4-INCH DRILL
Operations and Maintenance Manual

November 13, 2019

U.S. Ice Drilling Program
University of Wisconsin-Madison Space Science & Engineering Center

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1.0 PURPOSE

1.1 This manual outlines the proper set up and operation of the 4-Inch Drill System.

2.0 SCOPE

2.1 This document applies to all personnel working with the 4-Inch Drill system.

3.0 REFERENCES

3.1 1008-0014 SSEC Safety Plan

4.0 DEFINITIONS

4.1 **IDP** – U.S. Ice Drilling Program, formerly IDDO.

4.2 **PPE** – Personal Protective Equipment.

4.3 **QAS** – Quality Assurance and Safety group.

4.4 **SSEC** – University of Wisconsin-Space Science & Engineering Center.

5.0 RESPONSIBILITIES

5.1 IDP Engineering is responsible for the generation and maintenance of this document.

5.2 SSEC QAS is responsible for ensuring that this document is created, reviewed, approved, maintained and changed per applicable SSEC processes.

5.3 Project personnel are responsible for understanding this document.

6.0 RECORDS

6.1 Drill logs.

7.0 SAFETY

The SSEC Project Safety Plan, 1008-0014, describes in detail the processes used to define, evaluate, mitigate, report, and communicate potential and real safety concerns for equipment and field projects. This section highlights key safety concerns for the 4-Inch Drill system and is not meant to replace the SSEC Project Safety Plan. Only trained personnel should operate the 4-Inch Drill. All drillers or those operating or assisting with operations of the 4-Inch Drill must read and understand the following safety precautions prior to operating this device.

7.1 Personal Protective Equipment (PPE)

7.1.1 PPE – Workers shall wear appropriate hand, eye, and ear protection during all drill operations and setup.

7.2 Mechanical Safety

7.2.1 Cutters – The cutters on the drill can be extremely sharp. Operators shall use care whenever handling cutter assemblies or cutter blades and should wear protective gloves whenever possible.

7.2.2 Pinch Points – There are several areas on the drill where a finger, hand, arm, or clothing could be pinched; specifically around the moving parts of the winch and winch cable. Operators should identify all pinch points prior to operation and should be mindful of all such points during operation and setup.

7.2.3 Suspended Loads – Users shall never stand under suspended loads. Injury may result from a moving, rotating, falling or unbalanced load.

7.2.4 Eye Protection – Standard operations of the 4-Inch Drill do not require eye protection be worn by operators, however, eye protection shall be available onsite in the event of non-standard operations such as those using chemicals to free a stuck drill.

7.2.5 Burn Hazard – The muffler and exhaust of the generator can be extremely hot. Avoid contact with either component. If service is required, allow time for the generator to cool before servicing.

7.2.6 Cold Hazard – Metal components and fuel may be extremely cold. Always wear appropriate gloves when handling.

7.2.7 Slippery Surfaces – The snow may become icy and slippery in high traffic areas. Roughen up walk areas as needed to prevent slips and falls. Always use caution whenever walking around the drill operations area.

7.3 Electrical Safety

7.3.1 Voltage – Extreme care shall be taken when assembling, disassembling and servicing electrical equipment. Equipment must be disconnected from the power source before servicing.

7.4 Chemical Safety

7.4.1 Use fluid resistant gloves and eye protection whenever handling fuel or chemicals.

7.4.2 Use care and observe all safety warnings when handling chemicals.

7.4.3 Combustibles – This system uses combustible fuel for the generator and may be supplied with ethanol for freeing a stuck drill. Take care to properly store all combustibles away from all major heat sources.

7.4.4 Secondary Containment – Fuels and other fluids should be stored in secondary containment to prevent spills and unplanned release. Secondary containment devices must be requested from the logistics provider.

7.4.5 Drilling Fluid Hazard – If used, note any potential for combustion or potentially present health hazards. Proper PPE must be worn when handling and using drilling fluids.

7.5 Fire Safety

7.5.1 No Smoking Areas – The following areas are non-smoking areas: Within any drilling and generator facilities, near chemical storage areas, near fuel storage areas, etc.

7.6 Environmental Safety

7.6.1 Cold – This drill will be deployed to extremely cold climates. Workers shall wear outerwear suitable to protect themselves from the cold, and monitor their own and fellow workers activities for exposure to cold.

7.6.2 Noise Hazard - Noise levels during operation of the drill are not expected to be of actionable levels.

8.0 SYSTEM OVERVIEW

The 4-Inch Drill is an electromechanical ice coring drill that produces a 104 mm diameter core and creates a 145 mm diameter borehole. Core length is nominally 1 m long, however it will vary depending on the density of the snow/ice. Cores can be retrieved from depths down to approximately 350 meters. Winches with 100, 200, and 400 meter cables are available. The drill is of a mature design and has been used successfully for several decades. It is particularly useful on projects requiring a larger diameter core than produced by the Badger-Eclipse drills. Depending on configuration, the drill can be transported by light aircraft or helicopter. An overview of the drill system specifications is shown in Table 1.

Table 1. 4-Inch Drill system specifications.

Systems in Inventory	2
Max. Practical Depth	300-350 m
Hole Diameter	145 mm (5.7 inches)
Core Diameter	105 mm (4.15 inches) or 104 mm (4.09 inches) depending on cutter type
Core Length	1 m
IDP Driller Required?	Yes; 1 required, 2 preferred
Drill Fluid Required?	No
Power Requirements/Source	240 V, 5 kW generator
Estimated Drilling Time	100 m – 30 hours 150 m – 50 hours 200 m – 75 hours
Time to move (breakdown and setup)	6 hours
Helicopter Transportable?	Yes
Light Aircraft Transportable?	Yes
Trench Required?	No
Shipping Weight With Tools and Spares	2600 lbs.
Shipping Cube With Tools and Spares	146 cubic feet

The goal of this manual is to provide a practical reference for the deployment and operation of the 4-Inch Drill. There are three main phases of any drilling operation; pre-deployment preparation, field operation, and return of the equipment from the field for maintenance and repairs. Understanding the relationship between the phases is essential for successful field operation. This manual is intended to provide the user with information on how best to execute each phase.

9.0 Pre-Deployment Preparations

As the drill is prepared for shipment to the field, the condition and function of each component should be inspected. The 4-Inch Drill has six major component groups:

- Drill Tower
- Drill Sled and Drill Winch
- Drill Motor, Anti-Torque Sections, and Barrels
- Drill Heads and Cutters
- Control and Display Boxes
- Tools and Spare Parts

The pre-Season checklist, located in Appendix A, will facilitate the pre-deployment inspection and ensure the proper components are packed and shipped. This checklist should be completed each time the drill system is sent out for a project.

9.1 Drill Tower

9.1.1 Required drill tower components:

- Sheave
- Four tower tubes
- Three tower tube couplings
- One sheave to tube coupling
- One tower to winch sled coupling
- Nine guy ropes
- Nine snow stakes for the guy ropes and an additional eight for the winch sled

The tower components, Figure 1, starting from the bottom of the picture: tower sheave, black aluminum coupler connecting the sheave with the first fiberglass tower section, followed by three double-ended couplers connecting three additional tower tubes and finally a black coupler connecting the last tower tube with a hinged base on the winch sled. A total of four tubular fiberglass sections make up the tower mast. At the end of each tube is one or more holes that align with a screw on the side of each coupler. These screws are used to maintain the rotational alignment between each coupler and tower section. The sheave assembly attaches to the top coupler with four flathead screws, Figure 2. The assembled top of the tower, comprised of the sheave, top coupler, and tower section, is shown in Figure 3.

Figure 1. Laying out the tower.

Figure 2. Tower tube, sheave coupler and sheave.

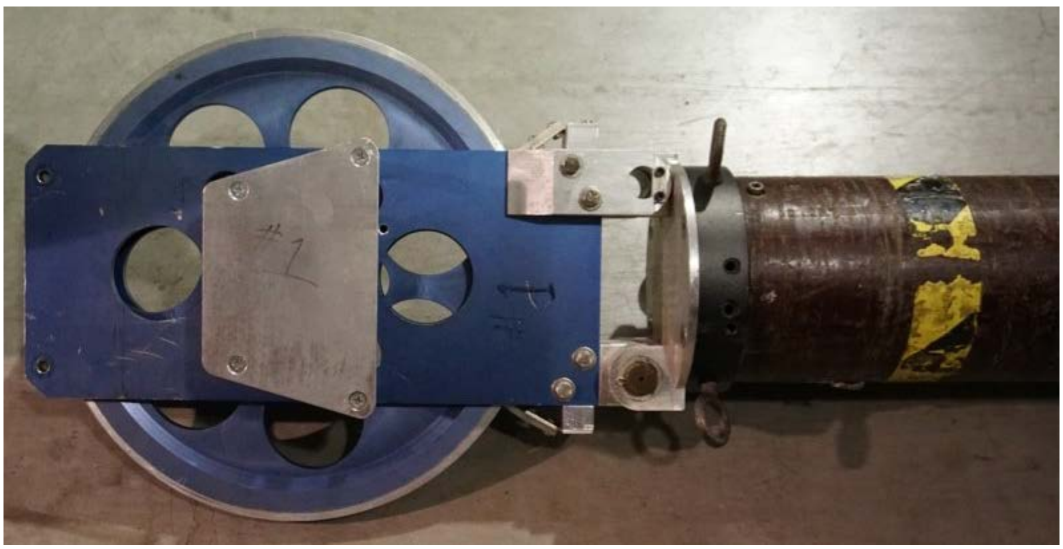


Figure 3. Sheave assembled with the tower.

When assembling the tower, the eye bolts on each coupler should be in alignment with those on the other couplers. This is to ensure the guy ropes will not interfere with the winch cable or drill.

Figure 4. Tower to sled coupler.

The bottom coupler, Figure 4, is used to attach the drill tower to the winch sled. The coupler mounts to the hinged base on the winch sled, Figure *5*.

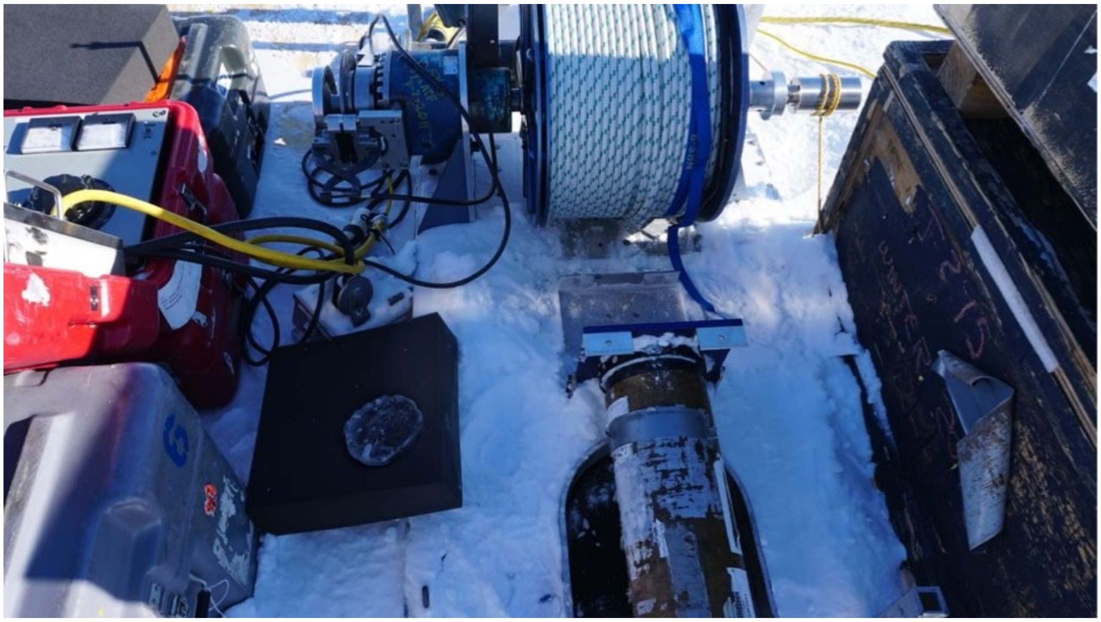


Figure 5. Tower (laying horizontal in this picture) attached to the winch sled.

Guy ropes attach to the eye bolts on the couplers and are tied off to snow stakes to secure the tower. Six ropes are sufficient to stabilize the tower under most weather conditions. Attach three ropes to the eye bolts below the top sheave and three to the middle coupler. If winds are expected to be above 50 knots, it is advised to add a third set of ropes between the middle and upper ropes to provide additional support.

9.2 Drill Sled and Drill Winch

The winch is the heaviest part of the 4-inch Drill. Having it mounted on the sled makes it much easier to move around and into position by hand. The drill sled has runners and can be towed behind a snowmobile or other form of snow transportation. Mounted on the sled are the cable winch and winch motor, Figure 6.

Figure 6. Drill sled and winch in their shipping crate.

The winch motor, mounted behind the winch drum, connects to the winch gear reducer with a timing belt. A hand wheel, mounted on the gear reducer, assists the operator in controlling the winch payout and slow-speed payout required for drilling. A slip ring mounts on the winch shaft on the opposite side of the gear box. The slip ring provides the electrical connection between the control box and the wires in the winch cable while allowing the winch drum to rotate, Figure 7.

Figure 7. Mounting the slip ring on the winch shaft.

9.3 Drill Motor, Anti-Torque Section, and Drill Barrels

The motor section and anti-torque are one unit on the 4-Inch Drill, Figure 8. The drill barrels attach to one end of the motor section, Figure 9, and the down hole slip ring and winch cable attach to the anti-torque end, Figure 10.

Figure 8. Motor section with anti-torque.

Figure 9. Motor section to outer barrel connection.

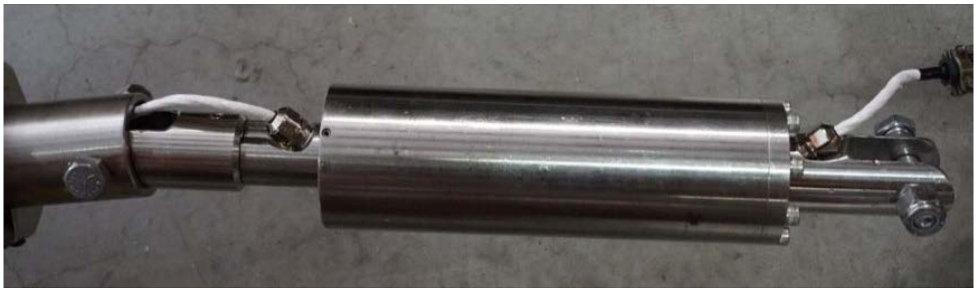


Figure 10. Motor section slip ring attached to the top of the anti-torque.

The orientation of the slip ring is not critical and it can be mounted in either direction. However, note how the cable is routed between the slip ring and motor section, Figure 10. The eyelet on the winch cable attaches to the clevis on the slip ring with a bolted connection, Figure 11. Mate the electrical connector, make a loop with the excess cable length and secure it into a tight bundle with a Velcro strap, Figure 11.

Note: It is very important that the cable loop is tightly bundled so it will not rub on the borehole wall, which will result in damage to the cable jacket.

Figure 11. Winch cable connected to the motor section slip ring. Cable pigtail is coiled and secured with a hook and loop strap.

The anti-torque section consists of three spring steel blades. The bow shape of the blades is adjusted by tightening or loosening the set screws at the end of each blade, Figure 12. It is important that the three blades are adjusted equally to ensure the top of the drill is centered in the borehole. Use a tape measure to set the bow of each blade. This is done by measuring the distance from the OD of the center shaft to the high point of each blade. A good initial starting point is to set the bow of each blade to 7 cm. The top connecting block slides, allowing the springs to change shape in the borehole. If the blades are set too loose, the anti-torque will slip, causing the blades to locally enlarge the diameter of the borehole. A rapid slip of the anti-torque can be identified at the surface by the cable whipping back and forth and also by a loss of penetration. The drill motor should immediately be turned off if this happens and the drill returned to the surface. Adjust each blade out, until the blades engage again. This may be several millimeters if in firn or only a millimeter or two if in denser ice. It is safer to spread them too much at once, than in smaller increments. The priority is to stop the spin that damages the borehole wall. More precise adjustments can follow once the drill is below the spin area. If the blades are too tight, the drill will stick-slip while drilling and not penetrate smoothly. In this case, the blades should be brought in a little bit at a time until the drill penetrates smoothly.

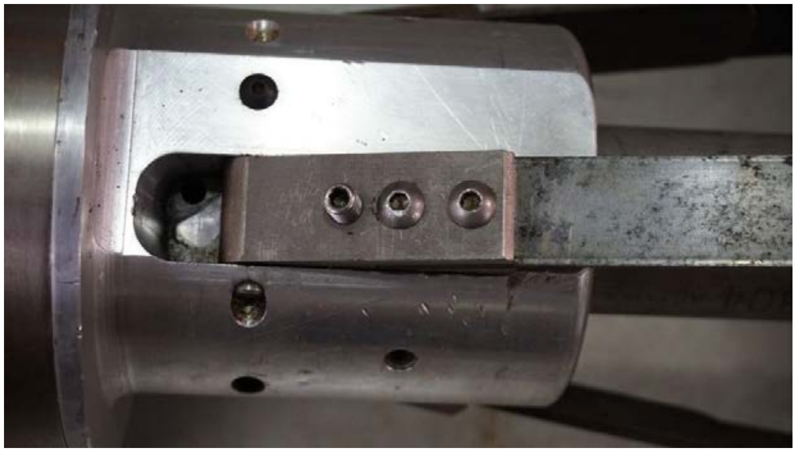


Figure 12. Anti-torque blade end block with set screw for adjusting the blade curve.

Two drill barrel sets are sent to the field, comprised of two outer and two inner (core) barrels. The inner barrel is matched to a particular outer barrel and should not be swapped between sets. The outer barrel attaches to the motor section with twelve flat head screws, Figure 9. Hand tighten all the screws before the final tightening. Next, using a hex key, tighten the screws in a pattern to ensure equal pressure on the outer barrel, Figure 13 .

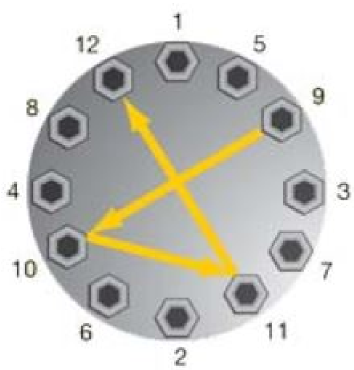


Figure 13. Outer barrel screw tightening pattern.

The inner barrel connects to the motor section drive adapter with a single pin. The pin is held in place with a spring plunger to facilitate quick removal. To insert or remove the pin, rotate the motor/inner barrel until the hole in the drive adapter aligns with the openings in the outer barrel. The outer barrel has metal strips running the length of the barrel ID, which are attached with epoxy and screws. These strips are essential for proper chip transport up the barrel length. The inner barrel has plastic spirals attach to the barrel’s outside surface. Cut chips are transported upwards via the spirals and fall inside the inner barrel through the openings, or windows, at the top. A core-chip separator is used to isolate the chips in the upper part of the barrel from the core in the lower part of the barrel. The core-chip separator is a plastic cup which is hung inside the inner barrel with a length of parachute cord and a clip that attaches in one of the windows at the top of the barrel. The core-chip separator should be initially set to about the mid-point in the barrel and adjusted as needed to maximize the length of core that can be drilled.

9.4 Drill Heads and Cutters

The 4-Inch Drill uses two types of drill heads. One type uses a collet for catching cores and the other uses core dogs.

The collet is a ring made of spring steel that moves freely up and down within the lower section of the drill head, Figure 14. The inner part of the head has a conical taper, forcing the ring to change diameter, grabbing the core and facilitating the core break when the drill is pulled up. During coring, the collet is pushed up above the conical taper in the head so the core can pass freely through it. The collet ring has multiple fingers to allow it to compress and grab the ice core, Figure 15.

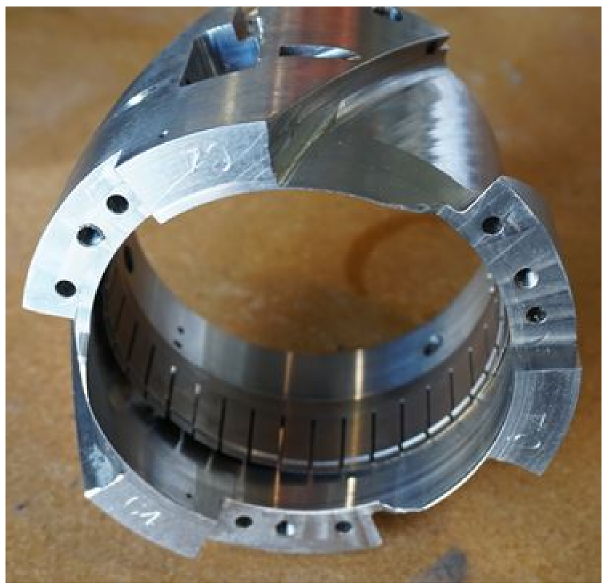


Figure 14. Cutter head with collet-type core catcher.

Figure 15. Collet core catcher.

Care must be taken to not damage the collet when pushing cores from the barrel and cleaning the head. The collet fingers have a limited range of movement and catching them with the core pusher or cleaning tool can permanently damage or break the fingers.

The drill head with core dogs has more parts as compared to the collet head, Figure 16. The core break is initiated by the spring loaded core dogs rather than a collet. The core dogs are supplied in three lengths, long - #3, medium - #2, and short - #1. Their selection depends on the hardness of the firn or ice. Generally, the long dogs work best in firn and the short dogs work best in dense ice. Pressure exerted by the core dogs on the core can be adjusted by selecting different coil springs. The springs provide the initial pressure required to engage the core dog with the ice core. Generally, softer springs are used when the surface of the core may be prone to damage by the protruding core dogs. When drilling, the core causes the core dogs to hinge back into their windows in the cutter head. When drilling stops and the drill is raised, the core dogs engage the ice core and initiate the core break.

Figure 16. Cutter head with core dog type core catcher.

The core dogs are secured in the drill head window with a pin and a set screw, Figure 17. The coil spring is also retained with the same pin. One leg of the spring locates in the groove of the core dog and the other in the slot at the bottom of the window in the head. The legs of the spring should be trimmed so they don’t stick out where they could injure the operator.

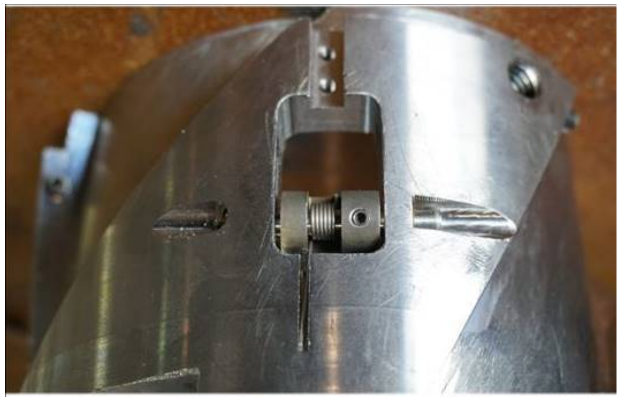


Figure 17. Core dog mounting.

The choice on when to use the collet drill head versus when to use the core dog drill head is not always straightforward. The collet is used only above the transition from firn to ice. This transition is typically between 80 to 120 meters depth. Due to differences in snow accumulation, and subsequently snow compaction, firn is not of uniform structure everywhere. Temperature, humidity, and wind affect surface conditions and influence differences in ice crystal formation within firn. As a result, some firn is softer and some is harder in structure. Since the collet head applies a more distributed and even pressure on the core than the core dogs do, it tends to cause less damage to the softer more fragile firn and provides a cleaner core break.

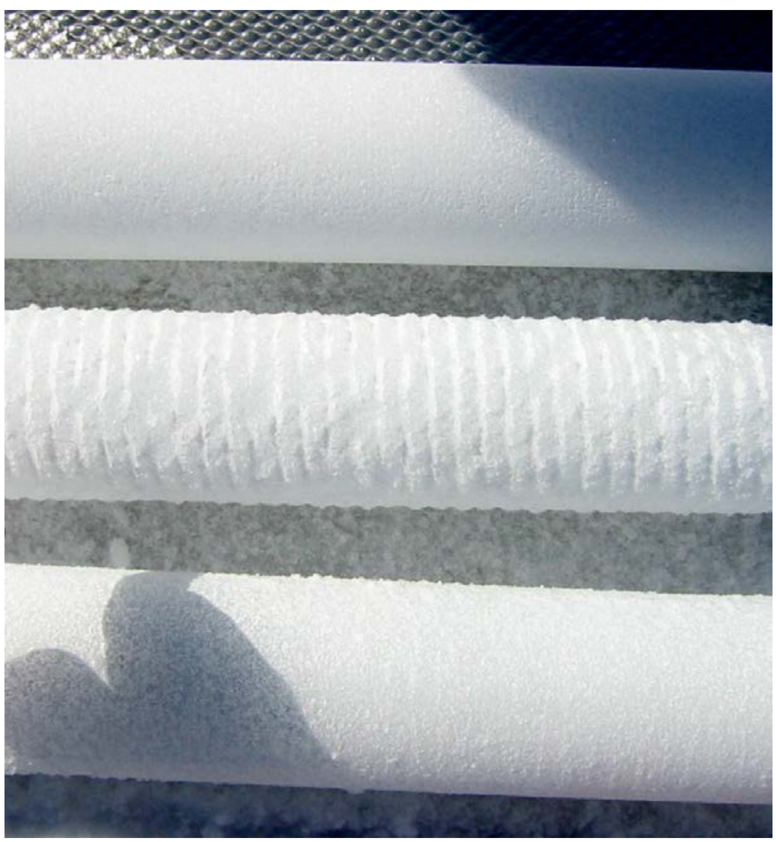


Figure 18. Surface finish variations in firn ice cores.

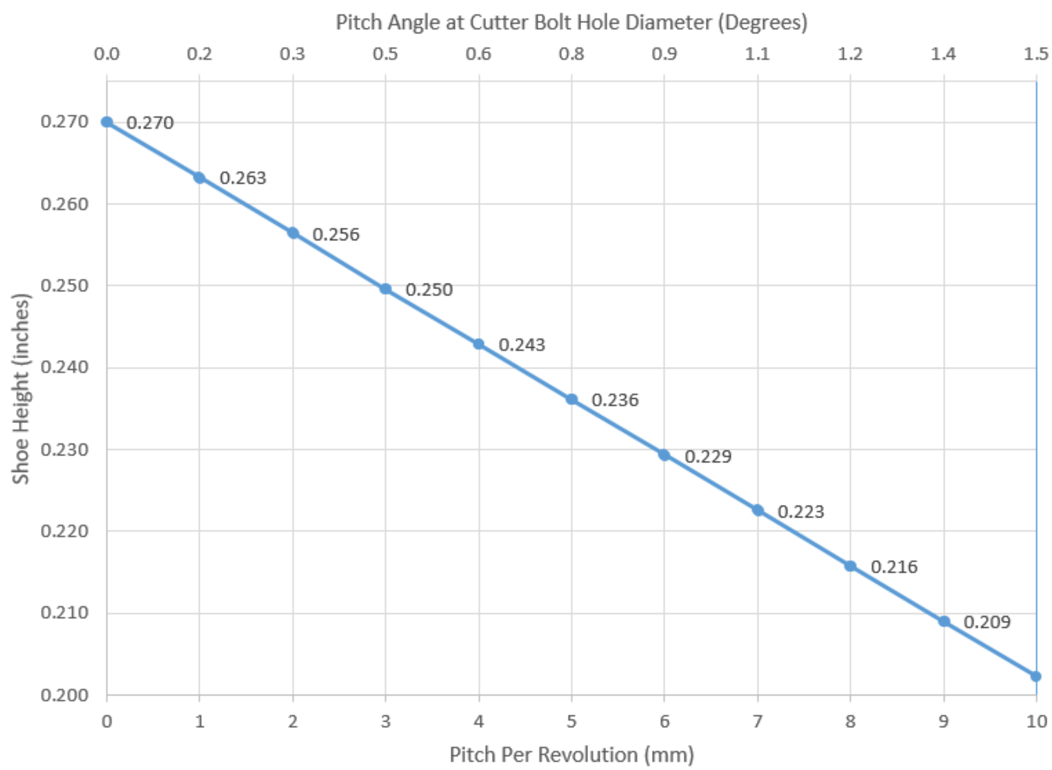
Figure 18 illustrates difference in surface finish of firn cores when using a collet or core dogs. These cores were drilled at Summit Station in Greenland. The middle core shows how core dogs can adversely impact core quality.

The cutters are supplied in matched sets of three. They must be kept in matched sets, meaning if one cutter needs to be changed all three must be changed. Failure to do this can lead to penetration issues or uneven cutting. The cutters also come in two widths, medium and wide. The medium cutters drill a 105 mm (4.15”) diameter core and 145 mm (5.7”) diameter borehole. The wide cutters drill a 104 mm (4.1”) diameter core and 147 mm (5.8”) diameter borehole. For most drilling, the medium cutters are the best choice. A few sets of wide cutters are provided as an option to try if the drill is not performing well with the medium cutters. Note: switching to the wide cutters will require the entire depth of the borehole to be enlarged or reamed with the wider cutters. The anti-torque blade settings will also have to be adjusted to compensate for the larger borehole diameter. Each cutter has three holes; two for the locating pins and one for the securing screw. When assembling the drill head, the cutters mount first followed by the penetration shoes, Figure 19. Confirm the flathead screw mounting the cutter and shoe is flush with the surface of the shoe. If they stick proud of the shoe face, they will affect the drill penetration.

Figure 19. Cutters and penetration shoes.

The penetration shoe angle limits the depth of cut. They are supplied in three different angles (1.0°, 1.2° and 1.4°), to provide different depths of cut. The aggressiveness of the cutting action influences the core quality. A penetration rate of 1.2° is a good starting point. A finer penetration rate will generally provide better core quality, however it comes at the expense of slower drilling rates and smaller sized chips. Larger chips transport up the barrel spirals better and cause less penetration issues and packing at the drill head. Table 2 shows the relationship of shoe height vs pitch (vertical distance the drill will progress in one revolution) or pitch angle, which is how the shoes are labeled.

Table 2. Shoe height vs cutter pitch chart.



9.4.1 Quick Set up Guide

In summary from the previous sections, Table 3 provides a quick reference for recommended initial drill settings.

Table 3. Initial drill settings.

Drilling in Firn	
Anti-Torque Blade Bow	7 cm
Collet Head	
Cutters	Medium width
Penetration Shoes	1.2°
Dog Head	
Cutters	Medium width
Penetration Shoes	1.2°
Core Dogs	Long Length - #3
Core Dog Springs	6 turn
Drilling in Ice	
Anti-Torque Blade Bow	7 cm
Collet Head	Not Recommended
Dog Head	
Cutters	Medium width
Penetration Shoes	1.2°
Core Dogs	Medium Length - #2
Core Dog Springs	6 turn

9.5 Control and Display Boxes

The control box enables the operator to control the winch and the drill. Only one motor (winch or drill motor) can be controlled at a time. Figure 20 illustrates the main features of the control box. At the top right are two switches; the upper switches between winch and drill, and the lower changes direction of the selected motor between forward and reverse. The three analog meters display input voltage and output voltage and current. The large black knob (Variac control) in the upper left controls the speed of the winch or drill motor, depending on which motor has been selected with the selector switches. In the upper center part of the controller are three cables. The lower cable is the drill power cable, which connects to the winch slip-ring. The middle cable connects to the winch motor. The upper cable connects to a 240 V power source. The 4-Inch Drill is normally powered by a 5 kW generator through the 120/240 V outlet.

Figure 20. Drill and winch controller.

NOTE: The control box does not have built-in current limiters. Instantaneously applying a high voltage to the winch motor when retrieving the string will cause the amperage to spike, resulting in a high risk of damaging the Variac. The operator should always slowly accelerate the winch and watch the amp meter to assure that the amperage does not exceed 30 amps.

The display box provides monitoring of the cable tension and drilling depth. Figure 21 shows the typical setup of the control and display boxes.

Figure 21. Controller and display box setup with the drill system.

On the right hand side of the display box are connections for the load pin (upper) and encoder (lower). In the middle, starting from the top, is a display for the cable tension (weight-on-bit) followed by two depth displays. To the left of each display is a reset button for zeroing each display reading. The yellow cable on the lower left connects to a 120 V power source. Above the power cable are two fuse holders and the main power switch. Two sufficiently long power cables (100 foot long cables are provided) are needed between the generator and the control/display boxes. One to supply 240V to the Control Box and another to supply 120 V to the display box.

The Load pin and the Encoder are mounted on the Sheave assembly, with cables secured along the tower to the display box. The encoder is located under a protective plate, on the left side of the sheave in Figure 22.

Figure 22. Cable payout encoder under protective plate.

The load cell has to be installed in the field. It slides into the circular opening at the base of the sheave mount and is secured in place with a small keeper plate that fits into the groove on the Load pin, Figure 23. The display boxes are calibrated for use with a specific load pin, so be sure to check the labels on the load pin and display box for the correct match. The display boxes will not be damaged if connected to the wrong load pin; however, since the calibration for each load pin is slightly different, the display may not read the correct weight.

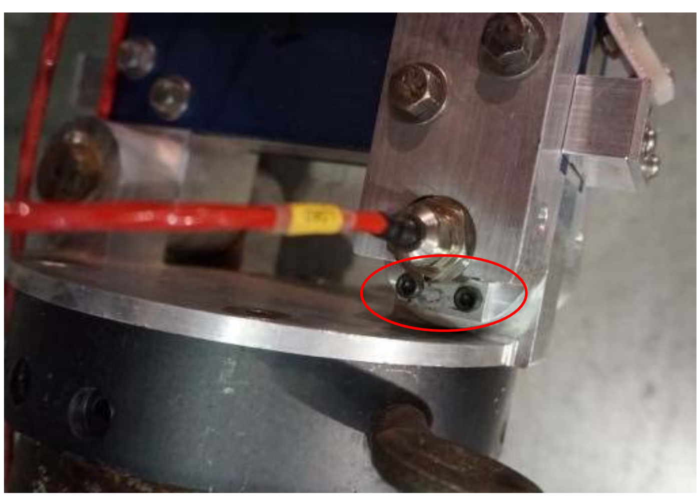


Figure 23. Load cell mounted in the sheave assembly. The keeper plate is circled in red.

9.6 Tools and Spare Parts

Toolboxes are provided with each drill and are an integral part of the drill system. A basic tool kit is included with each drill system; however, individual drillers often supplement the kits with additional or preferred tools that can be supplied by IDP upon request.

In addition to the tool kit provided with the drill is a selection of spare parts. These spare parts have either been identified as mission critical or at an elevated risk of failure due to use or environmental conditions in which the system is being used.

9.6.1 Tower

- Minimum of three spare guy ropes.
- Extra screws for the tower couplings, sheave coupling, and tower base coupling.

9.6.2 Winch and Sled

- Winch slip ring.
- Winch motor.
- Winch gear box.
- Extra bolts for mounting the slip ring to the winch shaft.

9.6.3 Drill String

- Complete spare anti-torque/motor section.
- Barrel set.
- Set of three anti-torque blades.
- Set screws for adjusting the bow of the anti-torque blades.
- Hardware for securing the blades to the anti-torque section.
- Down-hole slip ring.
- Cutter heads (both collet and core dog type).
- Screws for securing the head to the inner barrel
- Assortment of cutters appropriate for the amount and type of ice that will be drilled.
- Assortment of core dogs in long, medium and short lengths.
- Assortment of springs for the core dogs.
- Set screws and mounting pins for the core dogs.
- Collet.
- Screws and pins for securing the cutters and penetration shoes.
- Assortment of penetration shoes.

9.6.4 Control and Readout Boxes

- Second control box.
- Second display box.
- Encoder with cable.
- Load pin with cable.
- Load cell keeper with screws.
- Velcro straps for securing the load cell and encoder cables along the tower.

10.0 SHIPPING

It is rare for the drill shipment to go directly to a drilling site, and there is usually at least one stop in between. The equipment often transfers through multiple shippers and on several forms of transportation, such as truck, boat, and aircraft before reaching its final destination. The possibility for cargo to be damaged or lost increases every time it is handled. It is essential that the received content is verified against the packing list, before the final leg of a shipment to the actual field site. One should also look for potential damage incurred during shipping. Identifying any missing or damaged cargo as soon as possible will provide more time to resolve the issue and help minimize any impact to the field project. To minimize the chance of cargo getting lost, each piece of cargo should have its own shipping label, even for multiple items banded onto a single pallet. Contents of pallets often get rearranged during shipping and this is when unmarked boxes tend to get lost.

11.0 DRILL SITE

Once a drill site is selected, it should be properly marked with flags. The integrity of the snow surface should also be protected. The generator should be placed as far from the drilling site as possible and down wind, primarily to protect the snow surface from contamination and also to improve working conditions by limiting noise. The generator should be protected from drifting snow or intensive cold. Some generators come in protective boxes, allowing only certain sections to be exposed. If a protective box is not available, a cardboard box can serve as a simple shelter. Follow general rules of handling hazardous materials, and set up a proper refueling station to limit possible fuel spills.

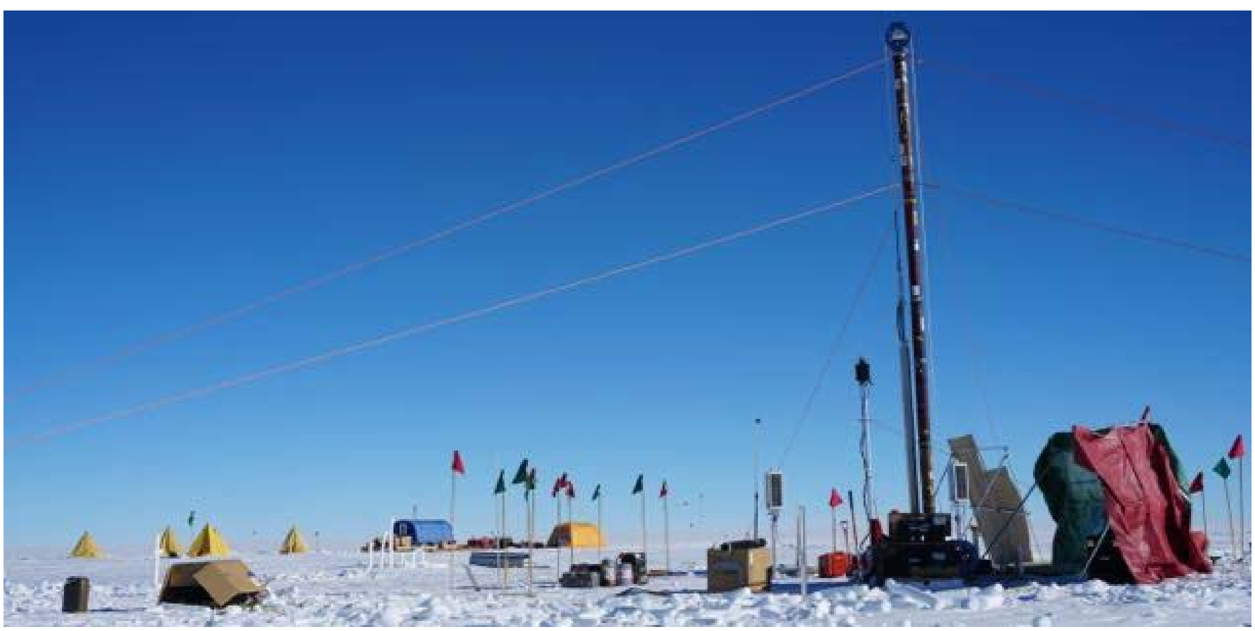


Figure 24. General site setup.

The prevailing wind direction should be taken into consideration when orienting the drill and selecting a location for the generator. Sastrugi are usually a good indication of the prevailing wind direction.

Wind breaks improve efficiency and comfort of the worksite and provide protection to sensitive equipment, Figure 24. They can be as simple as a wall made of snow blocks or tarps setup with bamboo flags. IDP also has an inventory of commercially-made wind breaks that can be deployed with the drill system, Figure 25.

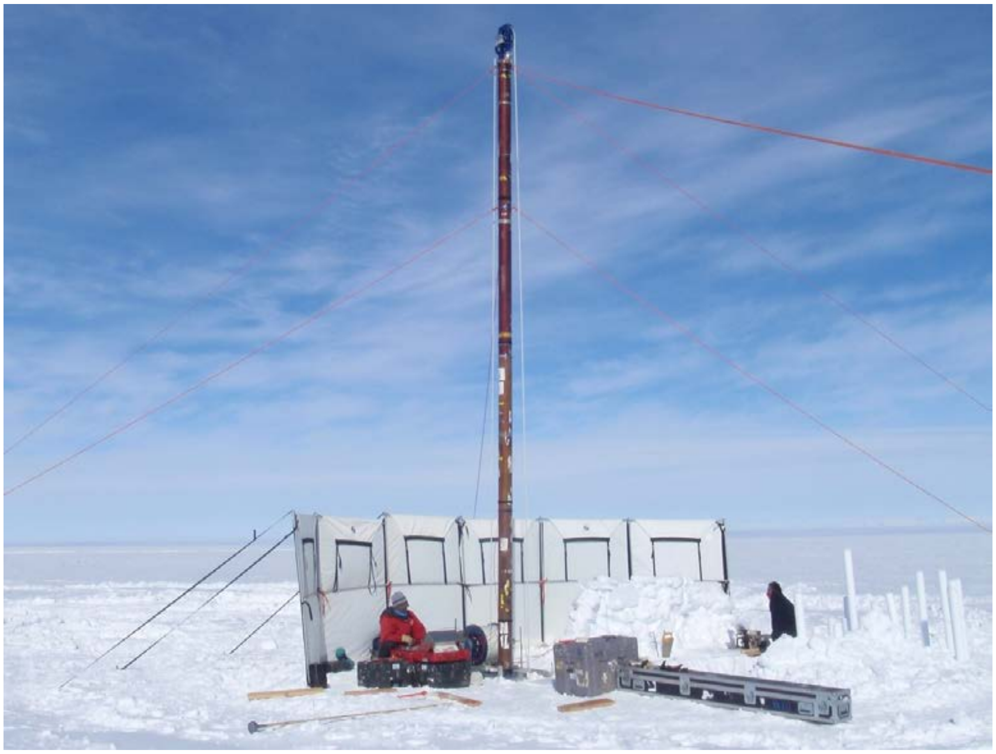


Figure 25. 4-Inch Drill system with IDP-supplied wind break.

12.0 ON-SITE SETUP AND PREPARATIONS FOR DRILLING

Aside from the winch, none of the 4-Inch Drill components are excessively heavy, but proper warmup and stretching should be done first before any lifting or dragging of the equipment.

Move the winch sled into position, orientating the sled so the winch drum will be upwind from the borehole. Two people can drag the sled relatively easy; however, if a snowmobile is available, it should be used for this operation to reduce the risk of injury. The sled should be anchored in place with aluminum stakes on all four sides.

It is critical to level the winch sled side-to-side and to a lesser extent front to back. If the sled is not level side-to-side and the tower is erected vertical, the top sheave will not be aligned with the midpoint of the winch drum. This will cause the winch cable to have a tendency to not level wind properly and to stack at one flange. This can quickly lead to the cable jumping off the winch drum, becoming jammed between the winch drum and end bearing, and damaging the cable.

In section 9.1, assembly of the tower is described in detail. Special care should be taken with the sheave. As shown in Figure 26, the sheave is elevated using an available box, allowing easier attachment of the load cell, encoder cable, and the winch cable. Pay attention to which side of the sheave the encoder is located. It should always be on the same side as the hand wheel on the winch. If by mistake it is on the opposite side, the drilling depth will show as negative number. This is more of an inconvenience than an actual issue. Place the control and display boxes and run power to them from the generator. Power up the winch and pay out enough winch cable to run it over the sheave and back to the sled, fit the cable to the groove on the sheave, and temporarily strap the cable end to the tower while raising the tower. The tower is ready to be raised after the cables for the load cell and Encoder are connected and strapped to the tower, and the six guy ropes are in place. This is also a good point to power up and test the operation of the display box.

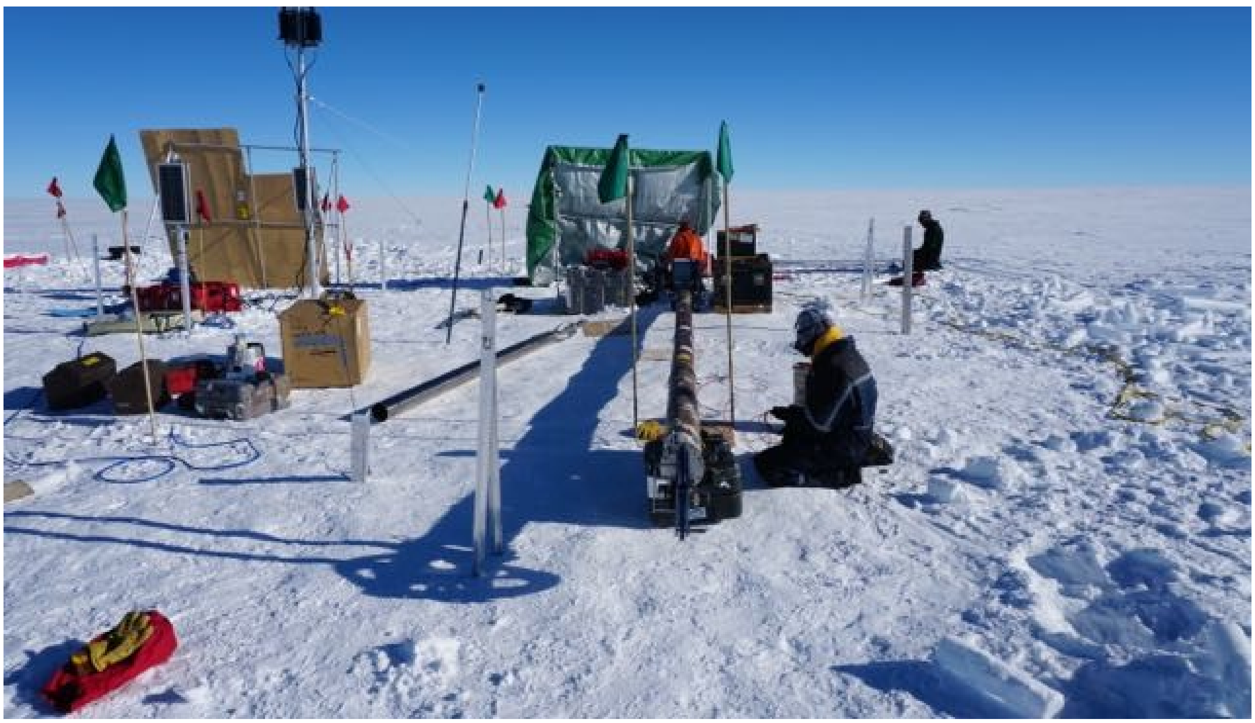


Figure 26. Assembling the tower on site.

With one person or preferably two, walk the tower up while two others pull it up with the guy ropes. Tower raising should always involve all available field team members for efficiency and safety. A guy rope can also be hooked to a snowmobile to assist with raising the tower. As the tower nears vertical, it is important to have a person man the guy rope opposite those being used to raise the tower. This is to prevent the tower from being pulled past vertical, and possibly tipping over, as it is brought to vertical.

Once the tower is vertical, one or two people can stabilize it with opposing guy ropes while the others secure the hinged tower base in place with the two bolts, place the snow stakes, and adjust the tension of the ropes. Since there are three guy ropes at each level it is suggested to have them 120 degree apart. The ropes should be guyed out so the angle between them and the snow surface is in the 15°-30° range. See Figure 24 and Figure 25 for reference. The snow stakes should be driven into the snow at about a 30° angle, with the top angled away from the tower. This will keep the stakes from pulling out when the ropes are tensioned. The angle of the snow stake may need to be adjusted depending on the rope angle and surface conditions. If the snow is very soft, the stakes should be used to put in dead-man anchors, Figure 27.

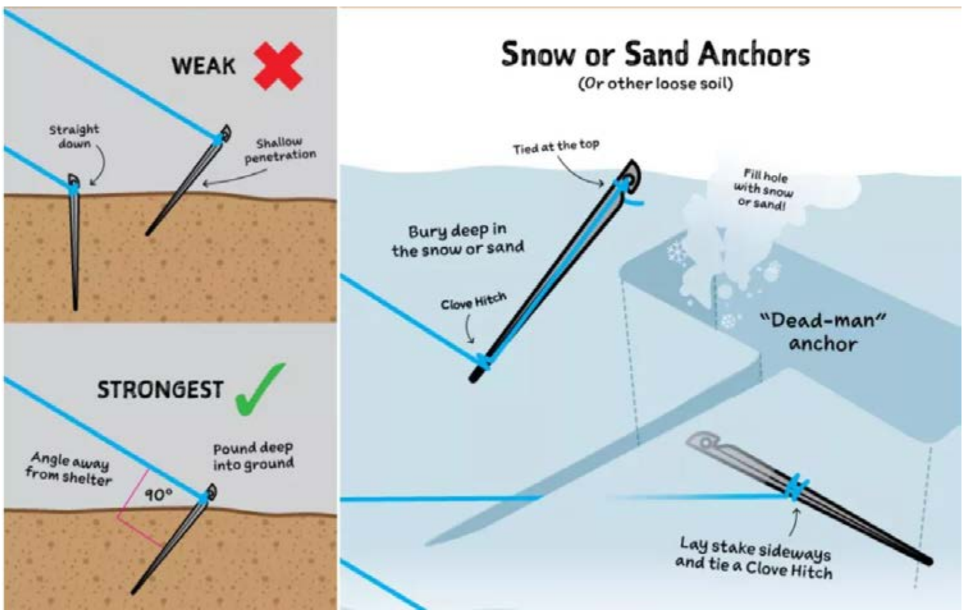


Figure 27. Proper placement of snow stakes and dead-man anchors.

Final adjustment of the drill head location will be performed when the drill is attached and hanging on the winch cable, as it will serve as a plumb bob. If a wind screen is going to be setup, now is a good time to do it.

The anti-torque/motor section can now be attached to the winch cable, followed by the outer barrel, as described in section 9.3.

To facilitate removal of the pin that connects the inner barrel to the motor section, a shallow pit should be dug or drilled using the drill just deep enough so you can comfortably reach the top of the inner barrel when it is placed in the pit. Figure 28 shows the general concept and location of the pit in reference to the winch location. Place a piece of foam at the bottom of the pit to provide a resting surface for the drill head.

Figure 28. Shallow hole drilled in front of the main borehole to facilitate barrel disassembly.

Prior to operation of the control box, the use of voice commands will ensure that all involved know what is going on and are clear of the area of moving drill parts, such as the drill and winch, both of which can cause injury when moving.

Examples of voice commands;

- CLEAR FOR CORE HEAD ROTATION?
- DRILL UP
- CLEAR FOR PIN REMOVAL?

Before turning on power to the control box, always verify the position of the two switches. They should be in off position and the Variac should be turned to zero.

You are now ready to raise the drill string in order to insert the inner barrel.

The drill should be placed in front of the winch and in line with the winch sled (where the drill tower was laying before being raised) and not off to the side. The winch cable must be kept aligned with the tower as the drill string is raised. If the cable is pulled to the side of the sheave, it can jump off the sheave and damage the cable.

The helper guides the drill string, as the driller slowly raises it with the winch. The helper should lift up the end of the outer barrel, so it will not drag in the snow as the drill string is raised. Next, place the inner barrel in the pit and lower the drill string over it.

Once the outer barrel has encased the inner barrel, insert the pin through the opening in the outer barrel to secure the inner barrel to the drive adapter. You should feel the pin click into place and it should be sticking out equally on both sides. If the pin hole is not visible in the opening of the outer barrel, you may need to slowly rotate the drill motor until it comes into view. With the pin in place, the driller next rotates the winch in reverse to raise the drill until the cutter head is just above the snow surface.

For safety, it is always best to run the drill head in reverse when out of the borehole.

If this is the first time raising the drill, check how the drill is hanging in relation to the tower. It should be in line with the tower side-to-side and centered in the opening in the drill sled. Adjust the tower guy ropes as needed to align the drill. Also, check that the tower is straight from top to bottom and the mid-point ropes are not pulling it out of alignment.

BEFORE THE START OF DRILLING, it is useful to **STEP BACK** and verify that all equipment is setup properly and the site is neat and organized for safe and productive operation. All tools used for assembly should be put away so they don't get lost in the snow. Any tools that will be routinely used during drilling, such as for removing the barrel pin or cleaning the cutter head, should be secured to the winch sled or tower with a lanyard so they don't accidently fall into the borehole.

A safe footing around the drill site is important. Some drill sites are extremely soft, while some can be solid ice. Areas where drilling personnel are working should be arranged to ensure safe and efficient operation. For example, plywood can be placed over soft snow, or crampon-type boot attachments can be used when the surface is slippery. Areas that become icy should be roughed up with a shovel so they don't become a slip hazard.

Synchronization of the driller and drilling helper(s) is important both for productivity and safety. **Proper explanation of all drilling tasks among the team members is essential. It is important that everyone understands each step and how it fits into the drilling sequence.**

Drill run times generally decrease as personnel get more familiar with their tasks and get into a rhythm. This will happen naturally, as people learn the equipment and tasks and get comfortable working as a team. This process should not be rushed. Everyone learns and works at different rates and that should be respected.

13.0 DRILLING SEQUENCE

13.1 Drill Run Operations - Reference Guide

1. Start a new drill run in the log book.
2. Remove the borehole cover
3. Place the control box selection switches to "winch" and "down". Release the parking brake. Lower the drill to the snow surface and zero the depth and load pin displays.

4. Lower the drill until it is positioned about 10 cm above the bottom of the borehole.
5. Move the drill selection switches to “drill” and “forward”. Start the drill motor by slowly turning the Variac knob clockwise. A setting of 50-80% on the knob provides a good cutter speed.
6. When the drill starts cutting (you will see a jump in current on the amp meter, though typically not for the first few cores in soft firn), zero the display for core length.
7. Drill the appropriate core length. The barrel is full when the current on the amp meter begins rising quickly. Stop the drill motor.
8. Record the core length in the log book.
9. Place the control box selection switches to “winch” and “up”. Increase winch speed after the core break occurs.
10. Raise the drill string to clear the hole. Install the borehole cover.
11. Push the drill to the side and run the cutter in reverse to clear any chips in the flights.
12. Lower the drill to the pit and remove the pin securing the inner barrel. Lift the drill string up and remove the inner barrel. Set the parking brake and set the direction selection switch to off.
13. Move the inner barrel to the core processing area. Pull out the core-chip separator to remove the cuttings, and push the core out of the inner barrel onto the core tray.
14. Reassemble the inner barrel with the drill string. Install the core-chip separator. Switch the selection switch to “down” and lower the outer barrel over the inner barrel and reinstall the locking pin.
15. Switch the selection switch to “up” and reposition the drill over the hole.
16. Clean the cutters, shoes, and core dogs/collet. Make sure they are free of built-up ice and core dogs/collet move freely.

13.2 Expanded Details for the Drill Run Operations – Reference Guide in section 13.1

Details for Reference Guide step 1.

Detailed records should be kept of each drill run in a log book. Information recorded about the drill setup and details of each run are very useful during a project for monitoring drill performance as well as historically to keep record of drill performance and ice conditions at a particular site. A drill log is included in Appendix A.

Details for Reference Guide step 2.

The borehole cover prevents objects from falling down the borehole, mainly tools and snow or ice chips. **It takes very little time to cover the borehole, but it takes a lot of time to retrieve objects that fall down the borehole.** When the drill is back at the surface after a drill run, it is often desirable to run the drill motor in reverse to remove cuttings packed on the inner barrel flights to make removal of the inner barrel easier. The cover prevents loose chips from falling down the borehole. It is usually the drill helper's task to cover the hole, but everyone present at the site should keep this in mind. **WHEN THE DRILL IS OUT OF THE BOREHOLE, THE HOLE COVER SHOULD BE IN PLACE.**

Details for Reference Guide steps 3 & 4.

There are two depth meters on the display box; one indicates total depth, another can be used to show the length of core drilled during the run. Zero the depth of the first meter at the top of the borehole. The driller helper should steady the barrel as the drill string descends and the drill head reaches the top of the borehole. Zeroing the meter is not necessary for every run, but the driller should double check it and zero it if necessary. The second meter will be zeroed at the bottom of the borehole when cutting action starts, as indicated by an increase in cutter amperage as the cutter engages the ice.

When starting a new borehole, the driller helper should guide the barrel until the anti-torque blades are able to engage the ice. When guiding the barrel, one should keep it as vertical as possible, as not to affect the borehole inclination.

When adjusting the anti-torque blade bow, one should consider the softness of the firn. There are many places, especially in Antarctica, where drilling the first 10 meters is very difficult, mainly due to the size of the ice crystals, Figure 29. Initially, the anti-torque blades may need to be set wider to avoid a drill spin in these firn conditions. Bring the anti-torque blades back in as the firn density increases.

Figure 29. Large crystals of the firn ice core.

Details for Reference Guide steps 3, 4, & 6.

The hand wheel on the winch is used to control the descent speed of the drill while the drill is being lowered and during drilling. This is done by applying drag on the wheel with a gloved hand. Once descent of the drill has been started with the winch under power (often this will not even be necessary), the direction switch should be switched to “off” to let the winch free-wheel. Descending speed is then controlled by the hand wheel.

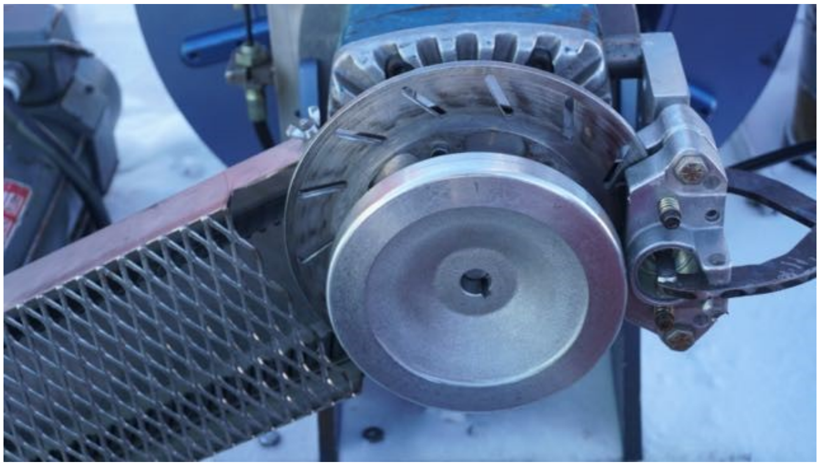


Figure 30. Controlling wheel and parking brake.

Since the hand wheel is mounted close to a brake caliper, Figure 30, proper position of the drillers hand is important to prevent pinching fingers, Figure 31. The drillers hand should be positioned away from the caliper and mounting bolts.

Figure 31. Controlling dill penetration rate with hand wheel.

Effective use of the wheel is not difficult, but requires some practice. The best time to practice is when the drill string is above the borehole. Observe how much movement of the wheel corresponds to movement of the drill string. **PRACTICE steady movement**. When drilling, the wheel movement should be **smooth and STEADY**. **STEADY** movement of the wheel, will translate to a **STEADY** penetration rate. A **STEADY** penetration rate helps ensure cut chips will move up the flights and away from the drill head. The amperage of the drill motor while drilling should show little fluctuation with steady penetration. With erratic penetration, the amperage will show significant fluctuation.

The load cell display provides the driller with additional feedback and specific information pertaining to the cutting action. When the drill is hanging above the cutting surface, the relative display value is high, since the weight of the drill string is not being supported by the ice surface. When cutting starts, the weight value will decrease, since part of the weight of the drill string is being supported by the ice surface. **Understanding how to interpret changes of the load cell values is essential.**

Each drill run sequence will have a unique set of the load cell values, corresponding to:

1. Drill hanging above the cutting surface.
2. Drill starting the cut.
3. Drill in a steady cutting state.

Movement of the wheel must be synchronized with the changes in load cell values. A typical drilling sequence can be described as follows; when the load cell value increases (corresponding to less weight of the drill resting on the borehole bottom), the driller increases the feed rate; the driller slows or stops lowering the drill when the load cell value decreases (corresponding to more of the drill weight being supported by the borehole bottom). Since the cutting action is relatively fast, changes of the load cell values will also happen fast, and oscillation of the weight values between high and low will occur throughout the run. Weight will increase as the drill goes deeper, due to the additional weight of the cable. The load cell values displayed at 10 meters depth will be different than those at 100 meters. What is most important are the relative changes between the high and low values during each run. The objective is to keep the high-low oscillation consistent from run to run, which translates to **repeatable** and **consistent penetration** from run to run. When the core is retrieved, observation of the core surface often shows delicate grooving left by the cutters. The maximum depth of cut is controlled by the pitch of the shoes, but the groove markings can provide some feedback to the actual penetration as a result of the hand wheel action. If penetration was steady through the drill run, spacing of the core markings should be uniform, Figure 32.

Figure 32. Grooving on the surface of firn cores.

Details for Reference Guide steps 5 & 6.

There are no set rules regarding how fast the drill should be run. However, the two main objectives are to drill good quality cores and to create proper size chips. If the chips are flaky and uniform, the rotation speed and penetration rate is correct. If there are a lot of very fine chips, often called flour, being generated, the rotation speed could be too fast, the cutters may be dull, or the penetration rate is too slow. Evaluation of the chips provides important feedback to the effectiveness of the cutting action. If the chip size is correct, they will move easily up the inner barrel flights and the bottom of the borehole will remain clean. If the chips are not removed efficiently from around the cutter head, they will negatively impact core quality and drill penetration. Normally, the Variac is set between 50-80%.

The core length is limited by the volume of chips being generated and collected in the inner barrel. Firn cores are generally longer than ice cores. Typical firn cores can be up to 117 cm long, whereas core length in dense ice will be about 80 to 100 cm. **The core quality is more important than the core length and should be the primary concern.**

Drillers should monitor the Amperage of the drill motor. An increase in amperage indicates that the inner barrel is getting full.

Caution: Do not exceed 10 amps on the drill motor while drilling.

Details for Reference Guide step 9.

Slowly increase the Variac control knob until the drill collet or core dogs make the core break. Slowly increase the winch speed and raise the drill string to the surface. The max safe ascent speed will depend on operator experience and borehole depth. Generally, ascending at up to 50% on the Variac control knob is ok. The main determining factors are safety, smooth drill ascent, cable spooling evenly on the winch, and the operators' comfort with the situation.

Caution: Do not exceed 30 amps on the winch motor.

Caution: Pay attention to the spooling of the cable, making sure the cable wraps correctly on the winch spool.

Details for Reference Guide step 10.

With the possibility of different core breaks each run, it is important to check and see if the core is sticking out of the drill every time it is brought to the surface. If the core is sticking out below the cutters, one has to manually push it back into the barrel, so the core is not damaged when the barrel is set down in the pit.

With a proper core break, the entire drilled core is retrieved from the borehole and it is not sticking out beyond the cutters. Comparing the length of the core the display indicates was drilled to the actual length retrieved indicates how effective the core break was and if the drill was allowed to cut free (full weight of the drill is hanging on the cable) at the end of coring. When drilling with the collet, not much adjustment can be made to improve the core break. Figure 33 and Figure 34 show typical collet breaks.

Figure 33. Proper collet core break.

Figure 34. Collet sliding on the surface of the core before break.

When drilling with the head equipped with core dogs, the driller can change the length of the core dogs, adjust the spring tension, or sharpen the leading edge of the core dogs. If the core dogs are sliding and leaving grooves in a firn core, the core dogs are probably too short. If the longest core dogs are being used, the engagement should improve in a few runs as the firn density increases. Alternatively, switch to the collet head if the firn core quality is a priority. While drilling ice, if the core dogs have been engaging well and then start sliding before engaging, leaving the core sticking out of the barrel as in Figure 34, then check that the dogs are sharp, switch to shorter core dogs, or try increasing the spring tension. Generally, as the density of the ice increases, switch to progressively shorter core dogs.

Details for Reference Guide step 13.

Once the inner barrel has been removed from the drill, the cuttings and core can be pushed out. Grab the clip and cord for the core-chip separator and pull it out to remove the cuttings. Rest the top end of the inner barrel on the edge of the core tray, insert the core pusher into the cutter head and push the core out onto the core tray, Figure 35. The core pusher should be carefully positioned on the center of the core. This is to avoid any damage to the cutters or core catchers when pushing out the core. Looking at Figure 34, one can observe that a core drilled with the collet sometimes can have two diameters. The collet teeth may reduce the core diameter slightly, so the section of the core below the teeth may have slightly larger diameter, making pushing out the core more difficult.

Replace the core-chip separator in the inner barrel before reinstalling the inner barrel in the drill.

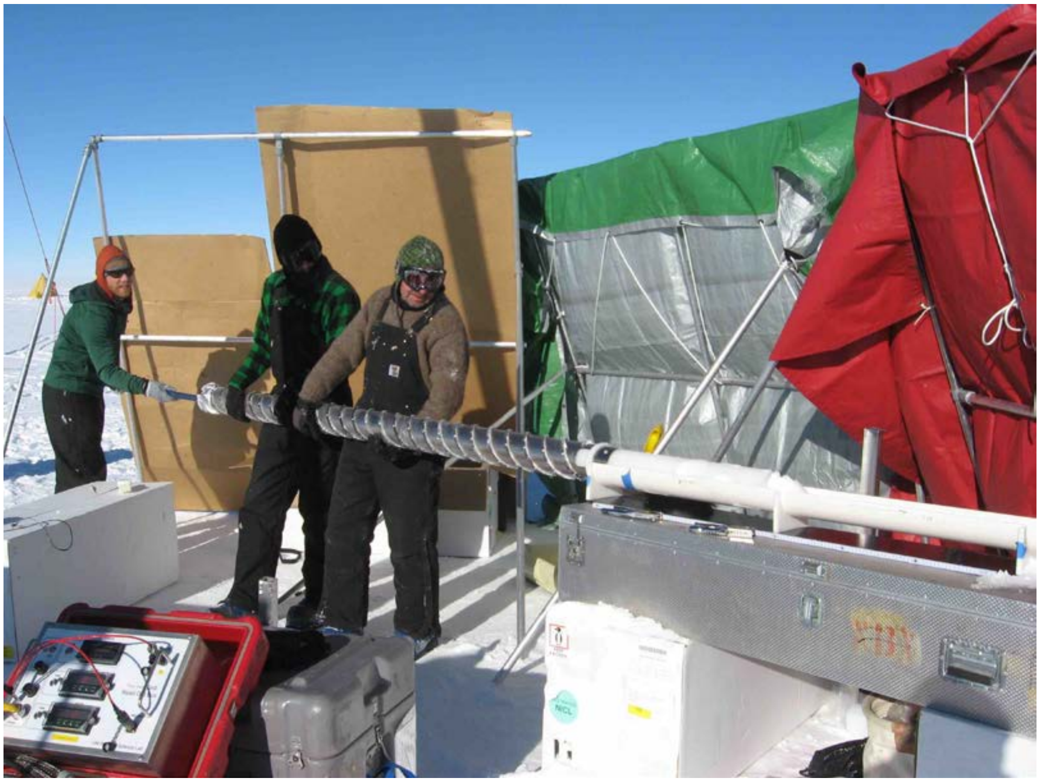


Figure 35. Removal of the core.

Details for Reference Guide step 14.

When lowering the outer barrel over the inner barrel, the helper holds the inner barrel with one hand and guides the outer barrel with the other hand. It is very important for the helper to keep their hands away from pinch points where the barrels are sliding together.

The position of the locking pin should be carefully verified each time it is installed, to make sure it is centered and clears the edge of the outer barrel.

Solar radiation can warm the drill barrel and cause ice chips between the inner and outer barrels to melt. Liquid water will freeze after returning the drill to the borehole and can cause the drill to freeze up, Figure 36. It is important to keep the drill cold and dry. In warm temperatures or on calm sunny days, surface operations will have to be made as efficient as possible so the drill string is at the surface for as short a time as possible and provisions are made to keep it out of direct sunlight. In some cases, you might have to lower the drill back down the hole to keep it cold while core is being pushed from the inner barrel.

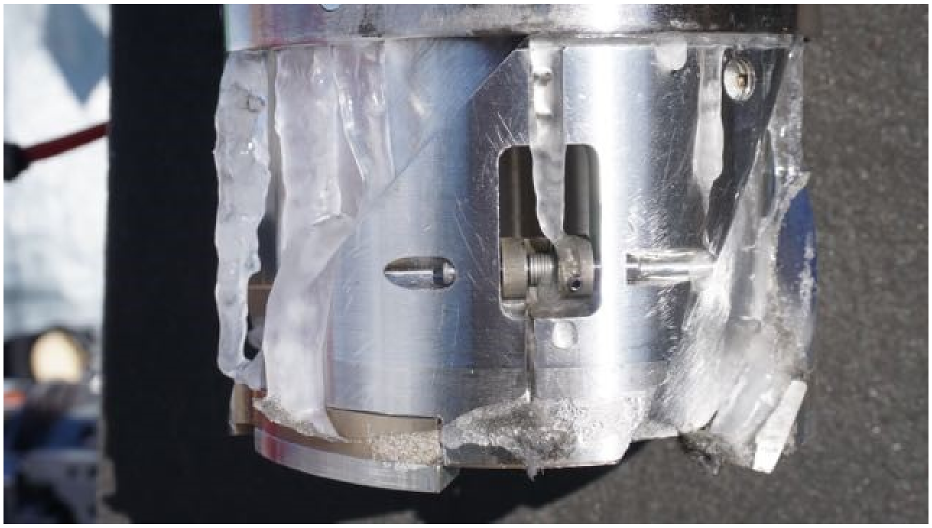


Figure 36. Solar radiation can warm the drill to above freezing even at cold ambient temperatures.

14.0 Returning Equipment From The Field

Packing of the drill should be a mirror operation to deployment. Drill components taken from specific storage boxes should be returned to the same location. Following that procedure makes packing of the drill components easier and ensures proper packing for shipping.

When packing equipment in the field, clean as much snow off as possible. Where possible, dry the drill components and tools. Accumulated moisture will corrode and damage components and tools during shipping. **Document any damage, lost components, or repairs that should be made when the equipment returns from the field.**

15.0 Appendix A

- Pre-Season Checklist
- Weekly Checklist
- Drill Log Template

4-Inch Drill Preventive Maintenance Checklist				
PRE-SEASON CHECKS (to be performed before the Drill System is shipped from IDP)				
Field Project:				
ITEM	**ACTION**	**DATE**	**INITIALS**	**COMMENTS**
WINCH BASE & TOWER				
Sled/winch assembly	Inspect components for damage			
Tower sections and couplers	Inspect for damage			
Tower crown sheave	Inspect for damage			
Tower ropes and mounting hardware	Inspect for damage			
Snow stakes	Inspect for damage and proper quantity (Min 10 each)			
Fasteners	Inspect for damage and verify proper quantity and torque			
WINCH				
Winch cable	Inspect for damage, tension			
Harmonic drive	Check level of transmission fluid, add fluid as needed			
Winch motor	Check motor for functionality			
Drive belt	Inspect for damage/wear/proper tension, replace as needed			
Slip rings	Inspect for function (2 each for drill, 2 each for winch)			
CONTROL & DISPLAY BOXES (2 EACH)				
Control box	Inspect for damage/functionality			
Display box	Inspect for damage/functionality			
Cables	Inspect for damage			
Encoder	Verify calibration, calibrate as needed			
Load pin	Verify calibration, calibrate as needed			

4-Inch Drill Preventive Maintenance Checklist				
PRE-SEASON CHECKS (to be performed before the Drill System is shipped from IDP)				
ITEM	**ACTION**	**DATE**	**INITIALS**	**COMMENTS**
DRILL MOTOR & ANTI-TORQUE SECTIONS (2 EACH)				
Drill motor	Inspect for functionality/oil leaks			
Core barrel retainer pins	Inspect for damage/functionality/proper fit			
Anti-torque	Inspect for damage/functionality			
Anti-torque blades	Inspect for sharpness			
Fasteners	Inspect for damage and verify proper quantity and torque			
BARRELS (2 EACH)				
Inner & outer barrel	Inspect for damage/wear			
Fit check and test barrel assemblies	Verify proper fit and interchangeability			
CUTTER HEADS				
Head - core dog	Verify proper fit with core barrels			
Head - collet	Verify proper fit with core barrels			
Fasteners	Inspect for damage and verify proper quantity and types are included for the project			
Springs	Inspect for damage and verify proper quantity and types are included for the project			
Cutters	Inspect for damage and sharpness			
Cutters	Verify proper quantity/types are included for the project (Medium/Wide for dog head, Wide for collet head)			
Core Dogs	Inspect for damage and sharpness. Verify proper quantity and lengths are included for the project (#1, #2, #3; Min 6 each)			
Collets	Inspect for damage and function (2 each)			
SPARE PARTS				
Fasteners	Verify spares are included			
Winch motor	Verify spare is included			
Drive belt	Verify spares are included			

4-Inch Drill Preventive Maintenance Checklist				
PRE-SEASON CHECKS (to be performed before the Drill System is shipped from IDP)				
ITEM	**ACTION**	**DATE**	**INITIALS**	**COMMENTS**
Winch Harmonic Drive assembly	Verify spare is included			
Transmission oil	Verify spare oil is included			
Load pin with cable	Verify spare is included			
Anti-torque springs	Verify spares are included			
Drill motor and Anti-Torque section	Verify spare is included			
Inner & outer barrel	Verify spare set is included			
TOOLS				
Hand tool kit	Verify tools are in good condition and kit contains an assortment of basic tools			
Cordless drill	Verify kit is complete and in operating condition, verify Philips and square drive bits are included			
Dremel tool	Verify kit is complete and in operating condition			
Drill bits, tap set	Verify at least one set of each is included and in good condition			
Multi meter	Verify function			
Soldering kit	Verify kit is complete and in operating condition, should include solder and heat shrink tubing			
Ropes, straps, bungie cords	Verify assortment of each is included			
Calipers	Verify a 6" caliper is included at a minimum			
Heat gun	Verify operation			
Cutter sharpening	Verify one set of diamond plates is included along with a sand paper assortment and glass lapping plate			
Safety glasses	Verify at least one pair is included			

4-Inch Drill Preventive Maintenance Checklist				
WEEKLY CHECKS WEEK OF: ________				
ITEM	**ACTION**	**DATE**	**INITIALS**	**COMMENTS**
WINCH BASE/TOWER				
Sled/winch assembly	Inspect for damage			
Sled/winch assembly	Verify all hardware is in place and tight			
Tower/crown sheave	Inspect for damage			
Tower guy ropes	Inspect for damage and verify proper tension			
WINCH				
Winch cable	Inspect for damage			
Drive belt	Check belt tension			
Winch	Check for oil leaks			
CONTROL BOX & DISPLAY BOX				
Control & Read-out	Inspect for functionality			
Cables	Inspect for damage			
Encoder	Inspect for functionality			
Load pin	Inspect for functionality			
DRILL MOTOR & ANTI-TORQUE SECTION				
Drill motor	Inspect for functionality/damage			
Anti-Torque	Inspect for functionality/damage			
Hardware	Verify all hardware is in place and tight			
BARRELS				
Inner & outer barrel	Inspect for damage/wear			
CUTTER HEAD				
Fasteners	Inspect for damage and tightness			
COMMENTS:				

Drill Log

Barrel Set ______________________
Head ______________________
Cutters ______________________
Shoes ______________________
Core Dogs (length)/Collet ______________________
Core Dog Springs ______________________
Anti-Torque Setting ______________________

Project ______________________
Location ______________________
Date ______________________
Weather ______________________
Drillers ______________________
____

Changes	Time	Run #	Start Depth	End Depth	cm Drilled	cm Recovered	Core Quality	Drill %	Winch %	Comments

Changes	Time	Run #	Start Depth	End Depth	cm Drilled	cm Recovered	Core Quality	Drill %	Winch %	Comments