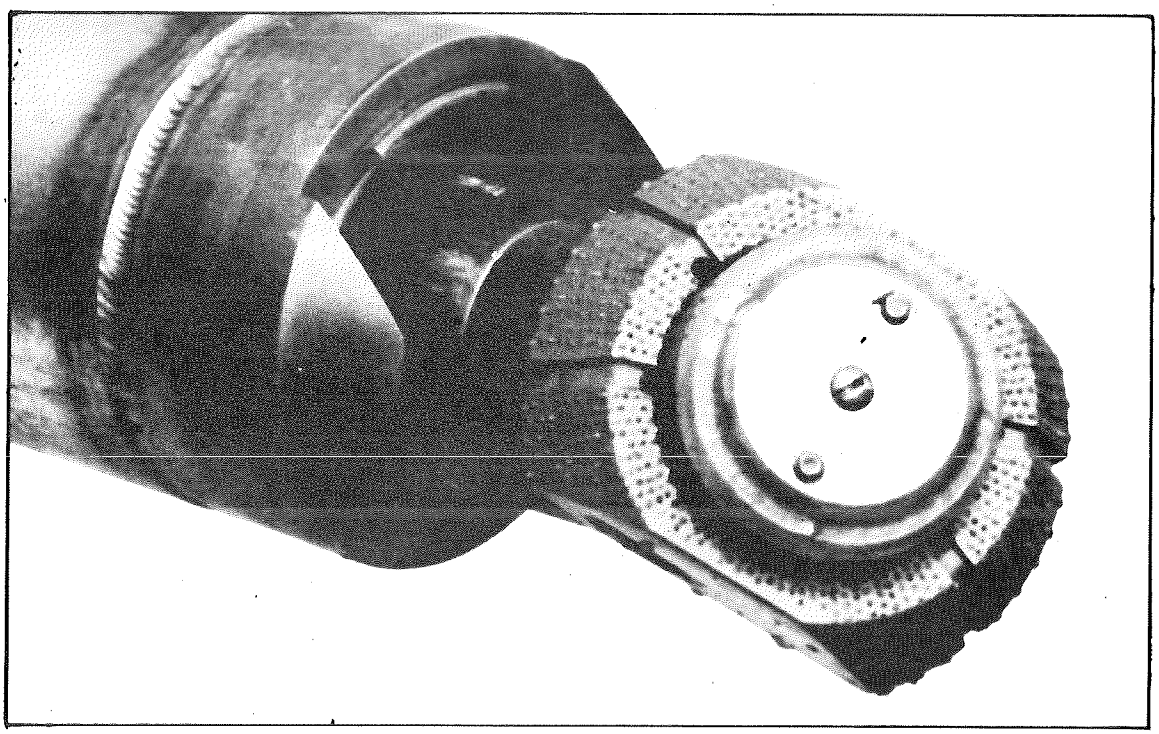


B). Retraction tool engaged, and ready to start retraction process.

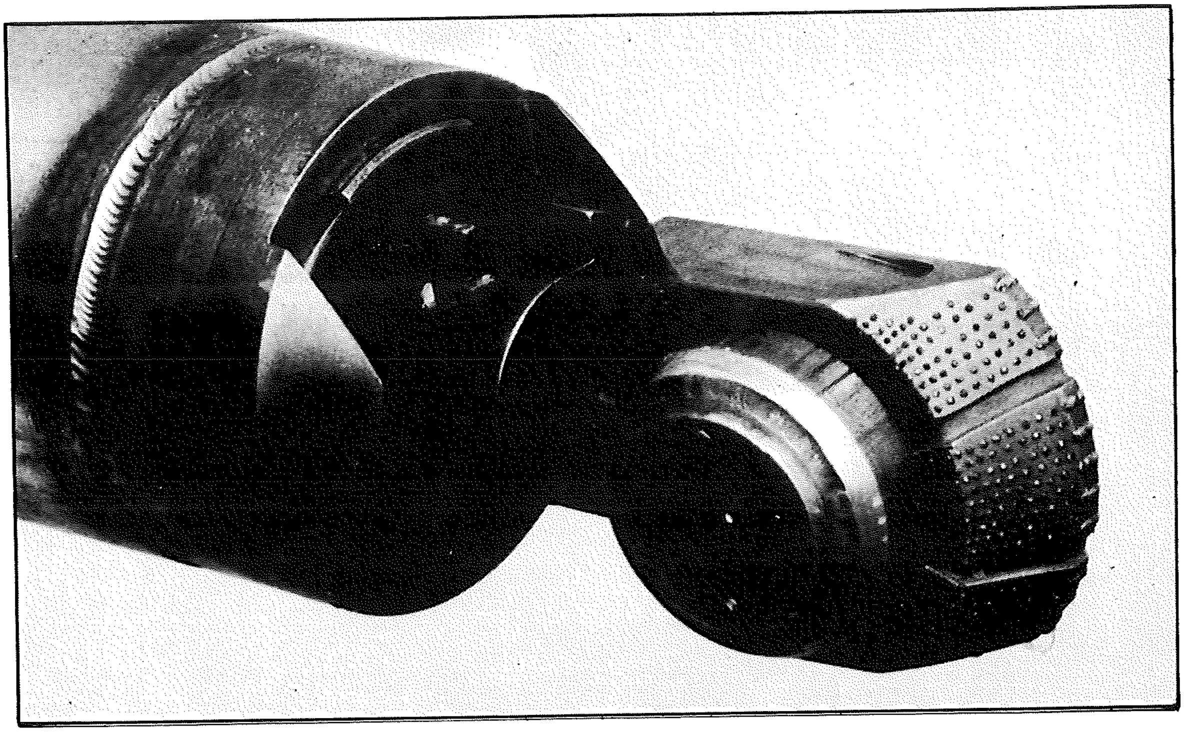
FIGURE 7 - (A - F) - Series of six photographs showing a bit retraction sequence from the drilling position **(A)** to the full retracted position **(F).**



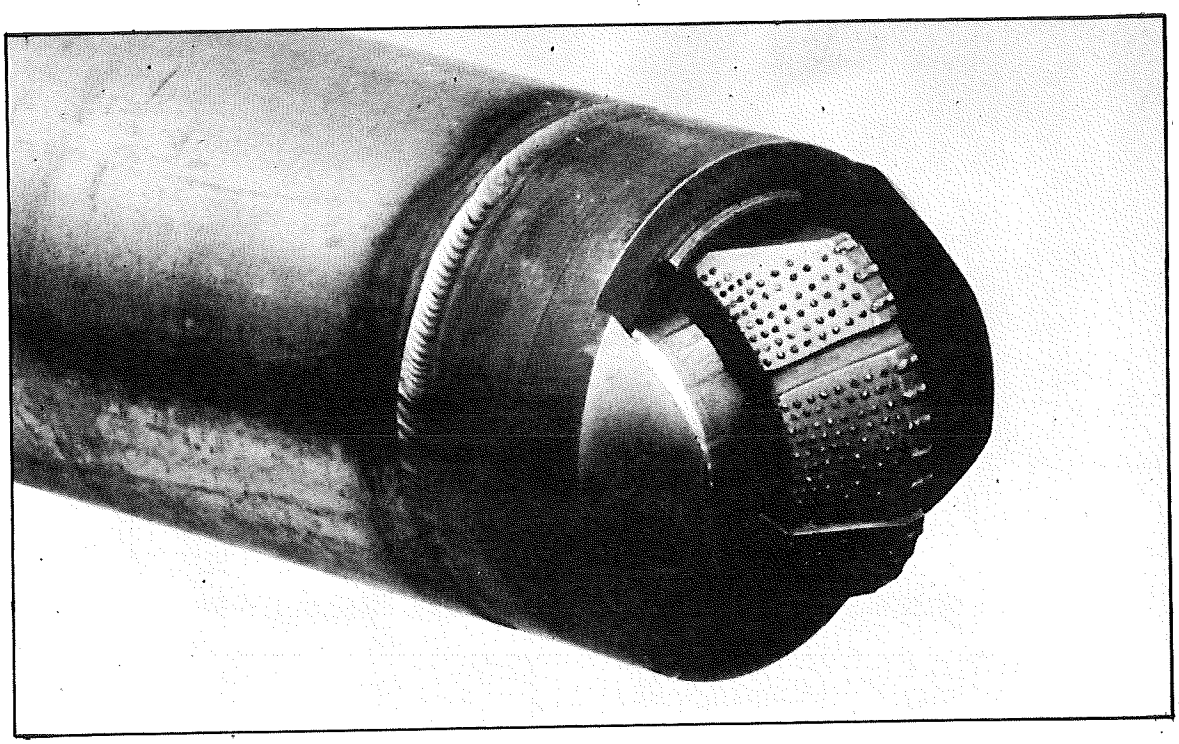
C.) Retraction tool pushing core bit clear of the bit holder.



D). Retractable bit undergoing longitudinal and lateral rotations during retraction cycle.



E). Retractable bit in final orientation at the end of the retraction cycle.



F). Retractable bit being pulled through the drills rods.

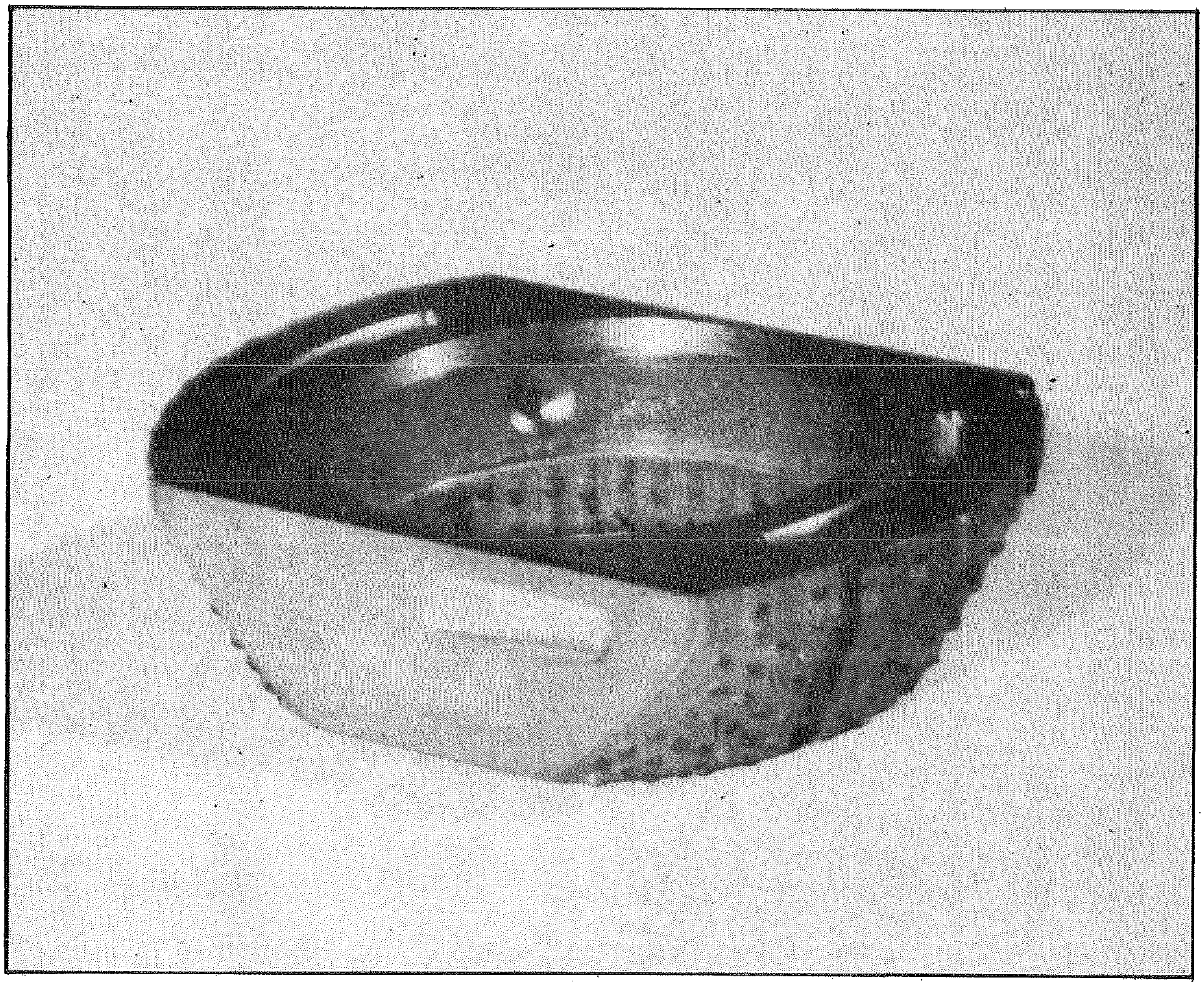


FIGURE 8 - The Downhole Changeable, Retractable Bit.

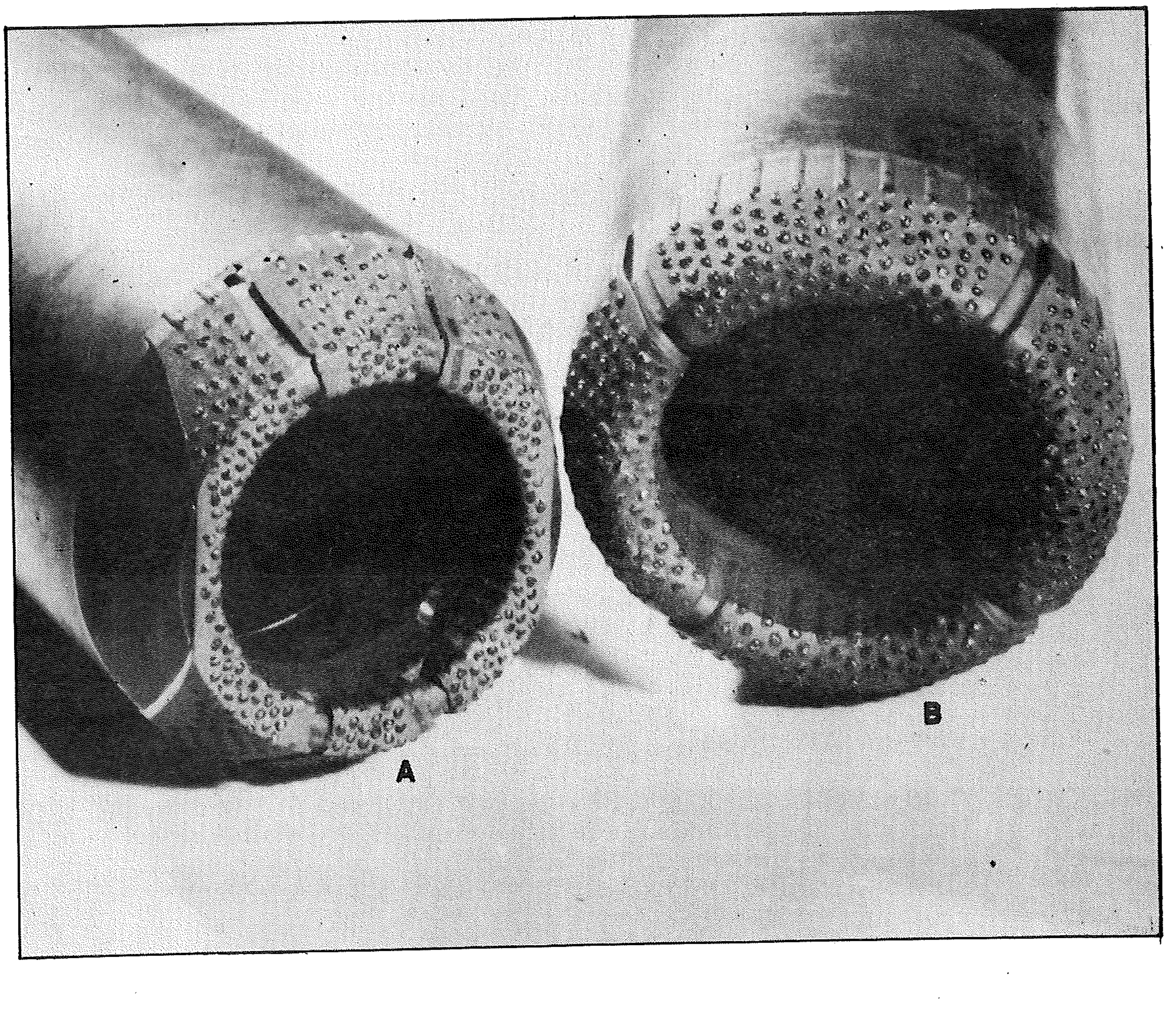


FIGURE 9 - The retractable bit (A) and a wireline bit (B).

The novel configuration of the bit allows it to be passed through the drill string, when it is removed from its drilling position between the lugs, and rotated in such a way as to make its smallest dimension available for passing through the drill string. When the bit is in the drilling position, the hole and core are still cut in a conventional manner.

b. The Modified Wireline Core Barrel

So far as the drilling operation is concerned, the modified wireline core barrel employed in the retractable bit system operates exactly as does the conventional wireline core barrel. The basic modification is represented by the addition of a bit holder (Figure 10). This device is fitted on the lower end of the outer tube and when actuated by the retraction or insertion tool releases the bit for withdrawal or locks the new bit in place. It does not interfere with the normal function of the inner tube assembly.

One minor modification to the wireline core barrel is the provision of a groove in the landing ring into which the inserted tool is locked prior to its bit replacement or withdrawing operation. Another difference is a direct connection (no spring) between the inner tube and the spindle bearing.

As a consequence of the retractable bit design, the diameter of the core cut in a N-size (3 inch or 76 mm) hole is reduced by 1/8 inch (3.2 mm). This is not considered a serious handicap.

A change from drilling with the retractable bit system to drilling with the present wireline system requires only a change of core barrels or minor modification of existing barrels.

c. Wireline Drill Rods

Conventional wireline drill rods are employed in the system. Hole size and annular fluid passage areas are maintained. There is no discernable difference in loads applied and stresses induced due to drilling with the retractable bit system.

d. The Drill, Rod Hoist, and Wireline Hoist

These elements of the system remain identical with those now used as do loads and stresses imposed upon them.

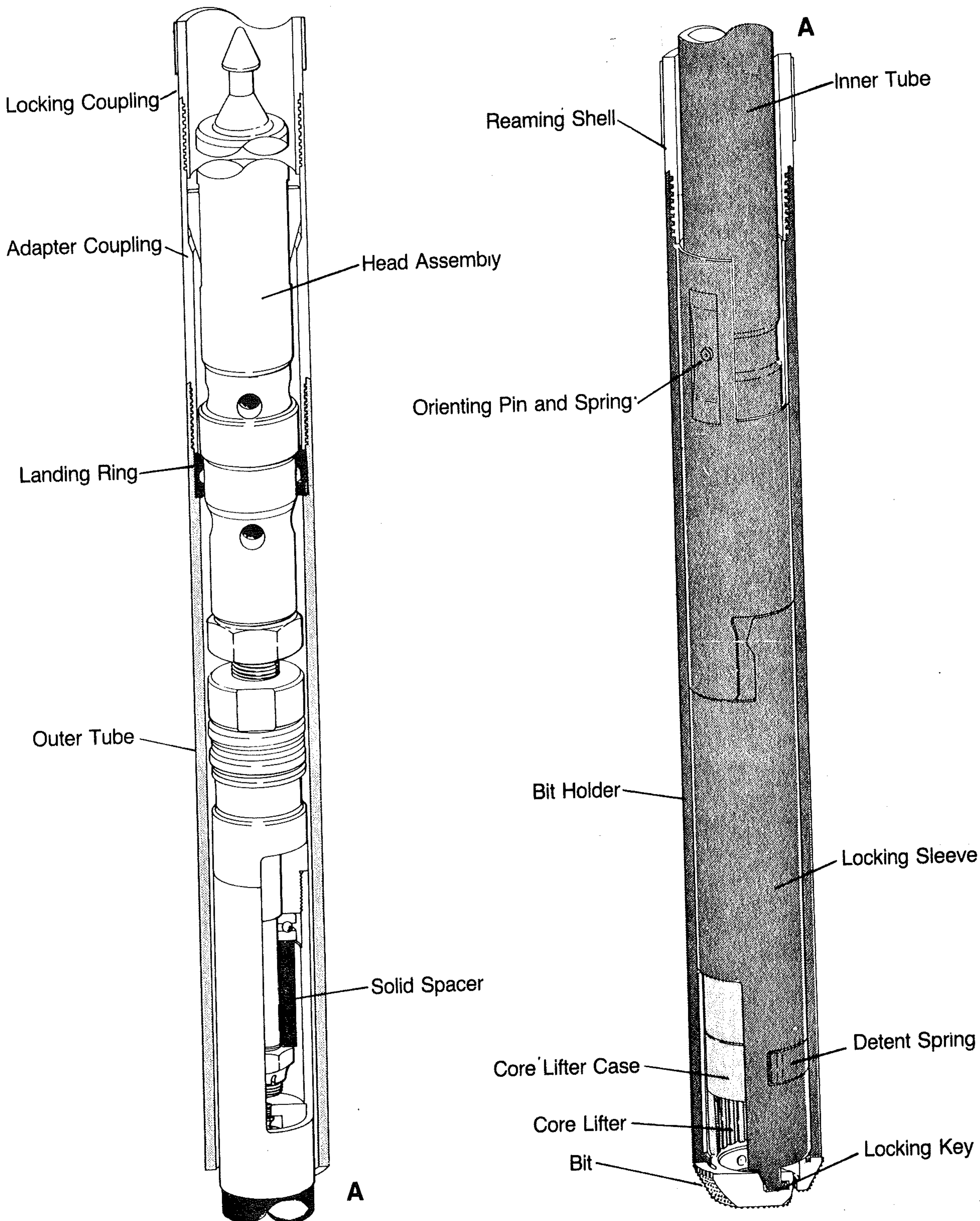


FIGURE 10- The Retractable Bit System Core Barrel

(Unshaded parts are the same as wireline core barrel parts. Medium shaded parts are changed in dimension only. Dark shaded parts are new configurations.)

e. Packer at the Top of the Drill String

This assembly (Figure 11) is threaded to the top of the rod string allowing fluid pressure to be applied through the drill string to lock the tool in place prior to its retraction or insertion action. Since the wireline cable remains attached to the tool, the packer is designed to allow pressurization while sealing around the cable.

The mechanism is simple in design, relatively inexpensive, and easily handled and removed.

f. The Pump

The conventional drill pump is used with no alterations. In the retractable bit operating procedure, its function is to supply fluid pressure which locks the tool in place. A separate retractable bit fluid circuit is connected to the pump, and a relief valve is included to release fluid at the desired pressure, which indicates that the tool is in place.

g. Mast and Wire Rope

No change from conventional equipment is required in these elements nor in the operational procedures now used.

h. Bit Retraction and Insertion Tools

Since these two tools (Figures 12 and 13) are identical in design and appearance except for one part, their operation will be described as one. The difference is that the direction of motion of the drive mechanism is opposite between the tools.

As simply as might be stated, the retraction tool contains mechanisms which, after the tool is lowered and encounters the core barrel outer tube assembly:

1. Lock the tool in place, ready for subsequent operations when subjected to fluid pressure.

2. Transform the pulling forces applied by the wireline cable into a series of mechanical actions which progress the internal mechanism through movements which (Figure 7 A-F):

    a.) Grasp the bit.

    b.) Advance it into the drilled hole clear of the end of the bit holder.

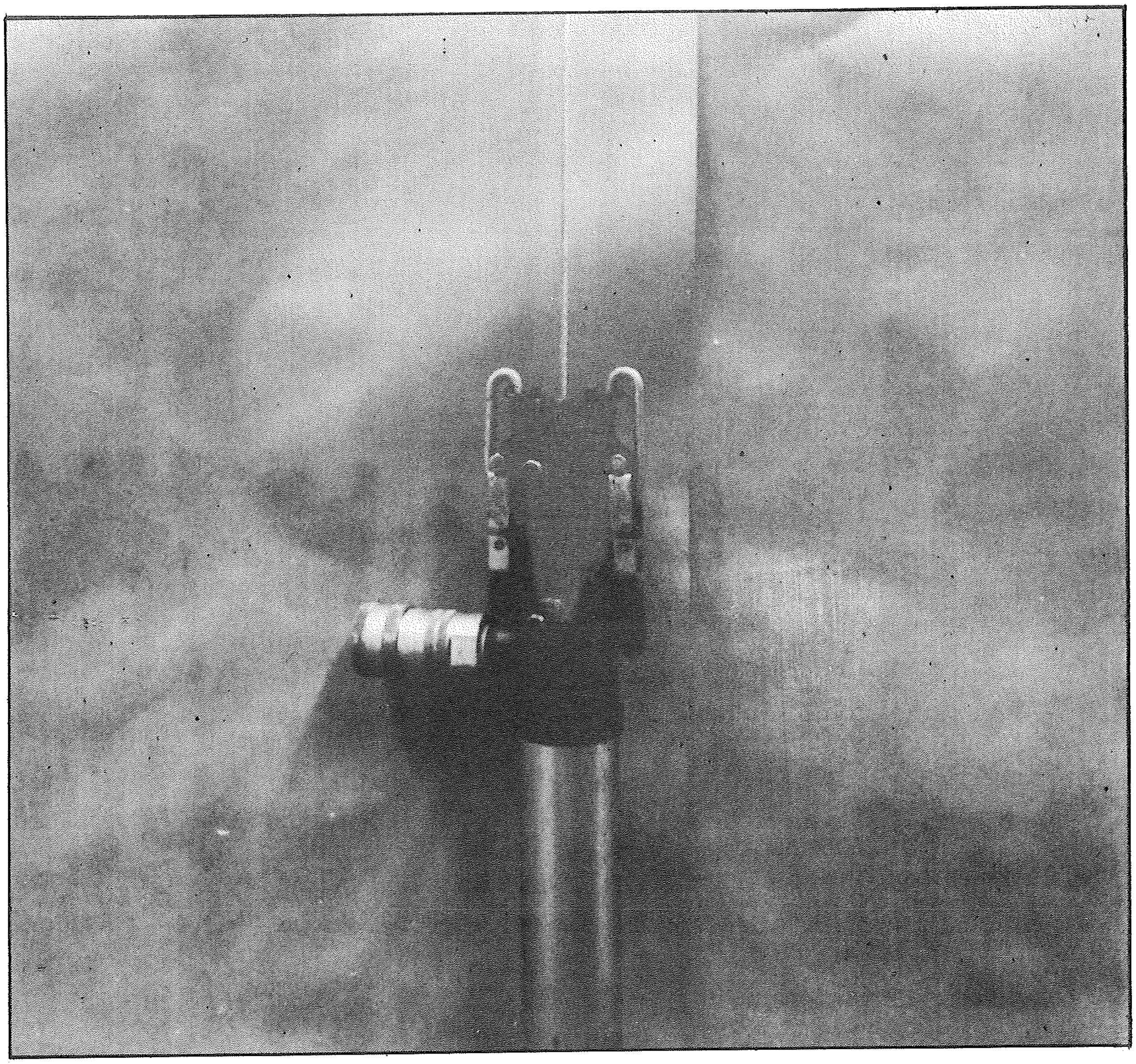


FIGURE 11 - The top of the drill string packer for the retractable bit system.

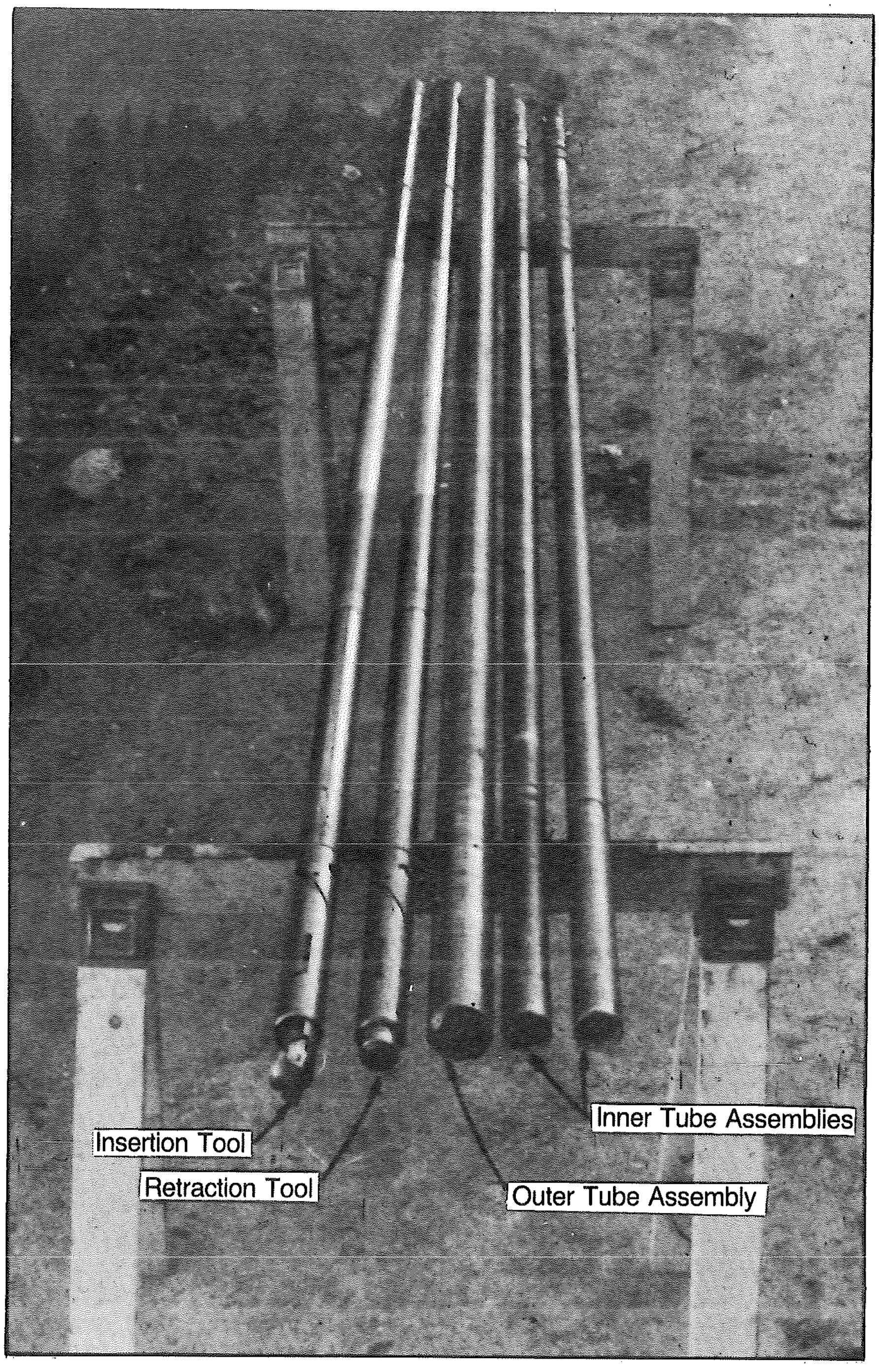


FIGURE 12 - The retraction and insertion tools and the retractable bit system inner and outer tube assemblies for 10 ft. (3m) core runs.

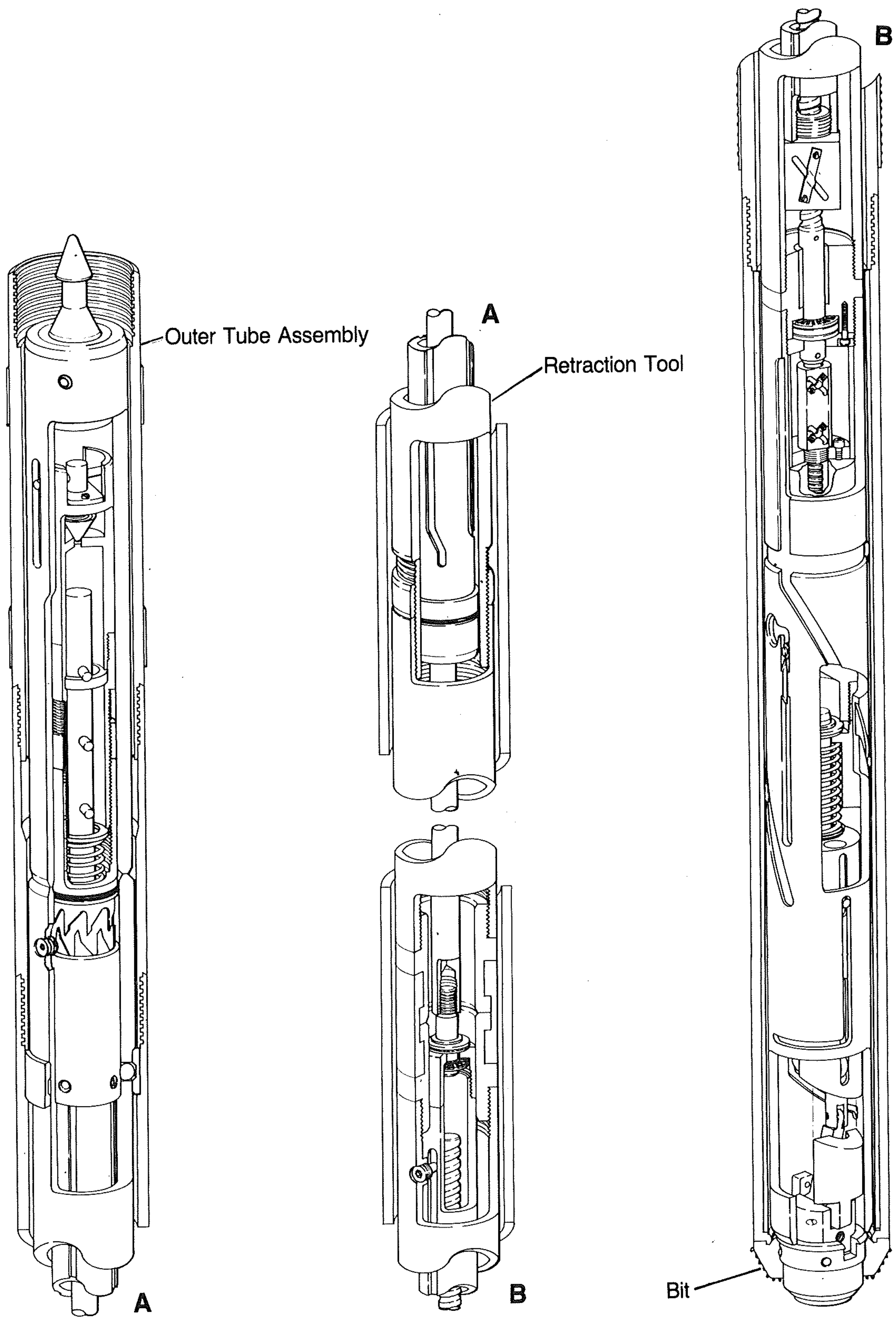


FIGURE 13 - The Bit Retraction Tool

c.) Rotate the bit into a position that will allow its passage through the drill string.

d.) Release the tool from the outer tube assembly, thus enabling the tool and bit to be withdrawn.

3. The insertion tool reverses these motions.

The vertical pull on the wireline cable induces downward rotative motions in the retraction tool and upward and reverse rotating motions in the insertion tool.

Both tools can accommodate the length of core barrel being used, for example 5 to 20 feet (1.5 to 6.0m) core barrels, by adding extension sections which fit between the upper and lower portions of the tool.

Externally the tools present the appearance of a strong rigid tube. Few moving parts are exposed. Internally, its function depends on the interaction of a number of sequential parts such as pins, cams, linkages, and drive mechanisms (Figures 14, 15, 16). Dimensions in some cases must be maintained to close tolerances, but the manufacture of the tool with its components is not beyond the capability of a good machinery production facility.

i. Specialized Hand Tools

These consist of the usual wrenches, gauges, and other tools peculiar to the rapid assembly, disassembly, and repair of a new piece of equipment.

4.6 Operating Procedure

In use, the procedures now employed in wireline drilling still apply to drilling with the retractable bit system. Drill set up and collaring of the hole is done as before.

Core drilling with the retractable bit system is begun by lowering the drill string with the core barrel and retractable bit in place. After drilling, the inner tube with core is extracted, and an empty one reinserted. Drilling is resumed until the bit shows signs of wear. At this point the bit is replaced and drilling again resumes, without requiring the removal of the rods to change the bit. When a change in formation indicates the desirability of a change in bit design for optimum drilling efficiency, the same procedure is followed for bit replacement. In this way overall drilling efficiency is improved.

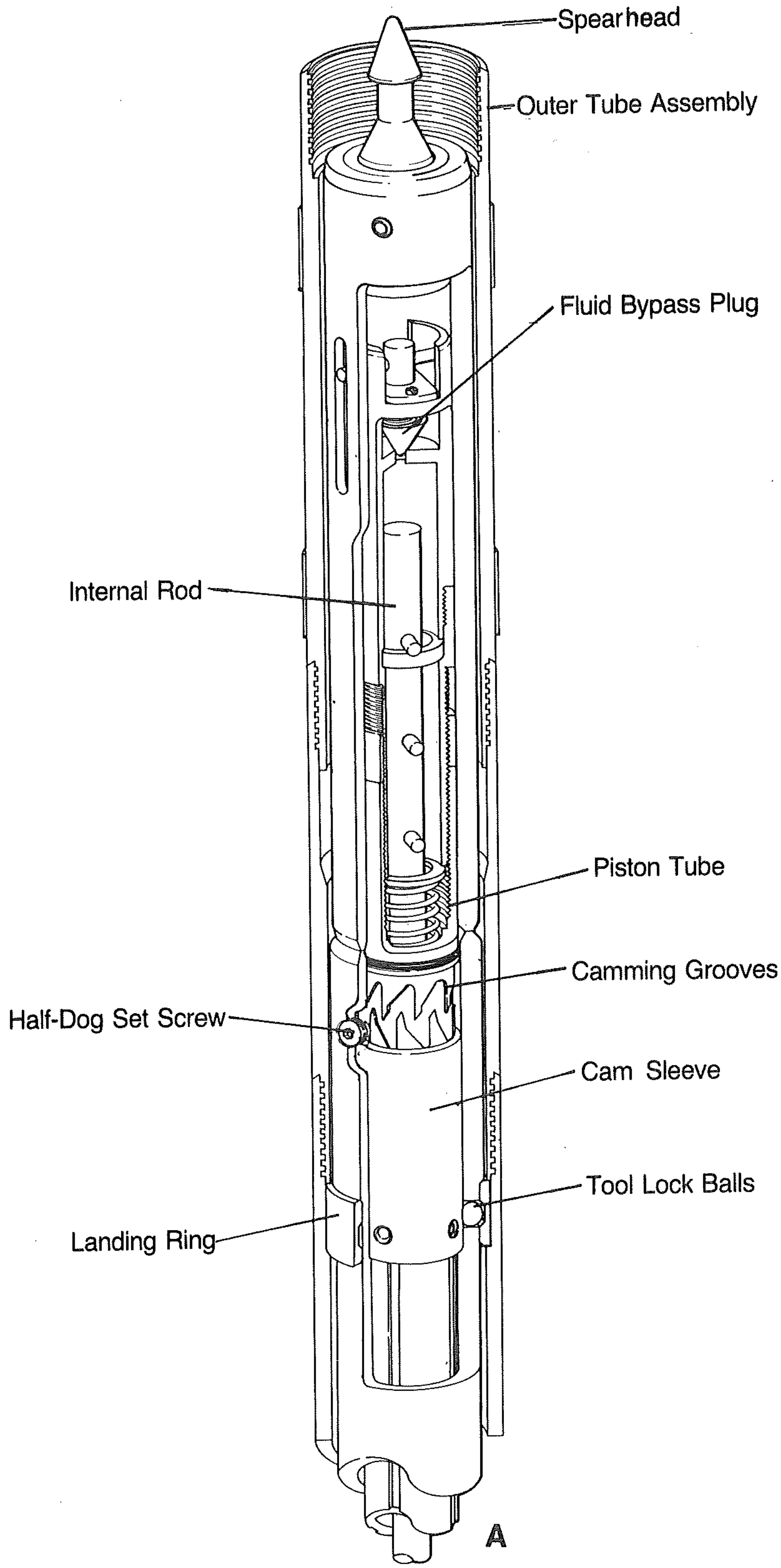


FIGURE 14 - The upper portion of the retraction tool.

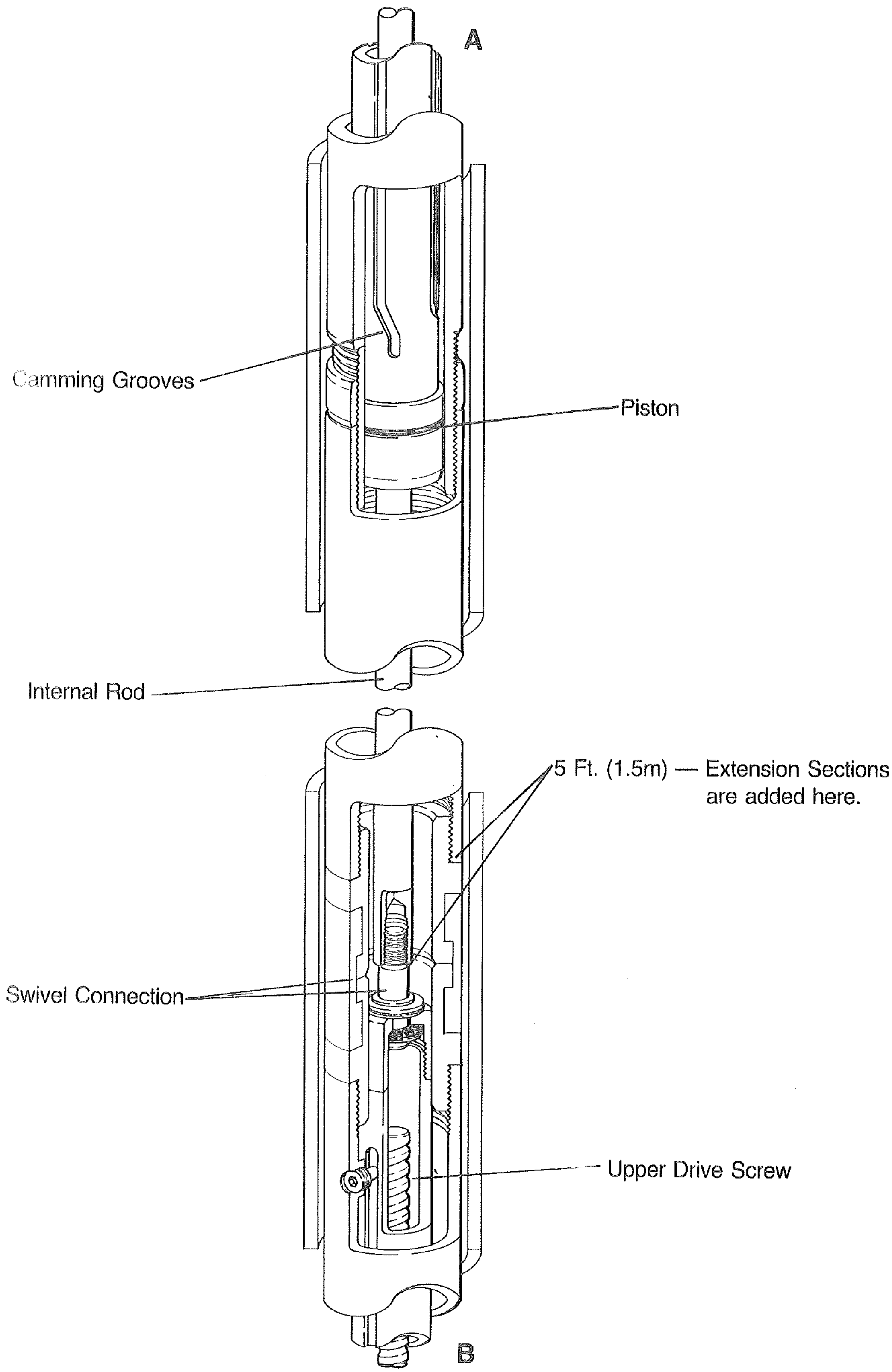


FIGURE 15 - The middle portion of the retraction tool.

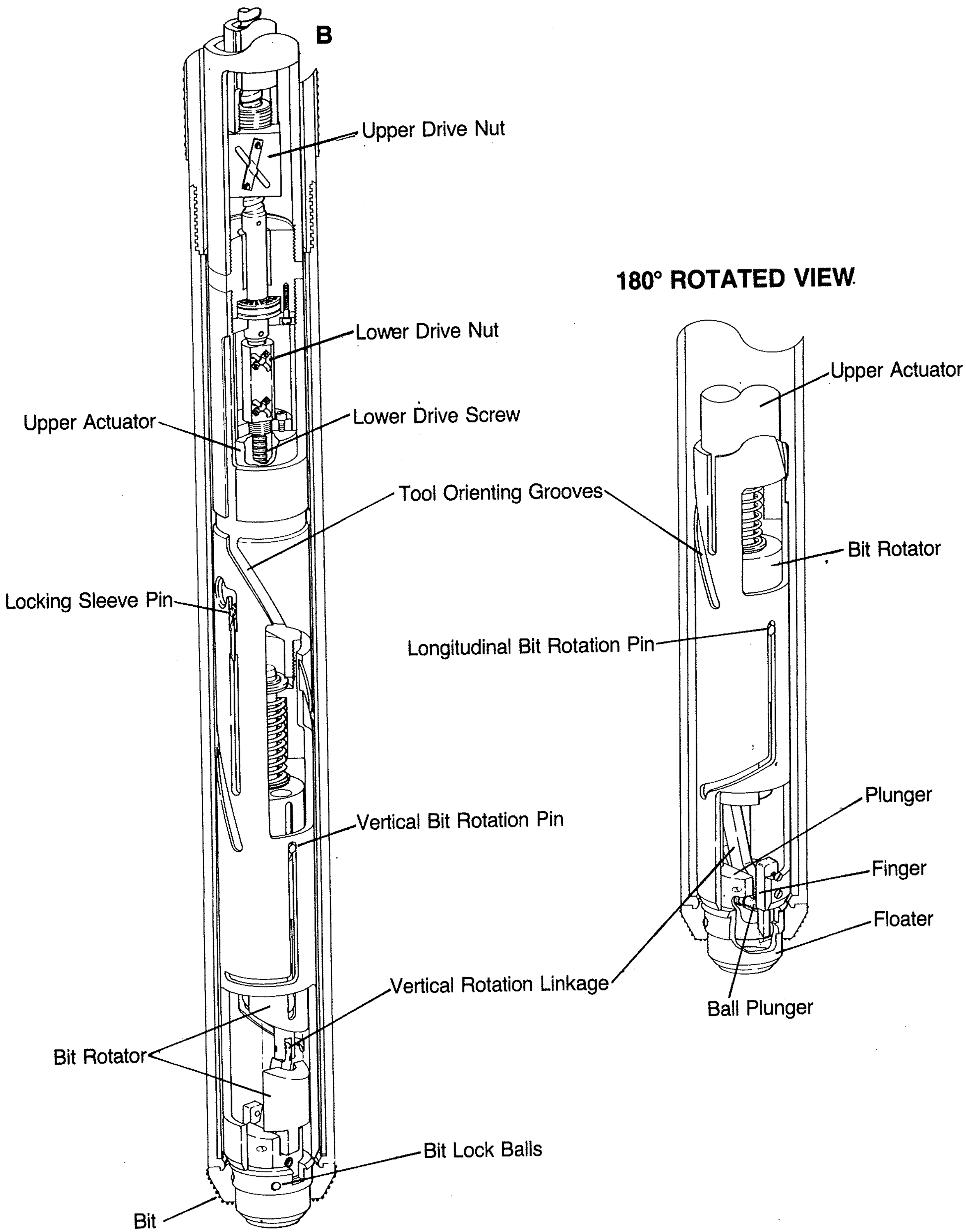


FIGURE 16 - The lower portion of the retraction tool.

Briefly, the added option in the drilling procedure, as compared to current procedure, is the ability to replace the bit at the operator's will without pulling the rods.

Should the operator find it efficient or economical to change from retractable bit drilling to conventional wireline drilling, he can accomplish it by changing the core barrel assemblies only.

4.7 Component Tests

After adopting the concept, whose main elements are the bit, bit holder, and bit changing tools, the research team tested and evaluated parts and components adjudged critical to the success of the system. As deemed desirable, much of this testing was done concurrently with design of such components and parts.

The Bit

The adopted bit concept utilizes approximately 30% less diamond set area for drilling than conventional wireline bits. A comparison of its drilling performance to wireline bits became an obvious necessity as soon as the bit concept was evolved.

Another feature peculiar to the conception is the surface interface of the bit with the driving lugs and the end of the bit holder. The ability of the interfaces to prevent loss of fluid was evaluated.

Laboratory tests were conducted at the U. S. Bureau of Mines facilities, Twin Cities, Minnesota (Figure 17) and later in the field at drill sites in Minnesota, Colorado, and Washington.

The results of the bit tests showed no meaningful difference in drilling performance, both in terms of bit penetration rate and bit life. Tests of the metal interface between the bit and bit holder did not show any appreciable fluid leakage. Data pertaining to these tests are appended (A2.0).

The Bit Holder

A structural test to determine the ability of the bit holder to withstand the forces applied to it during drilling indicated that the design was adequate (Figure 18). The various operations of turning, pushing, and pulling induced measured tensile and compressive stresses well within the limits of the material selected.

This structural test of the bit holder was extended to field testing at drilling sites in Colorado and Washington. No serious problems were encountered (See Appendix A2.0).

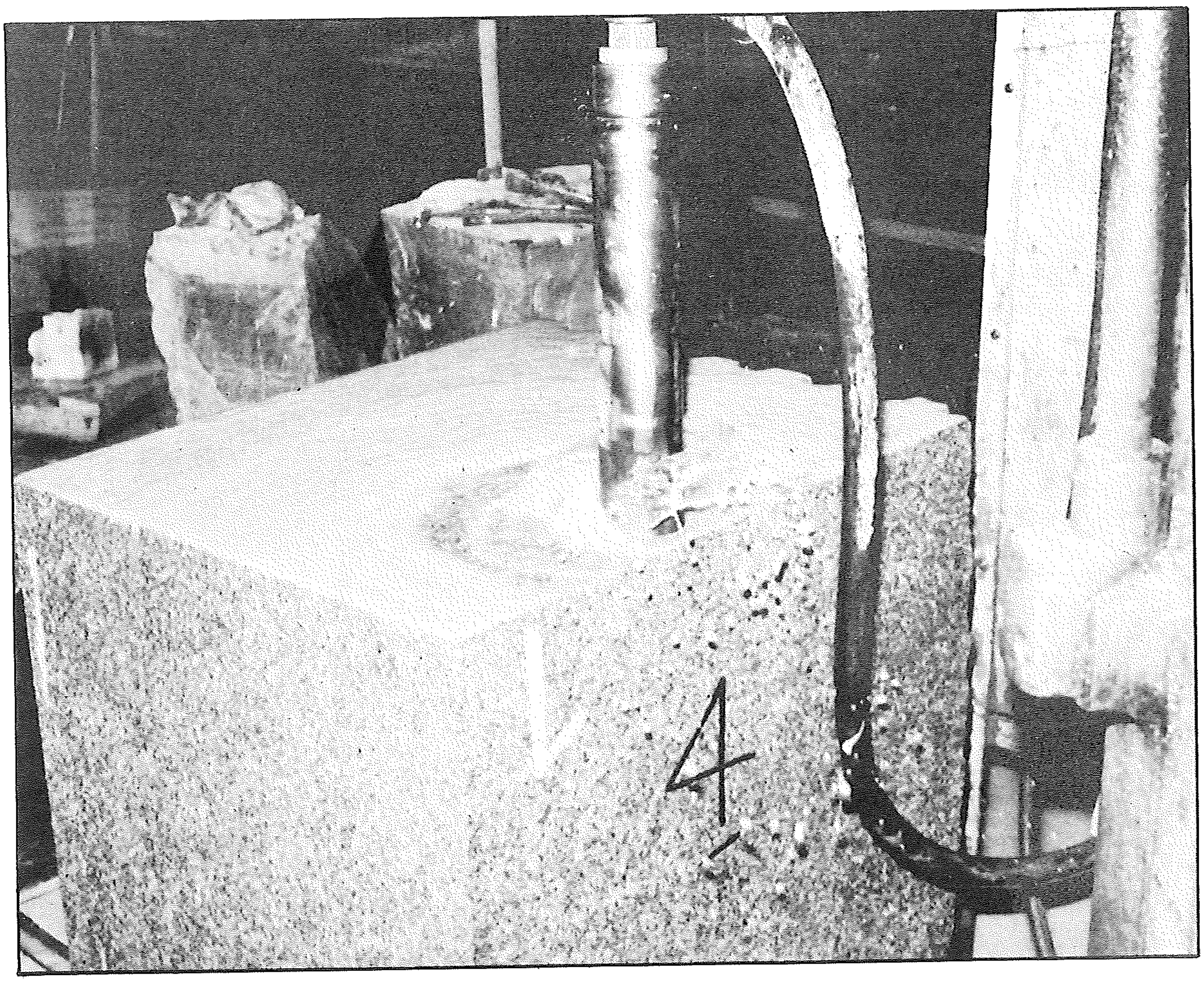


FIGURE 17 - Laboratory drilling at U.S. Bureau of Mines, Twin Cities Research Center, Twin Cities, Minnesota.

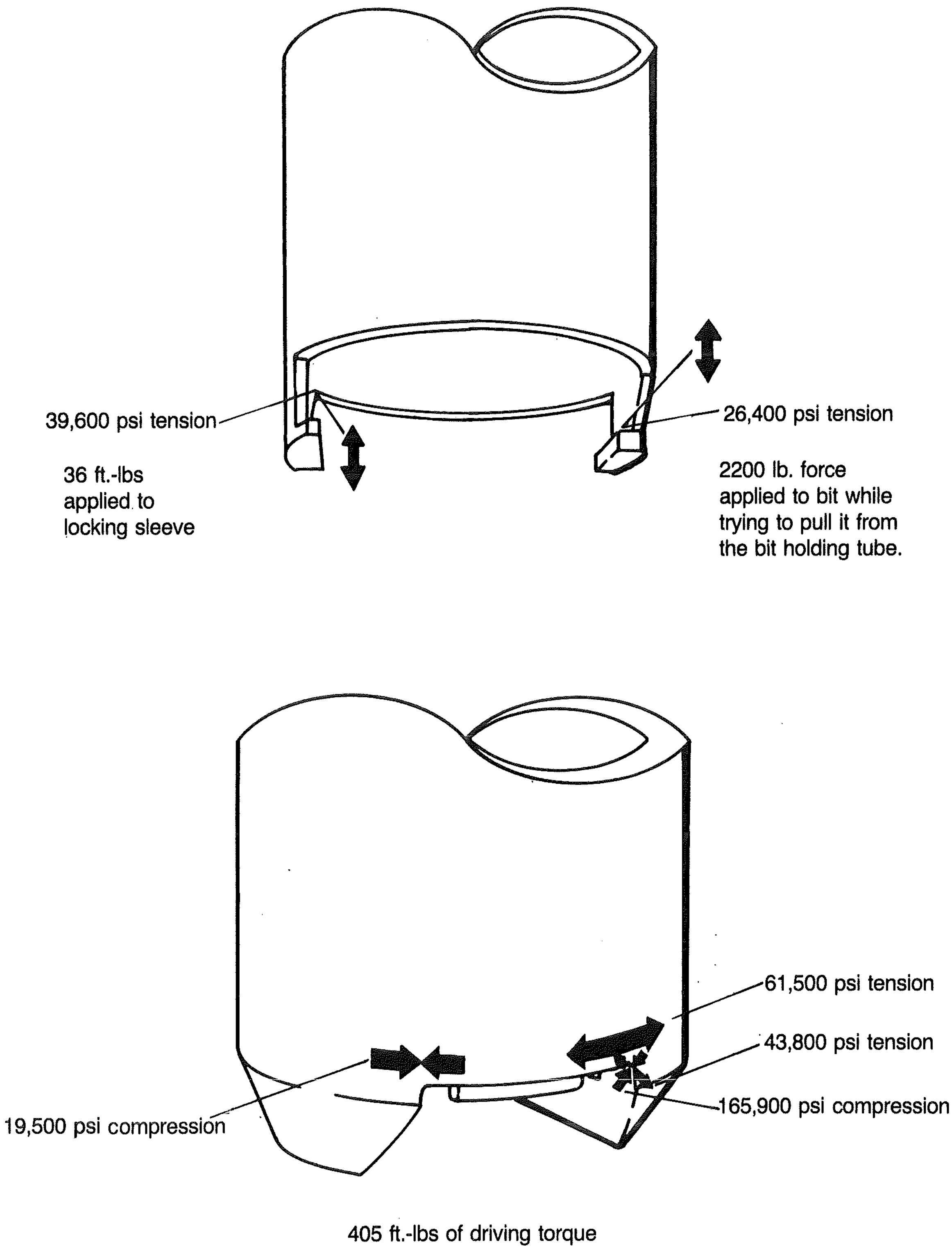


FIGURE 18 - Structural tests of the bit holder.

The Tools

Concurrently with design of the retraction and insertion tools, "proof-of-principle" and component adequacy tests were performed on parts which seemed to be of doubtful strength, rigidity, or reliability. Design changes were made when indicated.

Since the tool is an independent entity, tests were conducted by actuating it manually as each change was made. These tests were, in effect, a part of the design effort.

5.0 SYSTEM EVALUATION

5.1 Laboratory System Test

At the subcontractor's plant, a laboratory test was conducted to simulate, as close as possible, conditions which might be encountered in actual field operation. A hole was bored to a depth of 30 feet (9m); into which the core barrel with bit and sufficient drill rod was inserted. A superstructure which simulated a drill mast enabled the tools to be inserted into and withdrawn from the outer tube assembly (Figure 19). Both water and drilling mud were circulated through the drill string.

Under these conditions the bit replacement functions were performed at nearly 100% reliability. Not all field conditions such as the dynamic forces of drilling could be duplicated in a laboratory test.

5.2 Field System Test

Three field tests of the complete system were conducted (See Appendix A2.0). The tests showed little difference in drilling capability between the retractable bit design (the bit configuration, etc.) and that of conventional wireline bits. Core recovery as well as bit performance was not significantly different between the two systems.

Bit retrieval and replacement were accomplished at a depth of nearly 1300 feet (396m) without detecting any circumstance that would seem to prohibit deeper drilling. The bit was raised and lowered through the drill string without damage. Surface operation of the system was compatible to that of conventional wireline systems.

The results of the first field test were inconclusive. Hole caving, severe weather, and mechanical difficulties with the tools caused the abandonment of the site. The mechanical difficulties were corrected prior to the second field test in which a reliability of 15 successful bit changes out of 23 was achieved. Here the difficulties could be attributed to the inability to develop the required turning force on the bit locking sleeve during engagement and disengagement of the bit. A less important difficulty was caused by inadequate provision for retention of a set screw in the bit holder. This resulted in possible misalignment between the tool and bit.

Before the third field trial was begun, improvements were made to eliminate both problems. The set screw problem was easily corrected. Modifications in design of the bit holder and tools were effective and its operation and reliability were improved to a satisfactory level.

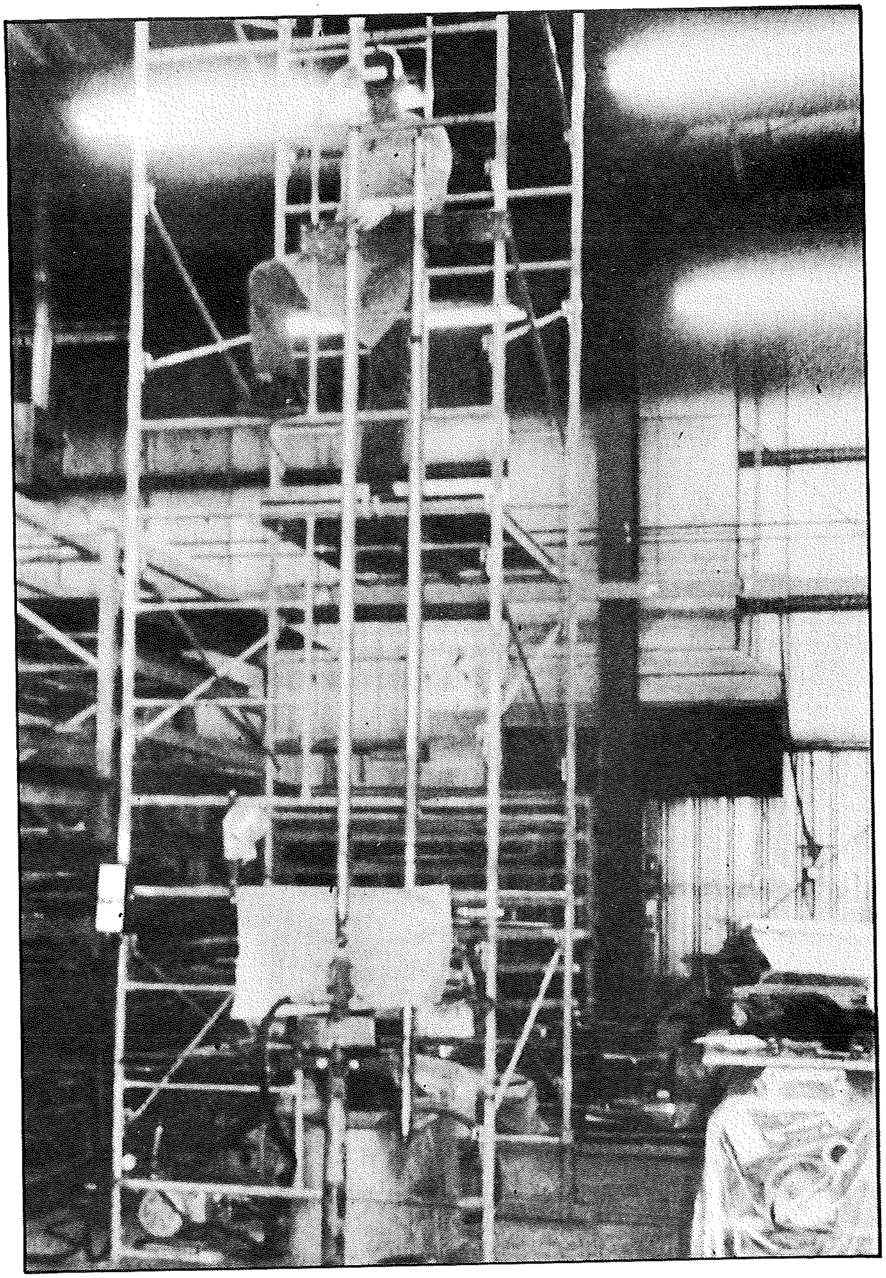


FIGURE 19 - The simulated in-hole testing of the retractable bit system.

In the third field test reliability of the bit retraction and replacement functions was demonstrated to be improved to the extent that ten of eleven bit changes were successful. The unsuccessful attempt was found to be caused by loss of a bit due, apparently, to damage to the steel surface of the inner diameter of the bit (a condition caused by blocky core). In this situation enough material would be removed from the inner diameter of the bit to prevent retention of the bit by the retraction tool.

Another bit was lost during drilling operation when fluid circulation was lost, increasing the friction between the rods and the wall of the hole. This resulted in severe rotational rod vibration. Under these conditions the spring detent which holds the bit locking sleeve proved inadequate which allowed the sleeve to back rotate far enough to release the bit. While this loss can be considered accidental, it is nevertheless, one whose possible occurrence must be considered in the development of a commercial system.

Changes in details of the design to reduce the probability of occurrence of the two malfunctions cited are not considered to be any more difficult than changes and modifications made as a result of earlier difficulties encountered. These are the type of problems which can be expected and can be corrected during the period of commercial development and marketing of the system.

The remainder of the system elements operated successfully in this final field test.

6.0 CONCLUSIONS

The principal objective of the project was to develop a system whereby the diamond cutting element of the core barrel could be retracted from the lower end of the rod string, pulled to the surface and a new cutting element repositioned without pulling the drill string from the hole.

A set of prototype tools and a one-piece diamond bit were developed and the system was tested in the laboratory and, to a limited degree, under field conditions.

During the field testing a number of operating functions were monitored with special instruments. These measurements were essential to evaluate the various operations the tool goes through in the process of changing the bit. Due to the time required to set up and remove the instruments, it was not possible to establish an accurate measurement of the time required to change the bit under production conditions.

During the field testing, several operational problems developed which prevented the completion of the drill hole and not enough data was established concerning reliability to enable meaningful projections to be made of cost savings which might be obtained through use of the system.

However, measurements of lowering and pulling speeds of the diamond cutting element were made and are discussed in this report.

Because of the complexity of the tools it is expected that certain design changes will be required before the tools can be understood, operated and serviced by the driller without the direct supervision of a technician or engineer. These design changes to permit production machining practices will be part of an extensive program to be carried out by the prime contractor.

At present, it is impossible to make factual comparisons of operating costs or comparisons between the retractable bit and the conventional wireline system. However, it is possible to make certain estimates based on experience with the tool while testing in the laboratory and in the field and these along with measured and recorded data can be used to establish estimates of potential savings in time that might be realized when using the retractable bit system.

Changing the Bit by Pulling the Rods

Times required for pulling and lowering rods will vary with the depth of hole and the efficiency of the crews, but an average time for pulling of one minute per 30 foot (9m) stand from 0 to 3,000 feet (914m) would be considered efficient. For estimating round-trip times, a time of 45 seconds is used for the lowering of each 30 foot (9m) stand. Pulling and lowering times increase with increasing depth, particularly beyond 3000 feet (914m). However, taller stands, greater than 30 feet (9m), are used for deeper holes, which tends to offset this increase. The same rates will therefore be applied for depths between 3000 and 6000 feet (914 and 1829m), which is the rated depth capacity of N size wireline drill rods.

In addition to the time required to pull and lower rods, there is some additional time required to change from the drilling mode to the pulling mode, inspect and replace the worn bit, and to change from the lowering mode to the drilling mode. Again, this time will vary with crews, optional features of the drill and other factors. Allowing 12 minutes per round-trip would be considered reasonable.

From the above we can establish a simple equation for determining cycle time. (D = Hole Depth)

D/30 ft. x 1.75 minutes + 12 minutes = total elapsed time
[D/9.14m x 1.75 minutes + 12 minutes = total elapsed time]
Example: 1500 foot (457m) hole
1500/30 x 1.75 + 12 = 99.5 minutes, total elapsed time

Retractable Bit Cycle Time

During our limited field testing, it was possible to measure with reasonable accuracy the speed at which the bit changing tools could be lowered and pulled through the drill string. Measured speed for lowering the tools through a fluid filled rod string has been determined to be 150 fpm (46 m/min.), while 200 fpm (61 m/min.) has been established as a reasonable pulling rate. These speeds may vary in dry holes or where in-hole conditions may dictate different speeds, but for average conditions the speeds indicated are considered to be practical.

When changing a bit by using the retraction and insertion tools there are certain additional operations that add to the total cycle time:

1. Changing the inner tube was measured at 420 fpm (130 m/min.) for lowering the overshot and for pulling the inner tube and at 200 fpm (61 m/min.) for the descent of the inner tube assembly. These operations are not required when changing the bit by pulling rods, since it is normal practice to pull rods with the inner tube in place.

2. Applying water pressure to the tool to actuate the locking device. Four minutes total for both tools.

3. Actuating the tool by generating a pull on the wireline cable. Six minutes total for both tools.

4. Switching from drilling to bit changing mode and back, plus miscellaneous downtime operations. Fifteen minutes total.

Pumping or flushing the hole prior to changing the bit or drilling is a practice that would apply to either the wireline or retractable bit systems and is therefore not considered as part of the comparison.

The estimated elapsed time for changing of bits with the retractable bit system is determined as follows: (D = Hole Depth)

Changing the inner tube assembly:
D/420 fpm + D/420 fpm + D/200 fpm
[D/(130 m/min.) + D/(130 m/min.) + D/(61 m/min.)]

Removing the bit:
D/150 fpm + D/200 fpm
[D/(46 m/min.) + D/(61 m/min.)]

Replacing the bit:
D/150 fpm + D/200 fpm
[D/(46 m/min.) + D/(61 m/min.)]

Fixed time operations - 25 minutes

Assuming a hole depth of 1500 feet (457m), the total estimated cycle time to replace the bit by the retractable bit system is:

Changing inner tube assemblies:
1500/420 + 1500/420 + 1500/200 = 14.6 minutes

Removing the bit:
1500/150 + 1500/200 = 17.5 minutes

Replacing the bit:
1500/150 + 1500/200 = 17.5 minutes

Fixed time - 25 minutes

TOTAL 74.6 minutes

Using the measured speeds and estimated times, it is possible to project the time expected to change the bit by the retractable system. This has been plotted to indicate the potential time savings at various hole depths. (See Figures 20 and 21).

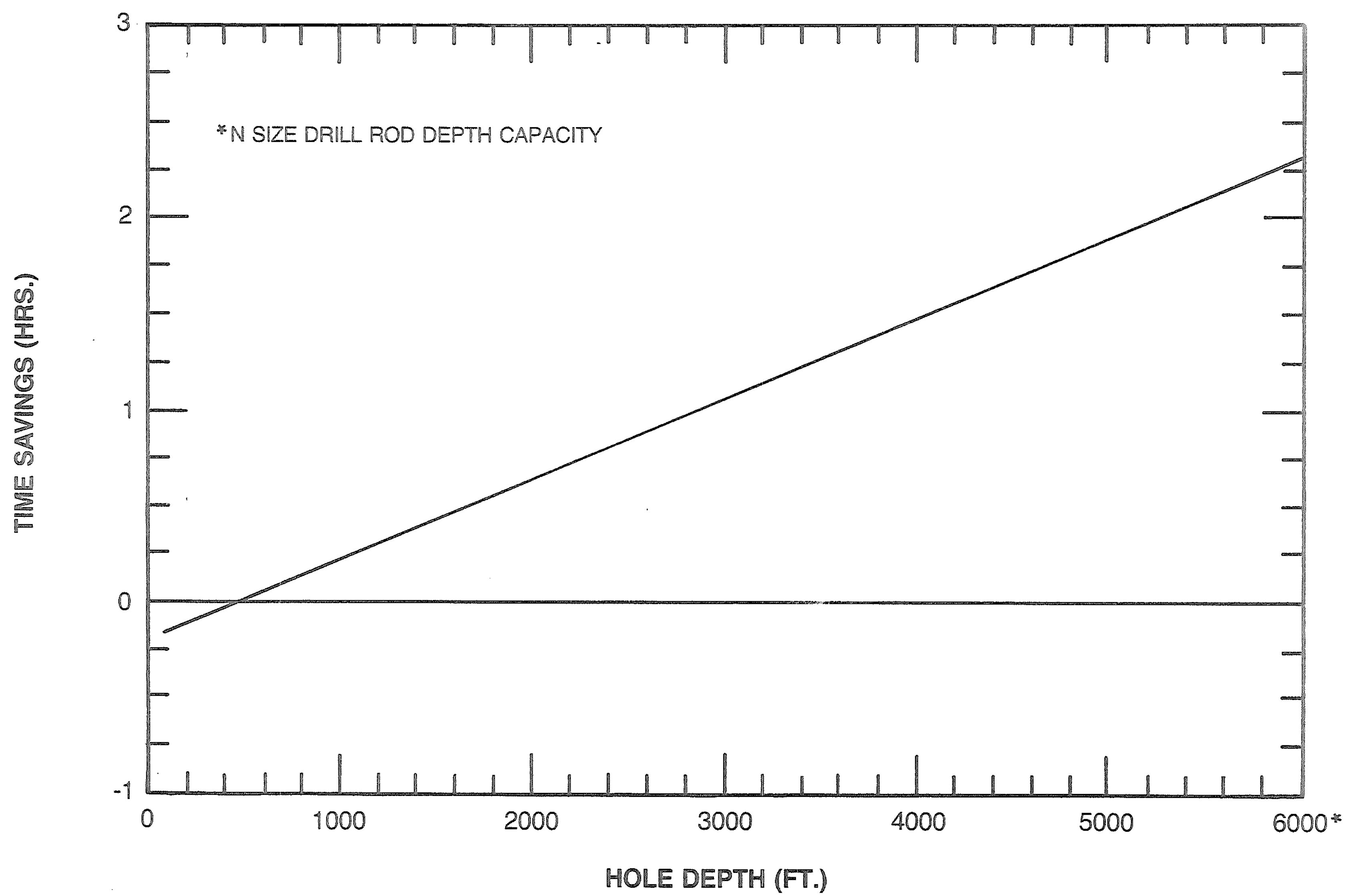


FIGURE 20 - Projected time savings per bit change of the Retractable Bit System over conventional wireline at various depths.

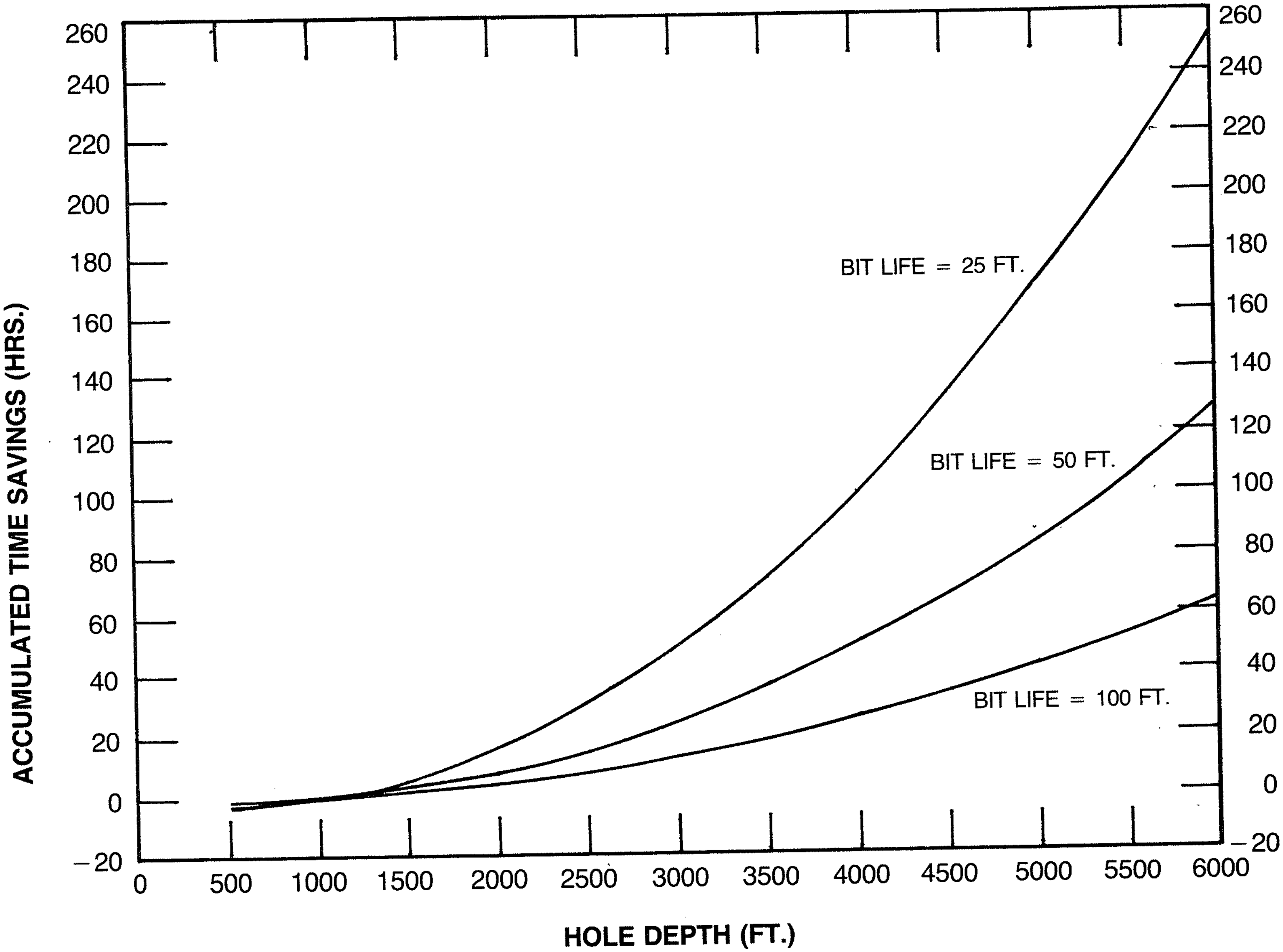


Figure 21 - Projected time savings of the Retractable Bit System over conventional Wireline System (Accumulated over entire hole depth).

The preceding equations and graphs are based on the best information available to date. As more extensive testing is conducted the time savings projections will be refined. To examine the potential impact such refinements could have on time savings, Table 1 was developed. Improvements to the system could also affect the projections. The data for Figure 21 is tabulated in column A of Table 1. Column B shows the difference possible with a 5 minute reduction in fixed time operating parameters of the retractable bit system. A variable time operating parameter reduction of 10% along with the 5 minute reduction is examined in column C. It is apparent from Table 1 that the time savings equations are very parameter sensitive. The data in column A was intended to be conservative, and presumably any improvements in the system will result in greater time savings.

All projections are based on achievement of 100% reliability of the tool.

Since drilling costs vary over a wide range depending on rock type, hole depths, machine sizes, geographical areas, climatic conditions, etc., it is impossible to predict the financial impact that this tool may produce. Cost comparisons can only be determined after the tool has been developed to a commercial status and operated extensively in a given area. The person familiar with drilling costs may apply known costs for a certain area and make estimates of cost reductions that might be achieved by applying the time savings shown in the Figures.

As previously stated in the report, it is expected that bit costs and penetration rates will be approximately the same as the wireline; and since the tools are expected to have a long life, tool costs would not reflect an appreciable increase to unit drilling costs.

If the tool can be developed to a reliable and efficient status and if applied to the majority of holes drilled in excess of 1,000 feet in depth (300m), the potential savings to the drilling industry worldwide could be substantial.

Extrapolating from the equations used, the retractable bit will provide the greatest potential savings where drilling conditions dictate frequent bit changes in holes in excess of 1,000 feet (300m). There are also other advantages that may be anticipated from a proven, reliable retractable system. Some of these are:

1. Less driller fatique. Changing the bit requires very little physical effort.

2. Lower fuel consumption. Pulling rods requires engine operations which result in high fuel consumption.

3. Safety. Pulling rods is the major cause of injuries to drillers and helpers.

TABLE 1 - Cumulative time savings (hours) of the retractable bit system over the wireline system

BIT LIFE (FT.)	DEPTH (FT.)	A*	B*	C*
25	1000	0	3	4
	2000	17	24	27
	3000	51	60	68
	4000	101	114	128
	5000	169	185	206
	6000	253	273	303
50	1000	0	2	2
	2000	9	12	14
	3000	26	31	34
	4000	51	58	64
	5000	85	93	104
	6000	127	137	152
100	1000	0	1	1
	2000	4	6	7
	3000	13	16	18
	4000	26	29	33
	5000	43	47	52
	6000	64	69	77

* A - Utilizing equations for Figures 20 and 21.

B - Utilizing a 5 minute reduction in fixed time operating parameters.

C - Utilizing a 5 minute reduction in fixed time operating parameters and a 10% reduction in variable time parameters.

4. Drilling efficiency. Drillers will tend to change bits to maximize drilling efficiency either due to formation changes or as bits become dull.

5. Less time required to complete hole. Savings in drilling costs due to fast drilling speeds are only part of the savings. Savings associated with maintaining support personnel and facility on site can also be significant.

6. Unusually difficult holes. Where hole caving is a problem or bit life is unusually short, the retractable bit offers significant advantages.

7.0 RECOMMENDATIONS

The primary project recommendation is the continued development of the retractable bit system by Longyear Company.

Limited testing under production drilling conditions points out the need for continued effort toward:

1. Drilling under a wide range of rock and climatic conditions.

2. Research and development of various bit types.

3. Establishing reliability of the bit locking system and insertion and retraction tools.

4. Development of operating and servicing procedures that can be carried out by drillers with minimal training.

5. Determining tool life and critical areas of manufacture.

The possible use of other tools in conjunction with the retractable bit system are recognized as having potential, but these are subject to the successful conclusion of the primary objective of this project.

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APPENDIX

A1.0 SOURCES OF INFORMATION

Patents

The U.S. and limited number of foreign retractable bit patents studied, dating back to the 19th century, could be divided into five groups.

A - Expandable core cutting bit

B - Non-expandable core cutting bit

C - Large diameter bore bit

D - Small diameter bore bit

E - Outside drill string retracting

Group A (coring) and group C (non-coring) proved significant and were examined more fully. A totally collapsible bit, Figure 1, and a solid pilot bit with expandable reamers, Figure 3, were the predominant methods of retraction. A description of the two methods can be found in section 4.1. A list of the past patents that were reviewed is found in A1.3.

Literature

A search of manufacturers' sales literature and of government and engineering computer data bases revealed no commercially available retractable core bit systems. The literature did establish the state-of-the-art of earth drilling, particularly the wireline system.

Other novel earth drilling techniques identifed were, for example, ultrasonic and electrical discharge. These were not expediately applicable to the diamond core drilling industry and were not pursued further.

Many articles acquired dealt with rock mechanics and individual diamond and diamond bit cutting mechanics and performance. Cutting mechanics of metal diamond cutting tools and non-diamond earth drilling bits were also studied. These articles and others are referenced in A1.1. A list of manufacturers' literature is included in A1.2.

Interviews

Discussions with technical and research personnel in the industry reinforced what was found in the patents and literature. Retractable bit concepts past and present have followed the expandable reamers or collapsible bit approaches. The information gained on diamond bit wear patterns did prove significant in the evaluation of the retractable bit concepts developed during Phase II. This information was gathered while visiting drill sites and bit manufacturing plants.

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A1.2 List of Manufacturers' Literature

A-Z International Tool Co.
Houston, TX

Acker Drill Company, Inc.
Box 830
Scranton, PA 18501

AEG Power Tool Corp.
One Winnendon Road
Norwich, CT 06360

Allied Steel & Tractor Products, Inc.
5300 Harper Road
Solon, OH 44139

American Jenback Crop.
530 Chapel Hill Road
Box 2115
Burlington, NC 27215

American Pneumatic Tool Co.
14710 Maple Avenue
P.O. Box 2453
Gardena, CA 90248

Arps - Division of Chromalloy
New Holstein, WI 53061

Atlas Copco, Inc.
70 Demarest Drive
Wayne, NJ 07470

Baker Drill, Inc.
P.O. Box 2641
San Angelo, TX 76901

BBN Instruments Company
50 Moulton Street
Cambridge, MA 02138

Bethlehem Steel Crop.
Bethlehem, PA 18016

Brown Oil Tools, Inc.
P.O. Box 19236
Houston, TX

Brown Trencher Division
Woodbine, IA 51579

Bucyrus - Erie
Mining Machinery Central Parts Depot
P.O. Box 1000
Racine, WI 53405

Calweld - Division of Smith International, Inc.
P.O. Box 2875
Santa Fe Springs, CA 90670

Chicago Pneumatic - Drill Div., Canadian Pneumatic Tool Co.
Bass Building
Enid, OK 73701

Christensen Mining Products
1937 South 300 West
Salt Lake City, UT 84115

Clipper - Construction Products Division, Norton International
P.O. Box 295
Worchester, MA

CMI Corporation
P.O. Box 1985
Oklahoma City, OK 73101

Construction Forms, Inc.
1033 Cardinal Road
P.O. Box 326
Cedarburg, WI 53012

Construction Machinery Co.
Waterloo, IA 50704

CP Oil and Tool Company
P.O. Box 20471
Dallas, TX 75220

Cushion Cut
1400 West 240th Street
Harbor City, CA 90710

Danuser Machine Company
500 East Third Street
Fulton, MO 65251

Davis Manufacturing
1500 South McClean Blvd.
P.O. Box 9228
Wichita, KS 67277

Delsteel, Inc.
Wilmington, DE 19899

Diamant - Boart Belgium

Diamond Dust Company, Inc. (Dia-Dusco)
77 Searing Avenue
Mineola, NY 11501

Drilling & Service International

Drilprodco, Inc.
P.O. Box 177
Hobbs, MN 88240

Earthdrill, Ltd.
7226 E. Slauson Avenue
Los Angeles, CA 90040

Earthworm Boring Machine, Inc.
P.O. Box 233
540 East Carlton Street
Ontario, CA 91761

Fagersta, Secoroc
Fagersta, Inc.
2 Henderson Drive
W. Caldwell, NJ 07006

Felker Operations, Dresser Industries, Inc.
1900 S. Crenshaw Blvd.
Torrance, CA 90509

Flame Industries, Inc.
122 Columbia Court No.
Chaska, MN 55318

Gardner - Denver Co.
Quincy, IL

GDM, Inc.
152 Aero Camino
Goleta, CA 93017

General Equipment Co.
Owatonna, MN 55080

Geolograph Company, The
P.O. Box 25246
Oklahoma City, OK 73125

Geophysical Research Corp. (GRC)

Grant Oil Tool Company

Grimmer Schmidt Corp.
Hurricane Road
P.O. Box 342
Franklin, IN 46131

H.E.A.D. - RB Industries, Inc.
P.O. Box 108
Pleasant Hill, MO 64080

H & L Tooth Company
1540 So. Greenwood Avenue
Montebello, CA 90640

Hossfeld Manufacturing Co.
Winona, MN 55987

Hughes Tool Company
5425 Polk Avenue
Houston, TX 77001

Hunt Tool Company
Houston, TX

Ingersoll-Rand - Cyclone Drill Co.
Orville, OH 44667

Joy Manufacturing Company
Montgomeryville Ind. Center
Montgomeryville, PA 18936

LeRoi - Industrial Products Division, Dresser Industries, Inc.
Sidney, OH 45365

Long-Airdox Co. - Division of Marmon Group, Inc.
Box 331
Oak Hill, WV 25901

Longyear Company
76 So. 8th Street
Minneapolis, MN 55402

Lor, Inc., International

Masonry Equipment & Supply Co.
P.O. Box 155
Brecksville, OH 44141

McLaughlin Mfg. Co.
Box 303
Plainfield, IL 60544

Mid-Continent Supply Co.
P.O. Box 189
Fort Worth, TX 76101

Milwaukee Electric Tool Corporation
13135 W. Lisbon Road
Brookfield, WI 53005

MKT (McTiernan-Terry) - Division of Koehring
100 Richards Avenue
Dover, NJ 07801

Mobile Drilling Company, Inc.
3807 Madison Avenue
Indianapolis, IN 46227

Morgan Manufacturing Co.
117 West Third Street
Yankton, SD 57078

Murray Equipment Co., Inc.
14011 Oakland Avenue
Detroit, MI 48203

New England Carbide Tool Co., Inc. (New Carb)
Industrial Park
Peabody, MA 01960

Nippon Kikan (NKK)
New York Office
277 Park Avenue
New York, NY 10017

Pengo Corporation
Box 950
Sunnyvale, CA 94088

Rampp Company
111 Third Street
Marietta, OH 45750

Reamco, Inc.
P.O. Box 52369
Lafayette, LA

Reed Tool Company
Mining Equipment Division
12400 North Freeway
Box 90750
Houston, TX 77090

Reed Tool Company
Percussion Equipment Division
P.O. Box 3641
San Angelo, TX 76901

Relton Corporation
317 Rolyn Place
Arcadia, CA 91006

Richmond Manufacturing Co.
P.O. Box 188
Ashland, OH 44805

Rucker/Hycalog
Houston, TX

Salem Tool Company
Salem, OH 44460

Security Rock Bits & Drill Tools - Division of Dresser, Ind.

SEECO (Special Earth Equipment Corp.)
1719 64th Street
Emeryville, CA 94608

Servco - Division of Smith International, Inc.

Soiltest, Inc.
2205 Lee Street
Evanston, IL 60202

Sprague & Henwood, Inc.
221 West Olive Street
Scranton, PA 18501

Sullair Corporation
3700 East Michigan Blvd.
Michigan City, IN 46360

Sumitomo Metals
New York Office
420 Lexington Avenue
New York, NY 10017

Target Hole Saws
Robert G. Evans Co.
4330 Clary Blvd.
Kansas City, MO 64130

Thermologic - Division of Dytron, Inc.
241 Crescent Street
Waltham, MA 02154

Teague Auger, Inc.
1701 Texoma Drive
P.O. Box 1224
Sherman, TX 75090

Timken Company, The
Rock Bit Division
Colorado Springs, CO 80901

Tone Boring Co., Ltd.
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Tri-State Oil Tool Industries - Subsidiary of Baker Oil Tool
P.O. Box 5757
Bossier City, LA 71010

Truco Masonry Diamond Products Division - Wheel Trueing
Tool Company
6340 Glenway Avenue
Cincinnati, OH 45211

Varel Manufacturing Co.
P.O. Box 20156
Dallas, TX 75220

Vulcan Tool Manufacturing Co.
P.O. Box 546
Quincy, MA 02169

Wabco Fluid Power - Division of American Standard
1953 Mercer Road
Lexington, KY 40505

Walker - McDonald Mfg. Co.
Box 1060
Greenville, TX 75401

Walker - Neer Manufacturing Co., Inc.
P.O. Box 2490
Wichita Falls, TX 76307

West - Trade Industries, Inc.
2311 Ross Way
Tacoma, WA 98421

Williams Diamond Bits - Division of Smith International, Inc.
P.O. Box 252
Greenville, TX

A1.3 List of Past Patents Reviewed

The patent search was directed toward the application of retractable bits to core drilling, oil well drilling, water well drilling, etc., what might be termed as "earth drilling". The search included looking for foreign patents pertaining to retractable bits.

Patents Ordered

The patents found applicable and ordered for further inspection were divided into five groups as follows:

Group A - Expandable core cutting bit. (Outer diameter of annular hole cut by the bit is at least as large as the outer diameter of the drill string.)

474,080	3,603,411
840,744	3,603,413
2,068,704	3,661,219
2,842,343	3,692,126
3,123,160	3,894,590
3,437,159	3,955,633
3,565,192	

Group B - Non-expandable core cutting bit. (Core bit cuts annular hole having outer diameter about equal to the inner diameter of an annular bit on the drill string.)

672,097
1,671,136
2,135,737
2,173,677
3,635,295

Group C - Large diameter bore, non-coring bits. (Cuts cylindrical hole of a diameter at least as large as the outer diameter of the drill string.)

229,074	1,741,497	3,185,226
519,405	1,833,134	3,393,756
551,824	1,862,629	3,545,553
1,017,206	1,978,119	3,552,507
1,068,015	1,996,132	3,552,508
1,087,353	2,120,240	3,552,509
1,171,790	2,133,564	3,552,510
1,192,419	2,239,996	3,554,304
1,197,882	2,277,989	3,661,218
1,290,340	2,692,116	3,847,236
1,410,674	2,764,388	3,848,683
1,451,794	2,876,994	3,965,996
1,532,330	2,978,047	
1,571,931	3,050,142	
1,585,540	3,050,143	
1,607,791	3,074,494	
1,612,338	3,097,706	
1,669,467	3,097,707	

It was felt that the patents previously listed provided a good cross section for Group C. Patents identified in this group, but not ordered, are as follows:

537,114	1,585,540	3,306,377
698,415	1,597,143	3,552,508
995,064	1,617,043	3,603,412
1,002,793	1,647,669	3,656,564
1,011,324	1,659,769	3,870,114
1,025,339	1,766,253	3,880,247
1,044,598	1,783,580	3,901,331
1,046,294	1,819,798	
1,058,013	1,836,703	
1,095,419	1,838,467	
1,159,172	1,908,227	
1,174,332	1,909,817	
1,192,419	1,978,119	
1,222,845	2,035,852	
1,269,449	2,073,279	
1,271,279	2,144,687	
1,295,969	2,169,283	
1,326,327	2,173,018	
1,326,509	2,208,457	
1,332,105	2,287,714	
1,360,328	2,239,996	
1,379,483	2,360,088	
1,412,101	2,375,335	
1,421,396	2,771,275	
1,424,662	2,890,022	
1,435,491	2,893,693	
1,439,092	2,979,144	
1,442,188	2,982,366	
1,456,158	3,050,142	
1,456,350	3,074,494	
1,502,463	3,077,235	
1,511,640	3,097,706	
1,532,330	3,097,707	
1,548,851	3,097,708	
1,574,280		

Group D - Small diameter bore, non-coring bits. (Cuts cylindrical hole of a maximum diameter that is about the same as the inner diameter of the drill string.)

763,212
1,142,460
1,391,626
3,199,613

Group E - Outside bits. (Retractable along outer surface of drill string.)

1,709,074
2,337,720
2,506,795
2,550,035
2,681,207
3,729,057

A2.0 SYSTEM TEST DATA

The project testing program included three segments each composed of laboratory and field tests.

a. Diamond set pattern evaluation

b. Bit and bit holder configuration evaluation

c. Total system tests

Each succeeding segment required successful results from the previous test before it could begin. Data from these individual tests are included in this section. Since it was never intended to collect large enough quantities of data for statistical performance comparisons, the information should only be used for qualitative purposes. Generally, the drilling performance of the retractable bit system was as good as present wireline systems.

A highlight summary of the testing follows:

1575 ft. (480)	-	System field test footage
24.5 ft. (7.5 m)	-	System laboratory test footage
5	-	Field test sites in different geographic areas and geological formations
2	-	Types of laboratory test rock
18	-	System bits tested in the field
5	-	System bits tested in the laboratory

a. Diamond Set Pattern Evaluation

The retractable bit diamond configuration was necessarily different from wireline bits. Tests where conducted to determine the effect of the new diamond distribution on drilling performance (bit penetration rate and life). Test bits were set in the conventional manner of wireline bits except for the omission of diamonds in the bit holder driving lug area (Figure 22). Tests were first conducted in the Bureau of Mines laboratory, Twin Cities Research Center, Twin Cities, Minnesota. Field tests were in northern Minnesota. The results indicate that the new diamond set pattern did not reduce drilling performance.

Rock and bit descriptions follow and Tables A-1, A-2, and A-3 contain data from these tests.

1. Rock

a. Laboratory - Mankato limestone and Barre granite

b. Field - Gabbro banded with hard chert, good coring

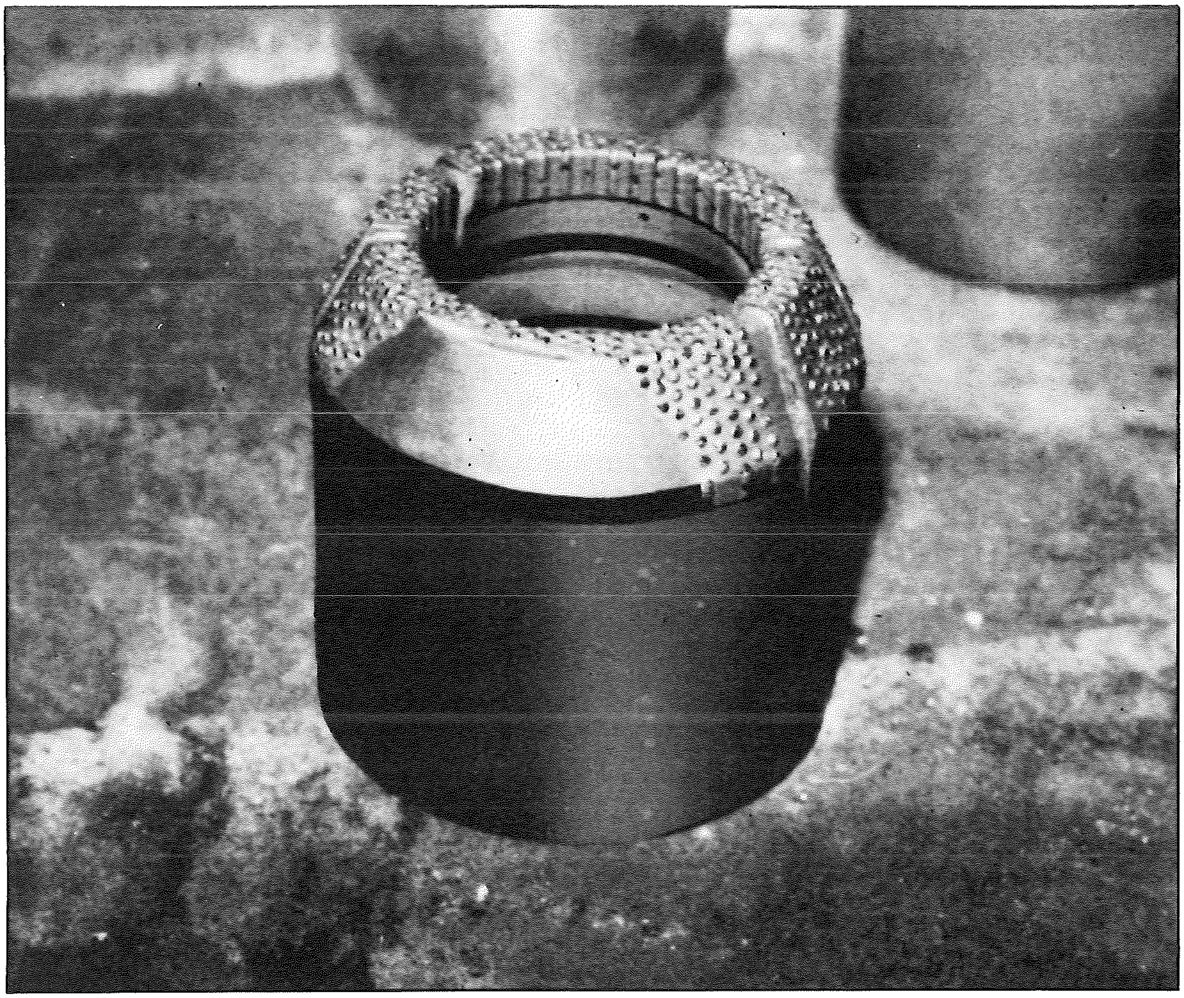

FIGURE 22 - The prototype core bit showing diamond test pattern.

2. Bits

a. Prototype

- First quality diamonds
- 25 per carat, 26.66 carats
- 4 full waterways
- Tapered profile
- 1.75" (44.4mm) core diameter

b. Wireline, laboratory

- Select quality diamonds
- 15-20 per carat, 32.17 carats
- 4 full waterways
- Tapered profile
- 1.875" (47.6mm) core diameter

c. Wireline, field

- Hard core diamonds
- 70 per carat, 16.5 carats
- 4 internal and external waterways, no face waterways
- 6 step profile
- 1.875" (47.6mm) core diameter

b. Bit and Bit Holder Configuration Evaluation

The next test addressed the ability of the bit and bit holder assembly to withstand the rigors of drilling. A shorter version of the bit holder was fabricated for the tests because the bit replacement tools would not be used. The bit and the end of the holder were identical to the system bit and bit holder. The laboratory test was conducted in the Bureau of Mines facility Twin Cities Research Center, Twin Cities, Minnesota. The field test took place in central Colorado and northeastern Washington. The bit and bit holder satisfactorily withstood the forces induced by drilling, and the design of the complete system continued including replacement tools.

The rock and bit information is below. Tables A-4, A-5, and A-6 contain test data.

1. Rock

   a. Laboratory - Mankato limestone and Barre granite

   b. Field - Porphyry in Colorado, blocky coring; dolomite in Washington, blocky coring

2. Bits

   a. Retractable

      - Premium grade Bortz (X00695-X00700)
      - Select grade Bortz (R00703, R00704)
      - 25 per carat, 20.21 carats (X00695-X00698)
      - 70 per carat, 10.80 carats (X00699, X00700)
      - 70 per carat, 10.62 carats (R00703, R00704)
      - 4 full waterways
      - Tapered profile
      - 1.75" (44.4mm) core diameter

   b. Wireline, Colorado

      - Select diamonds
      - 30-40 per carat, 20.34 carats
      - No face waterways
      - Step profile with semi-round face
      - 1.875" (47.6mm) core diameter

   c. Wireline, Washington

      - Select diamonds
      - 50 per carat
      - No face waterways
      - Step bit with semi-round face
      - 1.875" (47.6mm) core diameter

c. Total System Tests

The system was first tested and demonstrated at the contractor's plant. A five-foot (1.5 m) core barrel outer tube assembly and the bit retraction tool were put in a vertical orientation. The core barrel was put into a drilled hole in the granite block used in earlier laboratory tests. Fabrication of the insertion tool and extensions for a 10-foot (3 m) configuration were authorized as result of this successful demonstration.

The first complete system test took place under laboratory conditions in a 30-foot (9 m) hole in the sub-contractor's shop. Field conditions were simulated as nearly as possible. The test results were very positive with the tools operating at nearly 100% reliability.

Field tests of the system were conducted in southern New Mexico, western Virginia, and southern Arizona. The test in New Mexico was aborted because of a variety of environmental and mechanical difficulties. The next trial in Virginia was successful and proved the system was feasible; however, reliability of the bit replacement function was less than desirable. These difficulties were addressed and reliability was greatly improved in Arizona. More descriptive information on system tests can be found in section 5.0 System Evaluation.

The work schedule for the Virginia test was single 10 hour shifts, 5 days a week.

320 ft. (98 m)	-	Starting test depth
1294 ft. (394 m)	-	Ending test depth
771 ft. (235 m)	-	Retractable bit footage
203 ft. (62 m)	-	Wireline footage
9 of 10 attempts	-	Successful bit replacements without prior drilling
15 of 23 attempts	-	Successful bit replacements including prior drilling

The work schedule was single 10 hour shifts, 5 days a week in Arizona.

254 ft. (77m)	-	Starting test depth
788 ft. (240m)	-	Ending test depth
516 ft. (157m)	-	Retractable bit footage
18 ft. (5.5m)	-	Wireline footage
2 of 2 attempts	-	Successful bit replacements without prior drilling
10 of 11 attempts	-	Successful bit replacements including prior drilling

Rock and bit information follows and Tables A-7 and A-8 contain test data.

1. Rock - Sandstone and shale with coal and oxidized coal seams, good coring in Virginia; granite, good coring and occasionally blocky coring in Arizona

2. Bits

   a. Retractable

      - Premium grade Bortz (X00696, X00698, X00701, X32159, X32160)

      - Select grade Bortz (R00703, R11937-R11942)

      - 10 per carat, 28.20 carats (X32159, X32160)

      - 25 per carat, 20.21 carats (X00696, X00698)

      - 50 per carat, 17.50 carats (R11937-R11940)

      - 50 per carat, 18.60 carats (R11941, R11942)

      - 70 per carat, 10.80 carats (X00701)

      - 70 per carat, 10.62 carats (R00703)

      - 4 full waterways (except no face waterways on R11941, R11942)

      - Tapered profile

      - 1.75" (44.4 mm) core diameter

   b. Wireline, Virginia

      - Special grade Bortz

      - 9-11 per carat, 28.12 carats

      - 4 full waterways

      - Semi-round face

      - 1.875" (47.6 mm) core diameter

   c. Wireline, Arizona - impregnated bits

TABLE A-1 - Laboratory test of prototype bit, Bureau of Mines, Twin Cities Research Center, October 17 - 20, 1978

RUN[1]	BIT[2]		ROCK[2]	BIT THRUST (LB.)	BIT RPM	INCHES DRILLED	PENETRATION RATE (IN/MIN)
1	85-44784	W	L	726	328	19.3	3.64
2	97283	P	L	726	327	20.5	4.88
3	85-44784	W	L	726	330	20.3	4.43
4	85-44784	W	L	726	330	20.3	4.43
5	97283	P	L	726	330	21.1	4.63
6	97283	P	L	903	323	20.8	5.63
7	97283	P	L	903	323	20.6	6.07
8	85-44784	W	L	903	328	19.7	6.57
9	97283	P	L	956/903	328	20.4	6.38
10	97283	P	L	903	454	20.5	8.66
11	85-44784	W	L	903	457	21.9	8.38
12	97285	P	G	903	458	20.2	1.53
13	85-44783	W	G	903	459	19.9	1.26
14	97285	P	G	1151	605	20.3	1.41
15	85-44783	W	G	1151	603	19.8	.83
16	97285	P	G	1345	603	20.3	.76
17	97285	P	G	1505	606	13.3	.42
19	85-44783	W	G	1505	606	9.4	.37

[1]Waterflow was 4.5 gpm at 80 psig.

[2]W - Wireline, P - Prototype, L - Limestone, G - Granite

TABLE A-2 - Bit log for prototype bit field test, Babbitt, Minnesota, January 22 - 24, 1979

BIT	FROM	TO	FOOTAGE	COMMENTS
97287	540	559	19	New bit. Slight shank wear over about 135°. One fractured diamond noted. Noticeable wear flats on diamonds. No teardrop wear patterns noted in matrix around diamonds.
Wireline	559	584	25	New bit. Normal diamond wear.
97286	584	606	22	New bit. Slight shank wear over about 135°. Four fractured diamonds noted. Noticeable wear flats on diamonds. No teardrop wear pattern present. Wear on inside shoulder from core lifter case due to improperly set inner tube.
97288	606	629	23	New bit. Slight shank wear over about 270°. Two fractured diamonds noted. Noticeable wear flats on diamonds. No teardrop wear pattern present. Core lifter case wear on inside shoulder due to improper set-up.
Wireline	629	648	19	New bit. Bit was almost burned into the formation.

TABLE A-3 - Drilling log for prototype bit field test, Babbitt, Minnesota, January 22 - 24, 1979

DATE	BIT	FROM -TO	BIT RPM	BIT THRUST (LB.)	WATER GPM PRESSURE (PSIG)	PENETRATION RATE (IN/MIN)
1/22/79 2nd shift	97287	540 -559	1350	3630	6 130	2.7
1/23/79 3rd shift	Wire- line	559 -584	1400	4880	--- 125	2.4
1/23/79 1st shift	97286	584 -606	1350	3940	9 160	2.8
1/23/79 2nd shift	97288	606 -629	1350	4780	9 170	2.6
1/23, 24/79 2nd & 3rd shift	Wire- line	629 -648	1350	3750	--- 150	2.9

TABLE A-4 - Bit and short bit holder laboratory test, Bureau of Mines, Twin Cities Research Center, Minnesota, March 27, 1979

RUN[1]	BIT[2]	ROCK[3]	BIT THRUST (LB.)	BIT RPM	INCHES DRILLED	PENETRATION RATE (IN/MIN)
1	X00695	L	708	336	20	5.3
2	X00695	L	708	336	19	4.5
3	X00695	L	885	472	17	7.5
4	X00695	G	885	472	20	1.5
5	X00699	G	885/ 1150	472	18	1.1
6	R00703	G	1150	472	20	1.0

[1]Waterflow was 4.5 gpm at 80 psig.

[2]Refer to Table A-1 for comparison to wireline bits under similar conditions

[3]L - Limestone, G - Granite

TABLE A-5 - Bit log for bit and short bit holder field test, Colorado, June 23 - 25, and Washington, August 21 - 23, 1979

BIT	FROM	TO	FOOTAGE	COMMENTS
Leadville, Colorado				
X00698	500	520.0	20.0	New bit. Pulled to inspect bit holder and found no problems. There was no unusual bit wear and still had considerable life. Decided to try a 70 per carat bit.
X00700	520	587.0	67.0	New bit. The inner core tube mislatched. The resulting grinding of core and excessive cuttings production severely eroded the bit face. The bit holder driving lugs were somewhat eroded but still usable. However, a new bit holder tube was installed.
X00697	587	645.0	58.0	New bit. There was no unusual bit wear. The bit was still running well and had more life, but testing was discontinued at this site.
Metaline Falls, Washington				
X00696	420	426.0	6.0	New bit. Pulled early because encountered badly broken formation. A few I.D. gauge stones were missing or fractured.
R00704	455	525.5	70.5	New bit. Pulled because, again, encountered another broken zone and performance was dropping off. The driller felt there was 15' of life left in the bit. Several I.D. gauge stones were missing or fractured.

TABLE A-5 - Bit log for bit and short bit holder field test, Colorado,
(continued) June 23 - 25, and Washington, August 21 - 23, 1979

BIT	FROM	TO	FOOTAGE	COMMENTS
X00697	525.5	527.5	2.0	New bit. The bit was accidentally lost in the hole and was fished out. The bit was pulled loose when breaking core. Upon examining the bit holder, discovered that the locking sleeve was only partially engaged. The locking sleeve back rotation was probably caused when checking the inner tube-to-bit clearance on surface. The checking procedure created a relative rotation between the inner tube and bit holder which was opposite to that normally found when drilling. The bit was recovered intact although badly damaged. The bit holder could have been easily field repaired.

TABLE A-6 - Bit log for bit and short bit holder field test, Colorado, June 23 - 25, and Washington, August 21 - 23, 1979

DATE	BIT	FROM -TO	BIT RPM	BIT THRUST (LB.)	WATER PRESSURE (PSIG)	PENETRATION RATE (IN/MIN)
Leadville, Colorado						
6/23/79	X00698	500 -520	400	2500	30-100	2.5
6/23, 24/79	X00700	520 -587	425	3000	50-150	3.3
6/25/79	X00697	587 -645	480	3000	50-175	4.3
6/26/79	Wireline	645	---	---	---	3.5
Metaline Falls, Washington						
8/21/79	Wireline	-420	---	---	---	4.5
8/21/79	X00696	420 -426	360	1300	25-75	4.8
8/22/79	R00704	455 -525.5	650	3900	100-150	5.6
8/23/79	X00697	525.5 -527.5	650	3100	75-125	6.0

TABLE A-7 - Bit log for system field test, Virginia, April 21 - May 9, 1980, and Arizona, October 14 - 30, 1980

BIT	FROM	TO	FOOTAGE	COMMENTS
Richlands, Virginia				
X00698	320 420 536	345 524 714	307	This bit was also used in Leadville, Colorado, refer to Table A-5. It had drilled 20 ft. in fractured porphyry. There is evidence that here the bit came loose and wedged back into the bit holder during this test. This apparently occurred at 684 ft. The bit was retracted with the tool. A new spring detent was inserted in the locking sleeve and there was no reoccurrence of the problem during later testing. The bit was pulled because of decreasing performance.
R11939	714	814	100	New bit. The bit exhibited normal wear and seemed to be still usable. The driller preferred to go back down with a 25 per carat bit rather than this 50 per carat bit.
X00696	814	868	54	This bit had been used in Metaline Falls, Washington, refer to Table A-5. The badly broken dolomite there had damaged the bit face. The bit was retired here due to decreasing performance.
Wireline	868	984	116	New bit. The bit was retired due to decreasing performance. Normal wear patterns.
X32159	984	1254	270	New bit. The bit was retired due to decreasing performance. Normal wear patterns.
X32160	1254	1294	40	New bit. Stopped the testing program. Bit still in good shape.

TABLE A-7 - Bit log for system field test, Virginia, April 21 -
(continued) May 9, 1980, and Arizona, October 14 - 30, 1980

BIT	FROM	TO	FOOTAGE	COMMENTS
San Manuel, Arizona				
R11937	254	284	30	This bit had drilled 8 ft. before cancellation of the test in Deming, New Mexico. The driller here had been using impregnated bits and had to relearn the use of surface set bits. The bit was retired early because of prematurely polished stones.
X00701	284	314.5	30.5	New bit. Bit was retired early because of prematurely polished stones.
R00703	314.5	415	100.5	This bit drilled 1.5 ft. in the laboratory previously, refer to Table A-4. The driller here optimized the drilling parameters and there were normal wear patterns. The bit was retired due to decreasing performance.
R11938	415	476.8	61.8	New bit. The bit was lost in the hole and was not fished out. Apparently rod vibration caused by sudden lost fluid circulation was too severe for the spring detent to keep the locking sleeve from back rotating and releasing the bit.
Wireline	476.8	495	18.2	Wireline surface set bit was used to insure there was no metal left in the hole.

TABLE A-7 - (continued) Bit log for system field test, Virginia, April 21 - May 9, 1980, and Arizona, October 14 - 30, 1980

BIT	FROM	TO	FOOTAGE	COMMENTS
R11940	495	565	70	New bit. Normal wear observed after retiring bit due to decreasing performance.
R11941	565	705	140	New bit. Normal diamond wear observed after retiring the bit due to decreasing performance. Observed wear or grinding away of the bit I.D. above the set portion. Probably caused by core blocks.
R11942	705	788.1	83.1	New bit. The bit was lost in the hole and was not fished out. Apparently enough of the bit I.D. was ground away by core blocks that the retraction tool could not retain the bit after unlocking it from the bit holder. There were more core blocks this time than for R11941.

TABLE A-8 - Drilling log for system field test, Virginia, April 21 - May 9, 1980, and Arizona, October 14 - 30, 1980

DATE	BIT	FROM -TO	BIT RPM	BIT THRUST (LB)	WATER PRESSURE (PSIG)	PENETRATION RATE[1] (IN/MIN)
Richlands, Virginia						
4/21/80	X00698	320 -345	690	1440	180	10.8
4/23/80	X00698	420 -524	760	3540	200	10.9
4/25, 28/80	X00698	536 -714	760	3220	180	7.0
4/29/80	R11939	714 -814	710	2190	250	10.0
4/29, 30/80	X00696	814 -868	730	2650	280	7.7
5/1/80	Wireline	868 -984	730	4390	300	6.2
5/1,2, 5,7/80	X32159	984 -1254	730	4510	275	8.7
5/8, 9/80	X32160	1254 -1294	730	----	280	----

[1]Comparisons of Virginia data are cautioned because the formation was alternating layers of sandstone and shale. The layers were of varying thicknesses and influenced penetration values. Drilling in shale was significantly slower than in sandstone.

TABLE A-8 - Drilling log for system field test, Virginia, April 21 - May 9, 1980, and Arizona, October 14 - 30, 1980 (continued)

DATE	BIT	FROM -TO	BIT RPM	BIT THRUST (LB)	WATER PRESSURE (PSIG)	PENETRATION RATE[1] (IN/MIN)
San Manuel, Arizona						
10/14/80	R11937	254 -284	775	3000	150	1.3
10/14, 15/80	X00701	284 -314.5	775	3500	175	1.0
10/15, 16/80	R00703	314.5 -415	625	4400	180	2.6
10/16,17, 20/80	R11938	415 -476.8	625	4400	175	3.5
10/23, 24/80	R11940	495 -565	625	4000	185	2.3
10/24,27, 28/80	R11941	565 -705	625	4400	185	2.7
10/28,29, 30/80	R11942	705 -788.1	625	4200	180	2.9

A3.0 SUBJECT INVENTIONS

Performance of the project led to the filing for application for a United States patent. U.S. Patent Application, Serial #39283, filed May 15, 1979.

Applications have also been filed in four foreign corresponding countries namely: Australia, Canada, Japan and South Africa.