THERMAL DRILL
Operations and Maintenance Manual

October 23, 2019

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

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 Ice Coring 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 much of 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 painful 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.

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 daily guying the tower often since they melt out.
- Winch – Make the working area around the winch sled where you will be standing and walking safe by eliminating hazards such as sloping packed snow; 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

- There are opportunities for the human body to become part of the electrical circuit even without the presence of an electrical ground. Glacier ice and melt water are good electrical insulators, that is, they are poor conductors of electricity; this is because of 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 long wire 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 with a voltage difference between them, 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 freeze back of the borehole or freeing a stuck drill, realize its hazards when handling: being highly volatile, fumes can build up quickly and create a fire hazard. BEWARE: 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 through your skin and can be a skin irritant, as well as being a known carcinogen.

7.0 OVERVIEW

The IDP Thermal Ice Coring Drill has a long and successful history of drilling ice cores in temperate glaciers where the drill is immersed in water, which, along with the ice surrounding it, is at the freezing point. The Thermal Drill is well suited for wet drilling, whereas, if an electro-mechanical drill were to be used, it would have to be designed to be submersed. It is used at times in firn, although it is generally slower and takes more energy than mechanical drilling. The Thermal Drill sonde—the down hole portion, i.e. the corer—is very simple, having very few parts, and is comprised mainly of a tube with a heat ring attached to one end. The Thermal Drill sonde is also very lightweight, although the supporting surface equipment, the winching system, has often been heavier than needed because it is normally borrowed from another drilling system. The simplicity of the sonde and its light weight are among its key assets.

7.1 History – The Thermal Drill has been used to drill to depths of over 150 meters on the Fremont Glacier in Wyoming on two separate occasions and once on the South Cascade Glacier in Washington State to the same depth. It has drilled at depths of over 200 meters on the McCall Glacier in Alaska when used in combination with the IDP 4-Inch Drill (formerly PICO 4-Inch Drill). It has been used in Peru and other temperate glaciers and in Greenland, probing the extents of the perennial firn aquifer. It has, on at least two projects, been powered by a large array of solar panels.

7.2 Core and Borehole Diameter – The outer diameter of the drill sonde is 4.0 inches with a wall thickness of 0.250 inches and inner diameter of 3.5 inches. The core and borehole have approximately 1-2 mm clearance on the inside of the drill barrel and the outside, respectively. That makes the core diameter approximately 85-87 mm (3.4 inches) and the borehole diameter approximately 104-106 mm (4.2 inches).

7.3 The Sonde

7.3.1 **Simplicity of construction** – The original Thermal Drill sonde (down-hole portion) is very simple and is a 4-Inch diameter, quarter-inch walled aluminum tube with a heat ring on one end and a bracket for connecting to the cable on the other end. The only moving parts on the entire drill are the three core dogs (each with a leaf spring that flexes). The heat ring body is stainless steel and has a long tubular heating element, looped and overlaid, brazened to the end. The entire sonde weighs only about 25 lbs.

7.3.2 **Core length** – The aluminum Thermal Drill sonde is about 2.1m long and takes about 2 meters of core during one drilling run.

7.3.3 **Stainless steel version** – The heavier version of the Thermal Drill will travel faster going down hole through water and will make it easier to feel the bottom at greater borehole depths. It also has a short non-metal section that separates the heat ring from the barrel to minimalize the heat loss along the barrel; this should help control the heat loss up the barrel. The heavier version has not been tested as of this writing.

7.4 Thermal Drill Limitations

7.4.1 **Ice temperature** – The lower ice temperature limit for which the drill will collect good core has not been determined, however, in ice that is homogenous and right at the freezing point, the drill collects beautiful core. 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.

7.4.2 **Drilling firn** – This drill has drilled a fair amount of snow, but mostly warm snow, for example the snow layer above the ice on temperate glaciers, and 2-3m of the firn above the perennial firn aquifer in southeastern Greenland. The firn draws the melt water away from the heating element at least up to a certain density where it may begin to pool. This drill may be somewhat limited in cold firn because the wet core may try to freeze to the upper end of the core barrel, or the upper end of the barrel may try to freeze to the side of the borehole; it has not been tested in this median but it might be workable. Normally, mechanical coring is done in cold snow because it is fast and requires much less energy. The freezing problem may be mitigated by swabbing the barrel surface with propylene glycol before sending it down the hole (see more about firn drilling in sections 9.1 and 9.2).

7.4.3 **Dirty ice** – Too much dirt in the ice will bring the drilling to a halt. The dirt accumulates at the bottom of the hole in the annulus created by the drill and creates a blockage to drilling.

7.4.4 **Other debris** – One may or may not be able to drill past small pieces of debris such as pebbles or a lost drill piece. With luck, the drill can get past small pieces of metal (like the flathead screws that hold the core dog pivot pin) and maybe even retrieve it.

7.5 The Heat Ring

7.5.1 **Manufacturer** –

Rosemount later split up into two separate companies, both of which abandoned the expertise and equipment for making these heat rings. That element of the former Rosemount went an altogether different direction forming the company, Thermetic Products, Inc. of Minneapolis, MN. They recently have offered of quote for the manufacture of heat rings in the same configuration as it was first made. The body of the heat ring is stainless steel, a relatively poor conductor of heat. The heating element, a long tubular heater, is coiled upon itself on the end of the ring and brazed in place. The poor conductivity of the stainless steel body in combination with the concentrated heat at the bottom may be the key to its success.

7.5.2 **Power range** – The original heat ring design is the only one used with the IDP Thermal Drill to this point. The heat ring is rated at 1800W (180V) as is printed on the side of the heat ring body. Past field reports indicate drilling at power possibly as high as 2000W, although none of the reports indicate how much power was lost to the cable. In order to keep the heat rings from burning out, it is best that they are not exposed to voltages higher than 180V. This power limit, according to one of the original designers of the heat ring, should only be applied to the heat ring when it is immersed in ice/water.

NOTE: Calculate the voltage loss through the cable so that you will know how much voltage is actually getting to the heat ring. To calculate the voltage loss in the cable, measure the resistance on one of the conductors and multiply that number by 10amps, the full load amperage: V=IR.

7.5.3 **Voltage limitations** – Because of the size of the wire in the tubular heating element, this heat ring must have 180V (its maximum limit as suggested by the manufacturer, and then only in ice/water) to reach its rated power output. So, if using a generator with only 120V output, a variable transformer must be used to increase the voltage to approximately 200V.

7.6 Core Dogs

7.6.1 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 and must move freely. 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. 'Warm' ice is much more plastic than cold ice, and the point is the best way to catch it. 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 vertical, they may 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 vertical in their down position. There seems to be more than one core dog window configuration.

NOTE: There are a couple of suggestions in field reports to change the core dog springs from the leaf style to coil springs.

7.7 Power usage

7.7.1 Although rated at less than 2kW, the Thermal Drill is normally used with a 5kW generator. This is mostly due to the fact that the Thermal Drill must be supplied with about 180-200V (depending on cable losses) in order to reach its rated power output, and often only generators of this size or bigger offer the 240V receptacle. In addition, there are often altitude-related losses in power production. When the power/voltage drops too low (as is experienced with the solar panels when clouds are overhead), the drill stops moving downward and melts the core inward, and is therefore not workable. Cable losses are typically 10-30V.

8.0 SET-UP

8.1 Hanging the Thermal Drill Sonde and Use of the Drilling Platform – A History

8.1.1 **Drilling platform** – The drilling platform required for the Thermal Drill will serve as the attachment point for the sheave and tower and is where the operator will safely stand with access to controlling both the feed and tethering of the cable and the power to the heat ring of the sonde.

8.1.2 **Supplying power to the sonde, hanging the sonde and using a sheave for the hanging cable**

8.1.2.1 **Cable and winch** – The Thermal Drill sonde has on almost all projects been used by being hung from a cable that both tethers the drill and conducts the power to the heat ring. In almost all of these projects, the tethering cable was wound on a winch sled. Also mounted to that sled was a pivoting tower base.

8.1.2.2 **Hand Drilling** – On one occasion, a 1-meter version of the Thermal Drill sonde was tested with a short cable held by hand with a separate power cord alongside it, but only for a few meters depth.

8.1.2.3 **Tripod** – In another instance, a tripod and sheave were used to hang the drill sonde, with the power cord separate from the hanging rope, but this configuration was not adequately tested due to other issues.

8.1.2.4 **Sheave Tower Design Considerations** – In general, the sheave needs to be secured in one position and high enough to accommodate the entire sonde plus room to swing it outward at enough angle to retrieve the core out the bottom. The sheave should have cable retention devices to keep the cable from falling off the sheave.

8.2 Use with a Winch Sled

8.2.1 **Winch requirements** – For design purposes, the Thermal Drill winch sled should be capable of withstanding 100 lbs. of cable tension for core breaks, although core breaks are generally much less, like 10-20 lbs. The winch should be capable of holding 300 meters of cable. The winch should be able to wind cable at about 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.

8.2.2 **Borrowed winch sled** – The Thermal Drill has never had a designated winch sled specifically designed for it, so it is normally used with equipment over-built and over-powered for its needs. It has borrowed two different winch sleds from the 4-Inch Drill system, the '200-meter' winch sled and the '100-meter' winch sled. The latter was at various times reconfigured for thermal drilling with a smaller diameter cable and smaller diameter tower.

The names, '100-meter' and '200-meter' given to the winch sleds refer to the amount of cable they can hold of the diameter of the IDP 4-Inch' Drill drilling cable used upon their original design. A new, smaller-diameter, 300 m long water-shedding cable can fit on the 4-Inch Drill 200-meter winch.

8.2.3 **Re-configuring the '100-meter' winch sled for thermal drilling** – In one of the Thermal Drill deployments, the '100-meter' winch sled was modified to save weight and still be suitable for the Thermal Drill sonde. Two-hundred meters of the lighter/smaller cable was wound onto the winch, replacing the cable normally used with the winch (the cable, bright yellow, had been used to tether an electrical/mechanical ice coring drill designed by Victor Zagorodnov while at the Byrd Polar Research Center at Ohio State University and was donated for use with the thermal drill). The smaller cable was Kevlar re-enforced and had two co-axial conductors; its diameter was less than ½-inch. Further modifying the '100-meter' winch sled, a smaller mast (6-inch diameter fiberglass epoxy tube rather than the usual 8-inch diameter tubing) of the same material (the mast tube was also the shipping container for the Thermal Drill sonde) was implemented. This provided a much smaller and lighter winch sled capable of drilling to 200 meters depth and proved successful.

8.2.4 **Weight savings with the re-configured '100-meter' winch sled** – The '200-meter' winch sled, including mast and sheave, weighs about 350 pounds, so is quite heavy for the task of winching the Thermal Drill sonde, and breaking the core. The '100-meter' winch sled is not as strongly made as the '200-meter' winch sled, having a smaller motor and smaller gear reducer, and weighs about 250 pounds with same mast and sheave as the '200-meter' winch sled. Except for the limited cable length, it is better matched to the Thermal Drill. The modified '100-meter' winch sled weighed about 200lbs, about a 150-lbs weight savings over the '200-meter' winch sled. Its size and weight make logistics much simpler.

8.3 The Controller

8.3.1 **Controller requirements** – The Thermal Drill controller must be capable of supplying variable power (0-200V) 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 from zero up to 1-2 meters per second.

8.3.2 **Using the 4-Inch Drill controller** – The controller from the 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, or by using one's foot to push the belt.

There is also a second switch on the controller to reverse the polarity of the voltage to whatever the application; reversing the polarity to a DC motor reverses the direction of rotation. When this controller is used with the Thermal Drill, the polarity does not matter for the heat ring—electrons moving through the heating element and heat it up no matter which way they are flowing.

NOTE: On the use of the controller: As a rule, turn the control knob of the variable transformer to zero before resetting switches.

8.3.3 **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. The slip ring will connect to the controller with a matching plug (Bendix part no: 9724 PT06W12-8S) and has the same plug-in going out that matches the cable plug. The cable-side connection is made before the slip ring is attached to the winch.

NOTE: Place a stake into the snow beside the slip ring and tie the stake to the body of the slip ring by a bungee cord. This will prevent the slip ring body from rotating and twisting the cord.

NOTE: Be sure and connect all electrical connectors when preparing equipment to be sure of proper mating before going to the field.

8.4 Attaching the Thermal Drill to the Drilling Cable

8.4.1 **Mechanical connection** – Mechanically attaching the Thermal Drill sonde to the tethering cable is usually done with a threaded 'quick-link' shackle designed for lifting (use shackle rated about 500 lbs.).

8.4.2 **Electrical connection** – Connecting the sonde electrically to the tethering cable is not as simple. Usually, the wires are soldered directly to the tethering cable conductors. It would nice to have a waterproof plug-in connector, but to this point, one has not been found.

8.4.2.1 **When using the 4-Inch Drill cable** – When using the 4-Inch Drill cable, the connector on the drill cable (Bendix part no: 9724 PT06W12-8S) is cut off. The 4-Inch Drill cable has 7 conductors; the connector has 8 pins: conductors A, B, C and D are together and conductors E, F, G and H are together; that is, the seven conductors are only used as two, a group of 3 and a group of 4, and the connector has 8 pins—one redundant (See attached Control Box Schematic). 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.

8.4.2.2 **Yellow co-axial cable** – When using the smaller yellow, Kevlar reinforced cable, the conductors—only two situated co-axially—are soldered directly to the heat ring wires without regard to polarity. Use moisture-seal heat shrink tubing to cover the solder joints.

8.5 Generator

8.5.1 **Necessary outlet for IDP 4-Inch Drill control box** – The IDP 4-Inch Drill controller (described above) requires a generator with a 240V receptacle (NEMA L14-30R, 30A, 125/250V). Ensure the generator to be used has a matching outlet available. (Honda EG 5000 generators do).

8.5.2 **High altitude carburetor jet** – Check with the generator manufacturer or dealer to see if the carburetor jet should be changed for the altitude where it will be used. If it is necessary to change the jet for altitude, ensure the work is completed by an experienced mechanic, as it may not be possible to test this modification until you are up at altitude.

8.6 Power cord

8.6.1 **Rating** – The power cord that runs from the generator to the controller should compatible with the plug/receptacle mentioned above in 7.5.1.

8.6.2 **Length** – The power cord should be approximately 50 ft long or longer to keep some distance between the operator and the generator noise and exhaust.

8.7 Moving Equipment around the Drill Site

8.7.1 **Use a lightweight sled to position cargo and equipment** – Once onsite, equipment and supplies are moved to the selected hole location. A 'banana' sled or similar lightweight sled will prove useful for moving equipment over the surface snow and will save a lot of lifting and effort. The winch sleds have skids so they can be towed by hand(s) with hefty pieces of rope or cargo straps.

8.7.2 **Problems with surface melt** – Often times, solar input—the warming rays of the sun—causes problems with metal—especially aluminum—components getting warm and melting into or out of the snow. This especially occurs on temperate glaciers where the surface snow is melting away at a significant rate due to the warm ambient air. Shading things from the sun can help against melting into the surface. Insulating things from the snow will also help against their melting into the surface. Wooden stakes and plywood bases are good defenses against this.

8.7.3 **Anchoring the winch sled and tower** – Drill winch sleds and towers must be anchored securely to prevent injury. Anchor three guy ropes to support the tower. The sheave base will have three rope attachment points. Sturdy wood or aluminum stakes work well to secure winch sled. Place two stakes on each side of the sled base. Wooden stakes do not melt out as quickly. Ice screws are good anchors in solid ice. Check anchors at intervals to be sure they are not melting out.

CAUTION: The drill winch sled must be anchored securely to prevent injury. Check mast anchors at reasonable intervals to ensure they are not melting out; it is good if the winch stakes can be driven in deep enough to be even with the winch sled surface to prevent injury from a fall.

8.7.4 **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.

8.7.5 **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. Remember that drilling is done with one hand on the tethering cable. It should also be secure so that it cannot slide away or fall off.

NOTE: Plywood pieces are good for keeping components on a level surface, since plywood is a poor conductor of heat and will keep the snow below it from melting.

8.7.6 **Generator position** – Locate the generator as far as the extension cord will allow to limit the noise at the drill platform. 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

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. Turn the heat ring to about 1/3 of rated power (1/3 x 1800W = 600W or about 60V). Lower the drill sonde slowly into the snow while someone holds the drill in the line of plumb. Try to keep the sonde touching the snow without letting it 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.

NOTE: When drilling in firn, the heating element must be turned down to about one-third to one-half of its full rated voltage setting. Only apply full power when the heating element is fully submersed in ice/water.

Drilling technique – It is advantageous if the borehole remains plumb while drilling. This is accomplished by a very light weight-on-bit. Frequent momentary lifts of the drill to feel a gentle tap on the bottom as it penetrates allow the operator to monitor the freedom of motion of the drill and its weight-on-bit. The heat ring will spend about 95% of the time in contact with the ice/snow, with the remaining 5% of the time being the momentary lifting of the drill and setting it back down, stopping 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. It also enables the operator to 're-calibrate' their feel of the tension. You want the drill to be touching the bottom but you also want it standing perfectly upright, so you will carry about 98% of the drill's weight plus that of the cable in the hole. One would not be able to drill if one could not feel the bottom. Too much weight-on-bit leads to hole drift, the results of 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. This gives you mechanical advantage and allows the penetration control to be done with two fingers. Every minute or two you can release the cable long enough to manually feed more cable slack from the winch. If it is allowed to sit with its full weight on the bottom and the cable slack, it will quickly begin to drift from plumb and will stall itself because it cannot navigate the bend it has created in the borehole. If you sense that the drill is hanging up because of a drifted hole line, you can come up a meter or two and drill really slowly until you can feel the heat ring has begun a new, straighter path, and re-drill that section.

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.

9.2 **Drilling rate** – The penetration rate of the drill should be about 8-10 minutes per meter, whether drilling ice or firn. In firn, start at 1/3 the full power rating and adjust over time to get to about 10min/meter. In colder firn, you will be able to use slightly more power than in warm firn, but the penetration rate should be much the same for any median. It was noted in one report (McCall Glacier—Matt Nolan) that cloudy ice (from glacial silt) slowed the drill somewhat.

9.2.1 **What you might encounter within the ice in temperate glaciers or possibly within a perennial firn aquifer** – On occasion, the drill will encounter a water channel within temperate glacial ice or water saturated firn. The running water will remove the heat from the heat ring to the extent that the penetration rate will significantly slow. Sometimes, the drill will pass through this channel, however, it is conceivable that the drill cannot and the borehole must be abandoned.

9.3 **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. However, one must remember that the speed of the Thermal Drill sonde through water must be limited. Going down, the speed down hole is limited by the viscous friction of water; a speed too fast can loosen the wind on the winch. Coming up, the speed up hole is limited also by the viscous friction of the water; a speed too fast coming out of hole will apply undo forces that try to force the core out the bottom of the drill barrel.

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.

9.4 **Extracting the core** – When the drill is brought to the surface after drilling, the core is removed through the bottom of the drill, that is, it is extracted from the same end through which it entered. 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. To disengage the core dogs, one uses a piece of 'stove pipe', a piece of thin sheet steel with a curl slightly larger in diameter than the drill barrel. The stovepipe is cut so that it does not overlap itself when it lies against the inner surface of the drill barrel. The stove pipe is put over one's protected hand (edges can be sharp) like a cuff, then as the fingers push the core up off the core dogs, the stove pipe piece is slid upward over the hand until the core dogs are pressed back. The stovepipe is shaped so that it expands against the inner wall of the barrel and lies very flat against it. Its thickness is about 0.015", about that of a post card. The core passes by it and then it is simply pulled back out. This is definitely a two-person job.

NOTE: Always leave about 5 cm of space between the top end of the core to the hanger so that you have a little room to push the core up to release the core dogs. This is due to the method used to remove the core (see above).

CAUTION: The 'stove pipe' edges will be very sharp from being cut from a larger piece. Using stones, files and sand paper, round the edges to eliminate as much as possible any edges that might cut skin or clothing. Use gloves when using the 'stove pipe'.

NOTE: Be careful not to drill the barrel completely full. If this occurs, one may not have enough length within the core barrel to lift the core to release the core dogs. In this situation, it may be necessary to remove the hanging piece at the opposite end of the barrel to extract the core; either that or remove the core dogs; both are time consuming.

9.5 **Heating element failure** – The heating element on the heat ring is similar to that on an electric stove in construction, although it is a much smaller tube. What one sees is the outer tube, about three or four loops of it brazed onto the end of the heat ring body. Inside of this small outer tubing is an insulating tube, and inside of that is a wire filament that becomes hot from the current passing through it. The insulating tube insulates the outer tube from electrical current passing through the filament inside, while allowing heat to pass.

9.5.1 **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.

9.5.2 **Filament failure** – Another mode of failure of the heat ring is that of the filament wire simply burning in two, creating a short across which current will not pass, leaving the heat ring cold. In this case, the ammeter on the controller will read zero. There may be no external sign on the heat ring element.

9.5.3 **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.

9.5.4 **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—per measurements of four good heat rings. If the drill is mounted on the drill barrel, one must bare the conductors, which means cutting away the shrink tubing. Most likely, one can tell without having to do this. If there is no continuity, then the filament wire is burned in two and the heat ring is bad and will need to be replaced. If the resistance of the heat ring on the drill 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.

9.6 Replacing the heat ring

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

9.6.1 **Removing a damaged heat ring** – The heat ring body is held in place on the barrel tube by four flathead screws. The 2-wire tail of the heating element resides in a groove along the full length of the drill barrel that is covered by the thin metal strip that is held in place by numerous short flathead screws. First, remove all the flathead screws that hold the thin metal strip, taking care not to kink the thin strip. Then lift the wires from the groove by running something like a screwdriver shaft under the wires from the top end down. When the 2-wire tail is removed from the groove, then the heat ring can be removed off the end of the barrel. Finally, expose and melt the solder joints to free the heat ring.

NOTE: Handle the wire tail of the new heat ring with care, so as not to bend the heating element portion between the ring and the wire tail to avoid damaging the heating element.

9.6.2 **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 transition nodes 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. Re-solder each of the two wires to the two wire groupings from the suspending cable and cover them with moisture-seal heat shrink tubing.

CAUTION: Use care when using a heat gun on the shrink tubing to direct heat away from bare skin or poly-based clothing, as it can cause burns very quickly and melt clothing.

9.7 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', above which is a vertical groove in which a leaf spring is attached that extends down to about halfway into the window space. Near the bottom of the window is a groove into which sits the hinge pin on which the core dog hinges. The hinge pin is held in place by two flathead screws.

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

9.7.1 **Warm ice core dogs** – The core dogs are a 'bird beak' profile with a pointed end rather than a straight end as is often encountered in coring drills for cold ice and snow. Warm ice is less brittle and more pliable than cold ice and the point works very well. Normally, there is no need to change them, since they do not get dull and the ice density is nearly constant. The leaf spring keeps them from falling back. They are prevented from falling forward beyond horizontal by the window opening in the barrel.

9.7.2 **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. When the core dog is fully engaged, the spring is not in contact. The leaf spring is made of springy steel that is not easily bent, but not too stiff to prevent the core dogs from allowing core penetration into the barrel. The leaf spring acts to get the core dog leaning into the core, and then applying light, if any, force into the core. The end of the leaf spring is rounded on the edges so that it does not catch on the core dog.

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

10.0 Cargo And Logistics

10.1 Gasoline usage –Historically, the Thermal Drill uses approximately 0.10-0.15 gallons of gasoline per kilowatt-hour (rated power—elevation corrected). Five gallons of gasoline was reported to have provided about 10hrs of drilling using a Honda 5kW generator at an altitude of 12,000ft. *[As a general rule, a generator loses about 3.5% of its power for every 1000ft over 3000ft because of the lack of oxygen. Example: 12000ft is 9000ft over 3000ft which is a loss of 9 x 3.5% = 31.5% or about 30%. Thirty percent of 5kW is 1.5kW. So, this is a 1.5kW-loss of power, meaning that a 5kW generator is producing only 3.5kW at 12000feet.]* That is 5 gallons per 35kW-hrs, or 0.14 gallons per kW-hr.

NOTE: Keep an eye on generator fuel level to avoid shutdown while in operation.

10.2 Useful Auxiliary Equipment for Operation

10.2.1 **Sleds** – A banana sled is good for moving heavy objects around, such as the generator. A plastic sheet sled is good for moving heavy ice core boxes.

10.2.2 **Moving and cutting snow and ice** – A square-ended steel shovel is good for chopping and shoveling harder snow. A grain scoop (tempered aluminum) is good for moving large amounts of soft snow. A climbing axe is good for chopping ice and hardened snow. A snow saw might come in handy for making a snow pit for core or for digging an emergency shelter.

10.2.3 **Tying and lashing** – It is good to have ropes of different sizes (1/4-inch, 3/8-inch, ½-inch), straps, duct tape, bungee cords and baling wire.

10.2.4 **Extension cords** – Bring a couple of extension cords 120V approximately 50 ft. in length which can run from the generator to the drill borehole for use with tools like the heat gun for heat shrink tubing and soldering iron for soldering connections.

10.2.5 **Wooden stakes** – 2x2 wooden stakes (actual measurement 1.5 inches by 1.5 inches) by 4 feet in length are very useful in snow.

10.2.6 **Tarps and bamboo poles** – Plastic tarps are lightweight and useful in providing shade for the core processing station and for core storage. A tarp secured with a bungee cord is a good cover for the winch at night (the drill sonde can be left a short distance down the hole, with tarp stuffed in the hole around the cable to prevent blowing snow from entering the hole).

10.2.7 **A complete tool kit** – A tool kit should include, at the least, a heat gun, soldering gun, solder, electrical pliers, snips as well as other common hand tools.

APPENDIX A – DRILL SYSTEM PHOTOS

Picture 1: The first drilling project with the Thermal Drill. The project was conducted on Fremont Glacier in the Wind River Range of Wyoming where a core of 150+ meters was drilled. The core dog setup worked almost without flaw. One can see the heat ring mounted to the bottom of the core barrel as well as the groove cover that runs along the side of the barrel. Each heat ring has a 2-wire ‘tail’ that is over two meters length. The cutout, seen between the heat ring and the groove accommodates the joints of the heating element to the wire tail.

Picture 2: Extracting the core from the Thermal Drill sonde. This was the second drilling of the Fremont Glacier in the Wind River Range of Wyoming. Notice the yellow cable. It is co-axial with Kevlar reinforcement. The cable length is 200 meters and is spooled onto the 100-meter winch sled designed for use with the 4-Inch Drill. Here, the tower is of smaller diameter fiberglass/epoxy tubing that serves also as a shipping tube for Thermal Drill. The tower base that hinges on the sled was modified as was the sheave. This was a weight savings of 150 pounds over the 200-meter winch sled.

Picture 3: Core is being retrieved from the warm South Cascade Glacier of Washington State by helicopter. Here the 200-meter winch sled is being used in its normal configuration for use with the 4-Inch Drill. The Thermal Drill sonde, seen hanging from the drill tower, has a longer cable connection piece that was a one-off; usually just an eyebolt with a bracket that bolts to the end of the barrel is used. Notice the winch sled sits on a wooden pallet; this prevents the sled from melting into the surface snow. Snow was added to cover the pallet to reflect solar rays.

Picture 4: Using the stovepipe to hold back the core dogs, the scientists allow the core to slide out the end. The stovepipe is inserted by placing it around one's hand as the hand pushes the core up, relieving the pressure on the dogs. Then, it is slid along the inner surface of the drill barrel alongside the core until the core dogs are pressed back.

Picture 5: Moving the drilling sled to a new location. The Thermal Drill is tied to the tower. Moving equipment over the soft snow requires a lot of effort.

Picture 6: Core processing in the shade on the South Cascade Glacier in Washington State near the Canada border. Makeshift shade is very important because the solar input can be intense at altitude.

Picture 7: Snow is brought in on a sled to fortify the winch sled base on the Fremont Glacier in Wyoming. The surface loses a significant amount of snow every day in the summer time.

APPENDIX B – SPECIFICATIONS

Type	Thermal Ice Coring Drill
Core Diameter/Core Length	Ø86mm (3.4")/1 m-2 m
Nominal Hole Diameter	104mm (4.1")
Maximum Hole Depth	200m
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
Cycle Time	Varies
Notes	Shipping weight includes generator and 100-meter winch sled; complete operating weight is 800 lbs; uses 4-Inch Drill system winches.

APPENDIX C – 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 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			
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			

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			
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			
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:				

APPENDIX D – DRILL LOG

Barel Set
Head
Cutters
Shoes
Core Dogs (length)
Core Dog Springs

Project
Location
Date
Weather
Drillers

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