THERMAL DRILL
Operations and Maintenance Manual

April 14, 2023

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

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1.0 PURPOSE

This manual describes the IDP Thermal Drill System and what is to be expected when operating this drilling system. Issues or comments regarding this manual should be reported to:

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2.0 SCOPE

2.1 This document applies to the setup and operation of the IDP Thermal Drill.

3.0 REFERENCES

3.1 8329-0005 Safety Training

3.2 8329-0008 Thermal Drill Equipment List

3.3 8511-0057 4-Inch Drill System Operations and Maintenance Manual

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 Management is responsible for ensuring that operators of the Thermal Drill are provided with accurate, up-to-date operator procedures.

5.2 IDP Engineering is responsible for the creation and maintenance of this manual.

5.3 Thermal Drill operators are responsible for ensuring these procedures are followed and any safety warnings contained herein are heeded.

5.4 SSEC QAS is responsible for ensuring that the proper procedures of document creation, review, approval, maintenance and updating are followed for this manual.

6.0 SAFETY NOTICE

All operators of the Thermal Drill System should read this manual thoroughly prior to operating this equipment and understand the safety precautions described herein. Some are listed directly below. Only IDP trained and approved personnel should operate this drill.

Note to Operators:

A drill operator's primary duty is to ensure the safety of themselves and bystanders around the drilling equipment.

Personal Protective Equipment (PPE)

- Skin PPE – Personnel will likely be working on snow-covered terrain that reflects the sun's rays. In many instances, field sites will experience 24 hours of daylight during the drilling season. Sunscreen should be used on any exposed skin and applied repeatedly throughout the day.
- Eyes PPE – Keep eyes covered with glasses that provide protection against UV light to prevent snow blindness.
- General PPE – Operators shall wear gloves, eye, and ear protection whenever there is the potential for injury while operating, handling or repairing any equipment.
- Cold weather PPE – When working in extreme cold, be aware of any exposed skin and the potential for frostbite. When handling fluids like alcohols or fuels, be aware that evaporative cooling will greatly exacerbate heat loss from skin and may result in instantaneous freezing of the skin and long-term damage.
- Back PPE – Lifting of cargo pieces on uneven, sloped, and soft surfaces may compound the chances of injuring oneself. Take time to place your footing solidly. Take time to move cargo slowly, carefully and with good posture. Do not lift heavy items that may cause back injury.

Mechanical Safety

- Tower mast and sheave – A falling mast can cause serious injury; make sure the base is fully secured with stakes before attempting to raise the tower. Check the stakes and guyline anchors daily since they melt out.
- Winch – Make the working area around the winch sled safe by eliminating hazards such as sloping packed snow and loose cables; the operator must stay within reach of the controls and be attentive any time the winch is in motion.
- Winch sled – If using a winch sled, keep it securely staked to prevent movement. In temperate climates, use plywood or a wooden pallet below the winch sled to control melt that can create an uneven surface.

Electrical Safety

An electrical shock hazard is present even without the presence of an electrical ground. Glacier ice and melt water are good electrical insulators due to the high degree of purity of the ice and water. This being the case, establishing an electrical ground is not possible, although this does not present a safety hazard. The Thermal Drill electrical circuit is one long loop of wire, starting at the generator, flowing through the extension cord, the control box, the entire drilling cable, across the heat ring and back again to the generator. The generator provides the voltage differential (potential) between the beginning of the loop and its end, which makes electricity flow. Therefore, any electric cord contains the two conductors with the voltage potential between them. Any time one exposes the two conductors, there could exist an opportunity for the human body to become part of this electrical circuitry. If one were to touch both bared conductors, then one's body provides an alternate circuit for electricity to travel between the two points of contact. Normally, all electrical conductors are protected from exposure to prevent accidental contact. However, when working on any part of the electrical circuitry, unplug from the generator to eliminate any chance of accidental contact.

Chemical and Fire Safety

- Drilling Fluid hazard – If using ethyl alcohol to control borehole freeze or freeing a stuck drill, realize its hazards when handling: being highly volatile, fumes can build up quickly and create a fire hazard. Alcohol fires burn invisibly; handle alcohol away from any ignition source, such as electrical switches. In addition, the evaporation of alcohol from your skin can expedite frostbite.
- Gasoline hazard – Keep gasoline away from ignition sources. Always shut off the generator before fueling it. Clean any spills before re-starting or allow time for evaporation. Keep gasoline from your clothing; some of the volatile components can absorb and cause skin irritation, as well as being a known carcinogen. Always wear gloves and have a split kit ready to clean any spilled fuel.

7.0 OVERVIEW

The IDP Thermal Drill has a long and successful history of drilling ice cores in temperate glaciers. The Thermal Drill is especially well suited for drilling in temperate glaciers because, once ice is reached, the drill becomes immersed in melt water. The presence of water increases the heat transfer at the drill head, increasing thermal efficiency and drilling speed. When used in firn where melt water is wicked away, the Thermal Drill is generally slower and takes more energy than mechanical drilling. The Thermal Drill sonde (down hole portion) is comprised primarily of a tube with a heat ring (electrical resistance heater) attached to the bottom.

7.1 Specifications

Outer diameter of drill sonde	4.0 inches
Wall thickness of drill sonde	0.250 inches
Core diameter (approximate)	3.4 inches (85-87 mm)
Borehole diameter (approximate)	4.2 inches (104-106mm)
Maximum Borehole Depth	295 meters
Production Rate in Firn*	2-3 m/hour
Production Rate in Ice*	3 m/hour

*Values based on performance during the 2019 Juneau Ice Field project.

7.2 Thermal Drill Limitations

7.2.1 **Ice temperature** – In colder ice, the Thermal Drill would likely function acceptably with more power to the heat ring and the addition of minimal amounts of ethanol to the hole to limit borehole freeze-back, but this has yet to be extensively tested. The drill is best suited for isothermal glaciers.

7.2.2 **Drilling firn** – Up to a certain density, firn draws the meltwater away from the heating element. Without the presence of meltwater to conduct heat from the heat ring, the operator runs the risk of burning out the drill head if more power is supplied to the head than can be absorbed by melting. See more about firn drilling in Section 9.0, Operation.

7.2.3 **Dirty ice** – Dirt in the ice may bring the drilling to a halt. As the drill melts through the ice, dirt accumulates at the bottom of the hole in the annulus created by the drill and limits heat conduction to the ice, blocking drilling. Bouncing the drill up and down by manually pulling on the cable before starting the drill run may mix the sediment into the water enough to continue the drilling process.

7.2.4 **Other debris** – Pebbles or other debris dropped downhole may significantly slow or halt drilling progress. If the debris is steel, a magnet attached to the core barrel may be used to retrieve the components. The magnet should be attached high enough so that it cannot get hung up on the bottom of the heating element, Figure 1. With luck, the drill can get past small pieces of debris, and possibly retrieve it at the top of the next core.

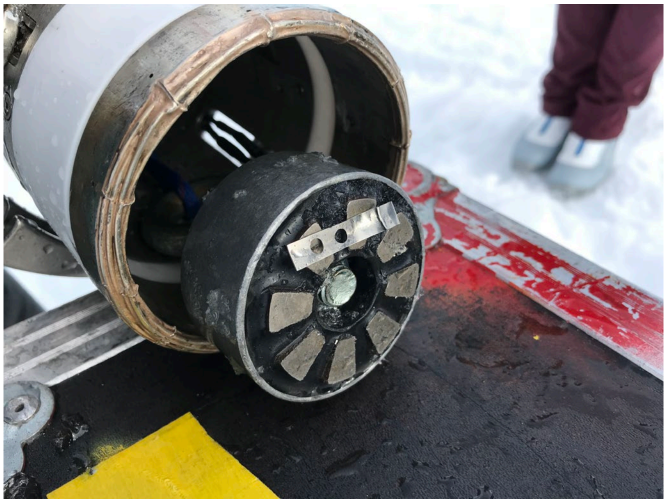

Figure 1. A magnet can be used to retrieve steel debris downhole.

7.2.5 **Hole Depth** – The thermal drill has a maximum depth capacity of 295 meters. This is limited by the drill cable; the sonde could theoretically drill deeper if the cable allowed.

7.3 Drill Components

7.3.1 **Core Barrel** – The Thermal Drill sonde is very simple; it is essentially a tube with a heat ring on one end and a lifting bracket for connecting to the cable on the other end. The only moving parts on the sonde are the three core dogs, each energized with a leaf spring. The heat ring body is stainless steel and has a long tubular heating element, looped and overlaid, brazened to the end. The Thermal Drill sonde is about 2.1 m long and takes approximately two meters of core during one drilling run.

7.3.1.1 **Material** – Thermal drill sondes are available in both aluminum and stainless steel versions. The heavier stainless steel sonde will theoretically travel faster going down hole through water and will make it easier to feel the bottom at greater borehole depths. The standard Thermal Drill kit includes two aluminum sondes. The stainless steel sonde is kept at the warehouse and can be assembled and included if required for a certain project.

7.3.2 **Heat Ring** – The heating element is a long tubular resistance heater that is coiled upon itself on the end of a stainless steel ring and brazed in place, Figure 2.

Figure 2. Thermal Drill heat ring.

7.3.2.1 **Power range** – The heat ring is rated at 1800 W (180 V). To keep from burning out heat rings, they should not be exposed to voltages higher than 180 V. In addition, this power limit should only be applied to the heat ring when it is immersed in water, not when drilling in firn. Never increase the power greater than 50% (approximately 90V) while drilling in firn.

7.3.2.2 **Voltage limitations** – Because of the size of the wire in the tubular heating element, this heat ring must have 180 V to reach its rated power output. If using a generator with 120 V output, a variable transformer must be used to increase the voltage to approximately 200 V.

7.3.3 **Core Dogs and Core Dog Springs** – Core dogs break the core at the conclusion of a drill run and hold the core in the drill barrel for transport to the surface. During drilling, they lean against the core and may be unaided by the spring at this point. They engage when the drill is lifted. The springs on the core dogs are leaf springs that only engage through a portion of the core dogs' swing. The core dogs are pointed like a 'bird beak' looking at them broad side. They have a slight curvature looking at them in profile. The core dog cannot fall past horizontal to maximize their protrusion into the barrel for the optimal carrying area while retrieving the core. When they are able to fall too far past horizontal, they may also stop the penetration of the core into the barrel.

NOTE: Always check the core dogs for their fit and travel on the particular drill barrel before going to the field. Make sure the core dogs do not go beyond horizontal in their down position.

7.3.4 **Drill Cable & Winch** – The cable both tethers the drill and conducts the power to the heat ring. The tethering cable is wound on a spool on a winch sled. Also mounted to that sled is a pivoting tower base. The drill can be run using a 4-Inch drill cable, but a jacketed thermal drill cable is strongly preferred, as it prevents ice build-up on the cable.

7.3.5 **Connections** – Mechanically attaching the Thermal Drill sonde to the tethering cable is done with a threaded 'quick-link' shackle designed for lifting, Figure 3.

Figure 3. Thermal drill mechanical and electrical connections.

- **Electrical connection** – Connecting the sonde electrically to the tethering cable is not as simple. The wires are either soldered directly to the tethering cable conductors or connected using a custom waterproof connector.

- **4-Inch Drill cable** – When using the 4-Inch Drill cable, the connector on the drill cable is cut off. The 4-Inch Drill cable has 7 conductors; the control box connector has 8 pins: pins A, B, C and D are grouped together as positive voltage and conductors E, F, G and H are negative; that is, the seven conductors in the cable are only used as two groups, a group of 3 and a group of 4. Each grouping is soldered directly to one of the wires from the tail of the heat ring coming off the end of the sonde. Use moisture-seal heat shrink tubing to cover each solder joint.
- **Black thermal drill cable** – When using dedicated thermal drill cable, the connection is made using a custom waterproof electrical connector shown in Figure 4. The electrical connector consists of a metal waterproof housing, O-ring sealed wire pass-throughs, and a two-pole automotive connector. Before deploying to the field, ensure the winch cable is terminated to a pass-through with a female automotive connector and the sonde is terminated with a pass-through with a male automotive connector. The sonde termination can be made without regard to polarity since it does not impact heat ring operation. Both connections should be soldered and protected with waterproof heat shrink. To attach the sonde in the field to the drill cable, first align the automotive connectors outside the metal housing before engaging the pass-through O-rings with the housing. Next, make the connection by installing both the cable and sonde pass-throughs into the metal housing taking care to maintain alignment of the electrical connectors. **NOTE:** Warming O-rings or applying grease can facilitate this step. Next verify proper electrical connection by checking for continuity at the winch slip ring. Finally, ensure snap rings are installed on both ends of the metal housing to retain the pass-throughs.

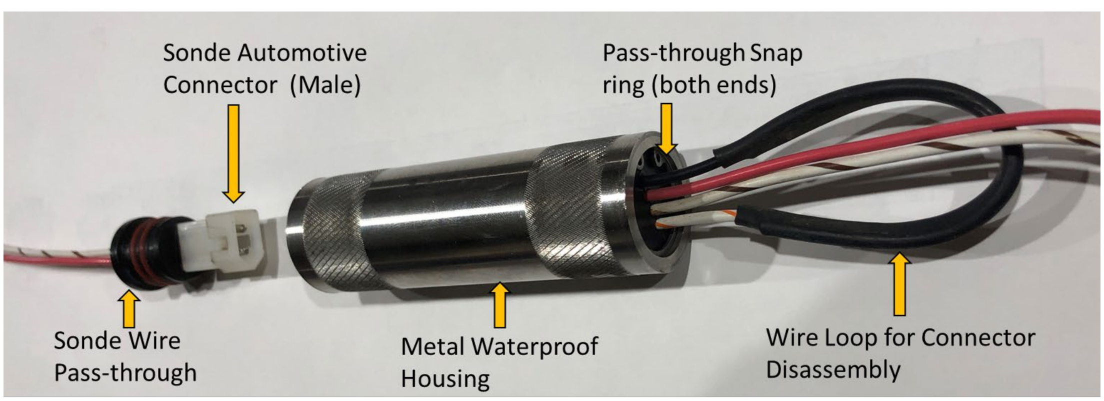

Figure 4. Sonde electrical connector components.

7.3.6 **Winch** – The Thermal Drill winch sled should be capable of producing 1000 lbs. of cable tension for core breaks. The winch should be able to wind cable at a rate of 1-2 meters per second. The winch sled should have plastic coated skids so that the winch sled can be moved easily across the snow surface.

- **Borrowed winch sled** – The Thermal Drill has never had a dedicated winch specifically designed for it, so the system normally is used with equipment over-built and over-powered for its needs. It has been used with both the 4-inch Drill '200-meter' and the '100-meter' winch sleds.

7.3.7 **Controller** – The Thermal Drill controller must be capable of supplying variable power (0-200 V) to the Thermal Drill sonde. Power must be variable since the power required for drilling in firn is much less than when drilling in ice. If the drilling system includes a winch, then the controller must also be capable of running the winch in both directions at variable speeds.

- **4-Inch Drill controller** – The controller from the IDP 4-inch Drill converts the alternating current (AC) coming from the generator into direct current (DC) and controls the voltage out by a variable transformer. It has two outputs, either directing power to the drill cable via 'slip-ring' mounted to the winch, or the winch motor. It controls only one of the two different DC applications at one time. Feeding the cable from the winch during drilling is done by hand using the hand-wheel.

7.3.8 **Slip Ring** – The controller from the 4-inch Drill, when used with a winch sled also from the 4-inch Drill, requires a slip ring, a rotating electrical connection that mounts to the side of the winch to make its connection to the drill cable.

7.3.9 **Generator** – Although rated at less than 2 kW, the Thermal Drill is normally powered by a 5 kW generator. This is due to the fact that the Thermal Drill must be supplied with 240 VAC and the smallest easily accessible generator with a 240 VAC receptacle is a 5kW unit. If using a 4-Inch Drill Control Box, it also requires a 240 V receptacle.

7.3.10 **Debris Vacuum** – The debris vacuum is an ancillary system that can be used to remove accumulated dirt or sediment from the borehole bottom. The debris vacuum is mounted inside the core barrel and is deployed to the hole bottom to remove dirt and debris that can insulate the heat ring slowing drill penetration. The debris vacuum will not remove large items (>2mm) from the borehole and should not be used as the first resort to remove metal objects.

7.3.11 **Ethanol Deployment** – The ethanol delivery system is used to prevent refreezing of the borehole meltwater during extended drill operation pauses. The system requires consumable layflat, a stapler, and 200 proof ethanol.

7.3.12 **Custom Core Tray** – To aid with core processing, a custom 2-piece core tray has been designed for the Thermal Drill System. The core tray supports the core barrel and has cutouts to install core dog retaining magnets for easy core removal. The long core tray helps to keep 2m cores intact and is recommended for all projects.

7.3.13 **Drilling Tent** – The Tentipi Safir 15 tent is a lightweight pyramid style tent that can be used to house the Thermal Drill during inclement weather. The tent has been modified with an extra door and pass through for the drill tower. The tent is waterproof to protect drill equipment and can allow for operation in poor weather.

8.0 SET-UP

From this point forward, it should be assumed that the thermal drill is operated with a 4-Inch Drill winch, control box, and display. If weight is a concern, the Eclipse LCI-90 display can also be calibrated to work with this system. Detailed instructions of the setup of the winch, control box, and tower can be found in document 8511-0057, 4-Inch Drill System Operations and Maintenance Manual.

8.1 Anchoring the winch sled and tower – Drill winch sleds and towers must be anchored securely to prevent injury. Anchor guy ropes to support the tower from the sheave base rope attachment points. Sturdy wood or aluminum stakes work well to secure winch sled. Place two stakes on each side of the sled base. Check anchors at intervals to be sure they are not melting out. Place a stake into the snow beside the slip ring and tie the stake to the body of the slip ring. This will prevent the slip ring body from rotating and twisting the cord.

CAUTION: Check tower anchors at reasonable intervals to ensure they are not melting out; it is ideal if the winch stakes are driven in deep enough to be even with the winch sled surface to prevent injury from a fall.

8.2 Protecting the generator and drilling platform from melt-in – The generator and the drilling platform will need to stay level and not melt into the surface, or move as the surface melts away. Wood is a great insulator of equipment from the snow. A piece of plywood under equipment or a wooden pallet that will maintain a space between the warm equipment and the snow are both acceptable solutions.

8.3 Position the controller – The controller should be on or near enough to the drilling platform so that the controls are within reach and the voltage-meter and amperage-meter can be monitored while drilling.

8.4 **Setting up core processing** – The core tray is assembled by using the over-center latches to connect the two tray halves. Position the assembled tray so that the side with core dog windows is oriented towards the drill tower. Take care to ensure the core tray is supported over its length and flat. If the core tray is not evenly supported and straight, ice core can break upon removal from the core barrel.

8.5 **Generator position** – Locate the generator as far away from the drill platform as the extension cord will allow to limit the noise. Also, locate the generator downwind to limit the site contamination and dangerous generator exhaust in tents.

CAUTION: Keep gasoline containers at least doubly protected from spillage or leakage upon falling over. Fuel containers should be kept in a stable and upright position as an extra protection against spillage. Use a portable containment berm on a level surface as a place to keep fuel containers. Use caution when transferring fuel between containers, especially when pumps are involved, to avoid spills. Keep absorbent rags handy for cleanup. If spills occur when refueling the generator, wipe clean or allow some evaporation time before starting the generator.

9.0 OPERATION

The following description of operation assumes that the drill has been assembled with the IDP 4-Inch winch, tower, and control box. All major control components are labeled in Figure 5.

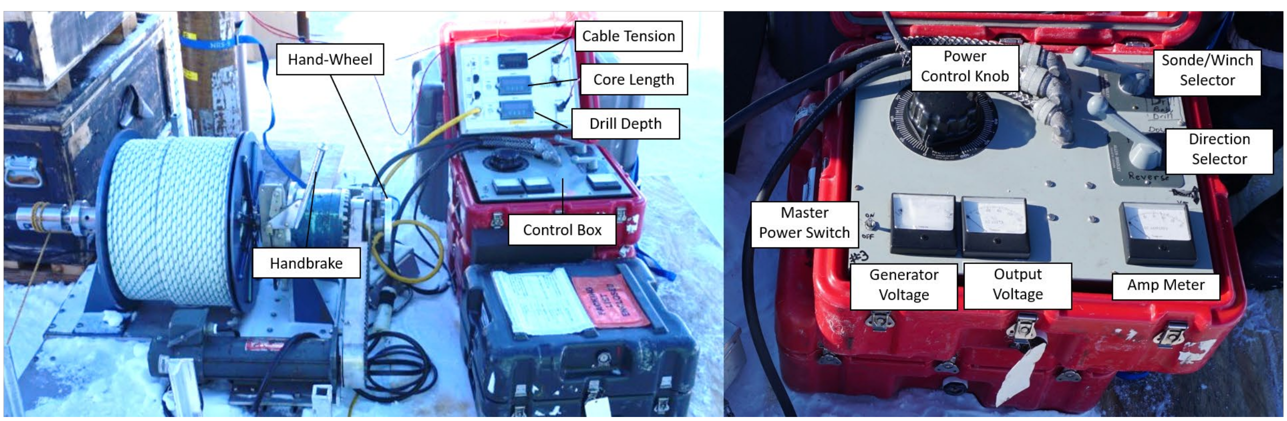

Figure 5. The Thermal drill is operated at the surface by an IDP 4-Inch Drill winch and control box. The major components required to operate the drill are labeled.

9.1 **Beginning the core from the surface** – To ensure that you begin a plumb hole, allow the drill sonde to hang just above the firn surface. On the control box, turn the selector knobs to “drill” and a direction (either direction work identically with the thermal drill). Turn the heat ring to 30% power. Release the handbrake and lower the drill sonde slowly with the hand-wheel until the heat ring just starts to make contact with the snow. Try to keep the sonde touching the snow without putting so much weight on the bit that the sonde begins to lean. This will involve holding the cable with one hand to control the sonde and to control the weight-on-bit while driving the winch manually. Monitor the tension reading on the display as a reference of the amount of weight on the bit.

9.2 **Drilling technique** – To keep the borehole plumb while drilling, keep a very light weight-on-bit. Frequently lift the drill briefly off the bottom surface of the borehole, in order to feel where the drill head is in relation to the bottom. Stop the release of the cable at just the point where the bottom can be felt. This ensures that the drill is not hanging up but is moving freely. You want the drill to be touching the bottom and also standing perfectly vertical, so you will manually carry most of the combined weight of the drill and the cable. Too much weight-on-bit leads to hole drift, which can slow progress of the drill. If using a sheave and a winch, you can pull the cable between the sheave and the winch outward, or toward you, to lift and lower the drill.

9.3 After a few cores have been collected and it is determined that the hole is straight, the power can be increased to 50%. Never increase the power greater than 50% while drilling in firn or the heat ring can be damaged. The winch can be used to lower the sonde to the bottom of the borehole. Use the selector knob to choose winch and a direction (down). When the handbrake is released, the drill will begin to coast down. Hold the hand-wheel to prevent this. Allow the hand-wheel to slip through your hand as you give the winch power. When the drill nears the bottom, remove power to the winch. The drill will continue to descend under its own weight. Slow the decent using the handbrake.

NOTE: When drilling in firn, the heating element must be limited at 50% power. Only apply full power after water has begun pooling in the borehole. Once the drill has advanced past the firn-ice transition and the heating element is fully immersed in water, you can increase power to 100%. If using a load pin, it is possible to note a drop in cable tension when the sonde becomes submerged. While drilling, use the hand-wheel on the winch to slowly lower the drill keeping approximately 20 N of tension on the cable.

NOTE: A dropped object in the borehole can have a large impact on production. Watch for loose items near the borehole, use lanyards and cover the borehole when not in use.

NOTE: Borehole water levels can change unexpectedly due to subglacial plumbing. Before starting coring, always confirm heat ring is fully submerged.

NOTE: Sections of melted core can occasionally be dropped by core dogs while tripping out of the hole. If the core chunk is large enough, it is possible it will float drill and hinder progress until the core barrel is tripped to the surface and emptied.

9.4 Drilling rate – The penetration rate of the drill should be about 8-10 minutes per meter, and somewhat slower in firn.

9.5 Winching speeds – The winch sleds and controllers normally used (borrowed from the 4-Inch Drill) enable the rapid movement of the sonde through the hole, as compared to lifting the drill string by hand. Going down, winch speed is limited by the viscous friction of the drill sonde through water; a speed too fast can loosen the windings on the winch. While ascending the drill, the speed can be run as fast as the winch is capable and is safe. Reduce speed as the drill exits the hole. Further reduce the speed as the sonde approaches the top of the tower.

CAUTION: The operator must be always be aware of proper cable wrapping and of all moving parts and places where clothing can become entrapped, or limbs can be trapped or pinched and must be ready to stop the winch very quickly.

CAUTION: There is no limit switch at the top of the tower. Damage can occur to the drill, tower, and cable if the sonde is lifted into the crown sheave.

9.6 Extracting the core – When the drill is brought to the surface after drilling, the core is removed through the bottom of the drill. The drill is pulled from its free-hanging position out to the side to an angle that provides enough space to remove the entire core out the bottom, Figure 6. Use the winch to lower the top of the drill so the sonde is in a horizontal position. The core dogs must be disengaged to remove the core. To disengage, first push the core up toward the top of the drill so that is out of the way of the core dogs. Then attach the magnetic T-handles to all three core dogs ensuring they are held in a retracted position.

NOTE: Always leave about 5 cm of space between the top end of the core to the hanger so that you have room to push the core up to release the core dogs.

Figure 6. Core removal using the long core processing tray.

9.7 Heating element failure – The heating element on the heat ring is similar to that on an electric stove, although it is a much smaller diameter. On the end of the heating element, you can see several loops of the outer tube, brazed onto the heat ring body. Inside of this outer tubing is an insulating tube, and inside of that is a wire filament that becomes hot from the current passing through it.

9.7.1 **Heating element damage** – When the insulating tube is damaged, current can pass from the wire filament to the outer tube. Usually, this results in melting an open circuit in the wire filament and melting locally of the outer tube that is visible upon inspection. Sometimes, the current still flows to some extent, leaving the heat ring warm, but not hot. Sometimes, the current is higher than normal although the drilling rate has nearly stalled.

NOTE: Keep from impacting the heating element of the heat ring during shipping and handling to prevent early failure.

9.7.2 **Filament failure** – Another mode of failure of the heat ring is that of the filament wire becomes too hot and melts itself, creating an open circuit, leaving the heat ring cold. In this case, the amp meter on the controller will read zero. There may be no external sign on the heat ring element.

9.7.3 **Loss of penetration** – Evidence of heat ring failure will be the sudden loss of penetration. Loss of penetration can also be caused by the sonde entering a water channel where heat is being carried away by the flowing water. Sometimes evidence of this can be seen on the retrieved core. The heat ring should be inspected for visible damage as one of the possible causes when there is a loss of penetration. The damage visible will be the melting of the outer tube of the heating element; it will appear as a rough spot or a hole in the tubing. Or the lack of power on the amp meter.

9.7.4 **Checking the heat ring** – To check if a heat ring is good, one can measure the resistance across it. A good heat ring measures about 18 Ohms. If the drill is mounted on the drill barrel, this can be checked at the connector at the top of the sonde. If the resistance of the heat ring is significantly different than 18 Ohms, or there can be measured any continuity between the heat ring body and the exposed conductor, then the filament wire is touching the heating element tube and the heat ring is bad.

9.8 Replacing the heat ring

CAUTION: Unplug the controller from the generator when replacing the heat ring.

9.8.1 **Removing a damaged heat ring** – The heat ring body is held in place on the barrel tube by four flathead screws, Figure 7. The 2-wire tail of the heating element resides in a groove along the full length of the drill barrel, terminating at the connector at the top of the sonde. The wires are contained by a thin metal strip that is held in place by numerous screws. First, disconnect the connector. Then remove the thin metal strip, taking care not to damage it; lift the wires from the groove. When the 2-wire tail is removed from the groove, then the heat ring can be removed from the end of the barrel by taking out the four flathead screws.

Figure 7. Connection between heat ring and drill cable.

9.8.2 **Installing the new heat ring** – Install the new heat ring into the end of the barrel so the wire tail is aligned with the groove holding the tail wires in proper alignment. Replace the four flathead screws that hold the heat ring to the barrel. Carefully press the connections into the slot in the core barrel. Press the two tail wires into the groove along the length of the barrel and replace the cover strip; then replace all screws. Attach the connector last.

9.9 Replacing core dogs and core dog springs – The core-catching apparatus on this drill is composed of three core dogs equally opposed near the bottom of the core barrel. Each resides in a cutout window and pivot about a dowel pin at the bottom. The dowel pin is held in place by two flathead screws. Above the core dog is a vertical groove in which a leaf spring is attached that extends down to about halfway into the window space.

NOTE: Check that the core dogs move freely before sending the drill down each time.

9.9.1 **Leaf springs** – A leaf spring is attached by two screws in a ¼-inch groove in the barrel above the core dog window. The spring touches the core dog partway along its length. This point of contact is within a groove on the backside of the core dog. The leaf spring acts to engage the core dog into the core, and then applying light, if any, force onto the core so they bite the core when the barrel is lifted. The end of the leaf spring is rounded on the edges so that it does not catch on the core dog. The spring can be bent by hand to apply more or less pressure as needed.

NOTE: Check the tightness of the hinge pin retaining screws often.

9.10 Operating the Debris Vacuum – Sediment and debris can be removed from the hole bottom using the debris vacuum, Figure 8. Before deploying the debris vacuum first ensure that no sediment has built up in the vacuum head spider and that it actuates freely without restriction. To deploy the vacuum first "arm" the vacuum by connecting quick-connect air fitting to vacuum head and the plunger to the vacuum spring and tensioning strap. Load tensioning strap, spring, and plunger into the vacuum tube and attach the vacuum head by aligning grooves in the tube with socket head pins on the head. Twist the head to lock it into position once pins are engaged. After the head is installed, the vacuum spring can be tensioned by pulling retaining cap towards the top of the vacuum tube. It is easiest to pass the detent pin through the spring loop to reorient the retaining cap.

CAUTION: This step is best performed with two people as the vacuum spring is strong and can be dangerous if inadvertently released.

Secure the retaining cap in place with two detent pins after spring is "armed". After vacuum is armed take care to not bump vacuum head spider as this will trigger the spring release. When armed, the vacuum should be loaded into the core barrel and then suspended from the core barrel spider using cordage.

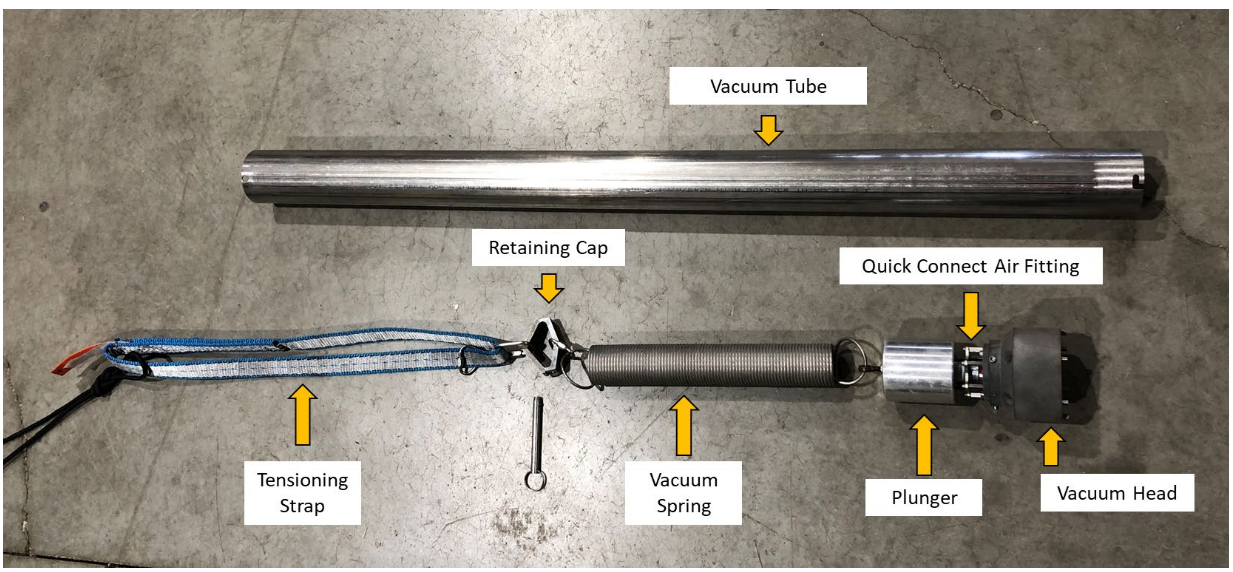

Figure 8. Debris vacuum components.

9.11 Delivering ethanol down the borehole – Ethanol can be added to the melt water to mitigate re-freezing and closure of the borehole overnight. A device has been developed to deliver ethanol to the bottom of the borehole, Figure 9. To use ethanol deployment system first "arm" the plunger by removing the safety pin.

CAUTION: The plunger has a sharp arrowhead at one end to puncture layflat.

Install the plunger into the ethanol tube taking care to orient the detent pins in the tube downhole so that the plunger arm hangs below the ethanol tube when installed. Next, load an empty layflat bag (sealed on one end) into the ethanol tube. Once loaded, take care not to puncture this bag by accidently depressing the plunger arm. Pour ethanol ~2/3 gal into bag leaving adequate space to seal the bag with staples and install the plunger weight on top, Figure 10. When loaded, install the capture detent pin to prevent any items from exiting the top of the ethanol tube. After completing assembly load the ethanol tube into the core barrel using the core dogs to capture the 3D printed ring on the bottom of the ethanol tube.

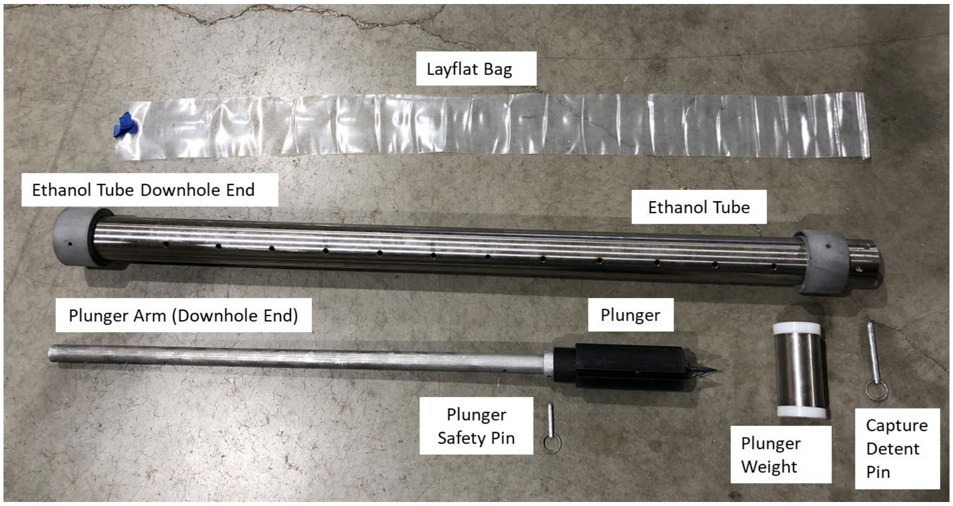

Figure 9. Ethanol delivery components.

Figure 10. Ethanol delivery procedure.

10.0 APPENDIX A – SPECIFICATIONS

Type	Thermal Ice Coring Drill
Core Diameter/Core Length	Ø86 mm (3.4”)/1 m-2 m
Nominal Hole Diameter	104 mm (4.1”)
Maximum Hole Depth	295m
Capabilities	Core in warm ice and firn. Transportable by Twin Otter or helicopter. Transportable by Snow Machine. Reel-driven cable payout.
Electric Power Consumption	220V/5 kW Generator
Crew Size	1 Driller
Drill Fluid Required	None
Shipping Weight	1200 lbs.
Shipping Cubes	66
Notes	Shipping weight includes generator and 100-meter winch sled; complete operating weight is 800 lbs; uses 4-Inch Drill system winch.

11.0 APPENDIX B – PREVENTIVE MAINTENANCE CHECKLISTS

Thermal Drill Preventive Maintenance Checklist				
PRE-SEASON CHECKLIST (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, test for short to frame, conductors, and for continuity. Check voltage (180-220 V).			
Harmonic drive	Check level of transmission fluid, add fluid as needed			
Winch motor	Check motor and brake for functionality			
Drive belt	Inspect for damage/wear/proper tension, replace as needed			
Slip rings	Inspect for function (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			
GENERATOR (2 EACH)				
Generator	Inspect for damage/oil level			
Generator	Operate/Check Smooth Operation and Output Loaded and Unloaded			
Generator	Verify proper jetting			
Generator	Run Dry, drain float cup			

Thermal Drill Preventive Maintenance Checklist				
PRE-SEASON CHECKLIST CONTINUED (to be performed before the Drill System is shipped from IDP)				
ITEM	**ACTION**	**DATE**	**INITIALS**	**COMMENTS**
EQUIPMENT, SPARE PARTS, TOOLS				
Equipment List	Verify all equipment, spares and tools are packed and in good condition per equipment list (see section 3.0).			
BARRELS (2 EACH)				
Fit check and test barrel assemblies	Verify proper fit and interchangeability			
THERMAL HEADS				
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			
Heat Ring (3x)	Inspect for damage, check resistance			
Core Dogs	Inspect for damage and sharpness. Check the core dogs for their fit and travel on the particular drill barrel. Make sure the core dogs do not go beyond vertical in their down position.			

Thermal Drill Preventive Maintenance Checklist				
DAILY CHECKLIST				
ITEM	**ACTION**	**DATE**	**INITIALS**	**COMMENTS**
SYSTEM				
Sled/Winch/Tower/Sonde/Control/Gen	Inspect for damage			
Sled/Winch/Tower/Sonde/Control/Gen	Verify all hardware is in place and tight			
Sled/Winch/Tower/Sonde/Control/Gen	Inspect electrical for damaged or loose connectors or wiring			
Sled/Winch/Tower/Sonde/Control/Gen	Verify ground wires in place			
Sled/Winch/Tower/Sonde/Control/Gen	Clear any snow accumulation and protect from blowing snow			
Sled/Winch/Tower/Sonde/Control/Gen	Check mast anchors to ensure they are not melting out			
WINCH				
Winch cable	Inspect for damage			
Drive belt	Check belt tension			
Winch	Check for oil leaks			
Winch	Check brake			
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			
Hardware	Verify all hardware is in place and tight			
BARRELS				
Core barrel	Inspect for damage/wear			
CUTTER HEAD				
Fasteners	Inspect for damage and tightness			
COMMENTS:				

12.0 APPENDIX C – DRILL LOG

Barrel Set ____________________ Project ____________________

Head ____________________ Location ____________________

____________________ Date ____________________

____________________ Weather ____________________

____________________ Drillers ____________________

____________________ ____________________

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Run #	Start Time	End Time	Start Depth (m)	End Depth (m)	Drilled (cm)	Recovered (cm)	Core Quality	Power %	Comments / Changes Fuel Consumption