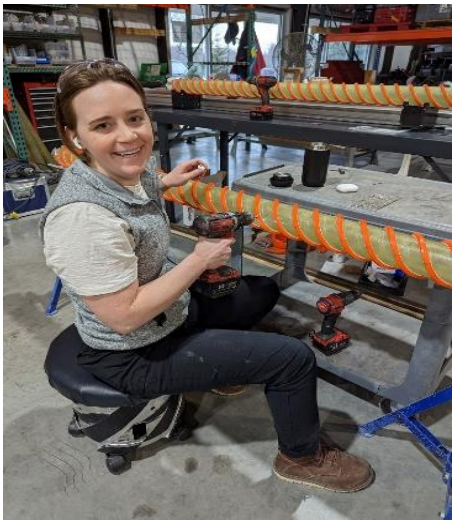
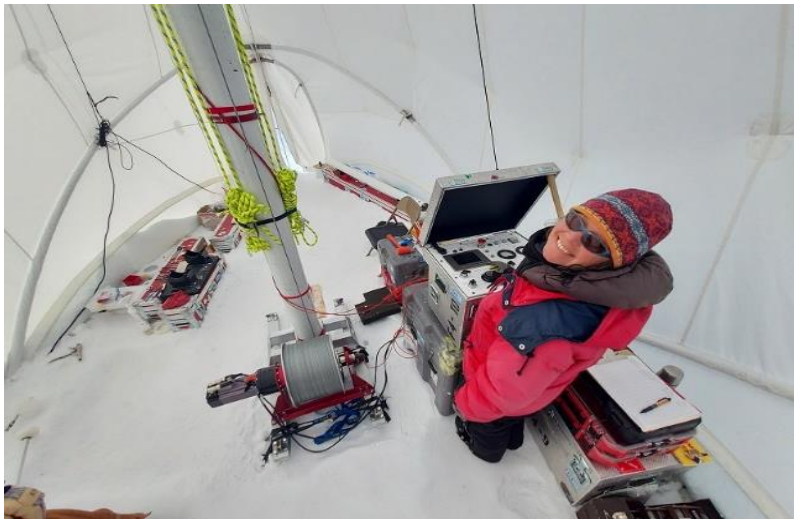
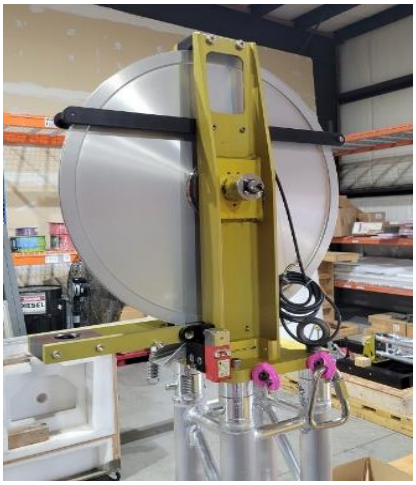
Ice Drilling Program

LONG RANGE DRILLING TECHNOLOGY PLAN



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Contents

Cover photos: (upper left) IDP Mechanical Engineer Barb Birrittella attaches flights to a hand auger barrel (photo credit: Jess Ackerman); (upper right) IDP Driller Elizabeth Morton operates the Foro 400 Drill at Allan Hills, Antarctica (photo credit: Mike Jayred); (lower right) The 700 Drill crown sheave is assembled at the IDP facility in Madison, WI (photo credit: Jay Johnson); (lower left) Drilling with the IDP Thermal Drill on Quelccaya Ice Cap in Peru (photo credit: Mariusz Potocki).

1.0 INTRODUCTION

The U.S. Ice Drilling Program (IDP) Long Range Science Plan lays out recommended directions for U.S. ice coring and drilling science. This companion Long Range Drilling Technology Plan addresses the IDP drills and technologies needed for implementation of parts of the Long Range Science Plan. Much of the equipment mentioned is already being developed or maintained by IDP as part of its inventory of NSF-owned equipment. This plan also describes the latest development projects at IDP and discusses potential technologies that could have positive impacts on NSF-funded science programs, if pursued. Finally, this plan briefly addresses the funding allocated for its implementation during the current Program Year (PY).

Highlights/Changes for this 2023-2033 Update:

Changes:

- Updated the list of Recommended Technology Investments based on the current Long Range Science Plan.

Deletions:

- Deleted portions of the Drill Fluid section to remove information that is dated.

The high priority tasks and investments identified by the IDP Science Advisory Board (SAB) are shown below as listed in the U.S. Ice Drilling Program Long Range Science Plan 2023-2032.

Recommended Technology Investments

The following investments in drilling technologies are needed to accomplish science goals planned for the next decade. Investments prioritized by time (but not prioritized within each Priority level), from consensus of the IDP Science Advisory Board as described in the IDP Long Range Science Plan, include:

Priority 1 (needed this year):

- Maintain and upgrade agile equipment in inventory, including: Hand Augers, Sidewinders, the Foro 400 Drill, the 4” Electromechanical Drills, the 3” Electrothermal Drill, the 3.25” Eclipse Drills, the Stampfli Drill, Logging Winches, the Small Hot Water Drills, the Blue Ice Drill, the Prairie Dog, the Agile Sub-Ice Geological Drill (ASIG), the Rapid Air Movement Drill (RAM) Drill, and the Winkie Drills.
- Adapt the commercial BASE drill rig for retrieving rock core from beneath 200 m of ice (BASE Drill).
- Develop the Conceptual Design for collecting a small amount (chips to 10 cm) of sub-ice rock/mixed media/mud in a frozen regime using an intermediate or deep ice core drill in a fluid filled hole, for example, with the Foro 3000 drill.
- Finish construction of the 700 Drill.
- Develop the updated IDP Conceptual Design and Detailed Design for a clean Scalable Hot Water Drill that minimizes its logistical footprint including fuel supply.

- Investigate a lighter weight source of power to replace generators for drilling systems, in order to ease demand on logistics, including renewable energy.
- Finish the Conceptual Design and begin the Detailed Design for replicate coring for the Foro 3000 drill.
- Develop the Detailed Design for a clean hot water basal ice coring mechanism for a hot water drill.
- Conduct an engineering feasibility study to evaluate and recommend longer-term drilling approaches to retrieve ice with good core quality down to 400 m depth in blue ice areas. Possible approaches include: replicate coring for Foro 400, large-diameter thermal drill (diameter < 241 mm TBD), complete re-design of the BID, and others. For each approach, estimate the anticipated improvement in core quality, impacts on associated logistics, and the time required to complete the resulting drill. Identify the most promising approach that could be implemented not later than 2028, but earlier if possible.
- Resolve Deep Logging Winch electrical noise issues.

Priority 2 (needed within the next three years):

- Build a Scalable Hot Water Access drill for creating access holes in ice that has modular capability for clean access.
- Identify procurement source and cost for potential purchase of a rapid hole qualifier (temperature and caliper) for field scientist use in borehole logging applications.
- Establish the IDP Science Requirements for identification and planning of borehole maintenance and fluid maintenance over time, including removing (or lowering) drilling fluid from a borehole (for example for freezing in a sensor).
- Create a second, updated Blue Ice Drill.
- Evaluate options for new drilling fluids for future ice and rock drilling projects.

Priority 3 (needed within three to five years):

- Continue investigation and modifications of the RAM 2 Drill to achieve the 100 m depth goal reflected in the system Science Requirements.
- Establish the Science Requirements for retrieving sidewall ice samples at specific depths in an existing borehole without using an ice coring drill.
- Draft a feasibility paper outlining the potential for using shallow drill fluid columns for ice coring.

IDP will address these priorities through the maintenance and modification of equipment already in its inventory, by developing or procuring new equipment, or through iterative discussion with the science community. The equipment involved in meeting these priorities is addressed in the following sections. Following that, the list of priorities is revisited with details of how IDP is addressing them.

2.0 ICE AND ROCK DRILLING SYSTEMS AND TECHNOLOGIES

Important technical aspects of ice and rock drilling equipment are its performance characteristics including its transportability (i.e. weight, size), its condition, and the availability of documentation such as component specifications, fabrication drawings, operations and maintenance manuals, etc. Major component inter-changeability and logistical agility is a major design goal of all new and refurbished drills. IDP follows rigorous documentation procedures throughout the design, fabrication, testing and deployment of equipment. This allows IDP to better maintain the equipment, and also allows IDP to undertake modifications that improve the equipment's performance and, hence, its usefulness to scientific investigators.

One of the guiding principles for development of drilling technology expressed in the U.S. Ice Drilling Program Long Range Science Plan 2023-2033 prescribes that *"Major drilling systems (e.g. sondes, winches, controls and other major electronics systems) should be fungible to the maximum extent possible. Major component inter-changeability and logistical agility should be essential deliverables for all new drilling technology projects."* IDP has made strides in this area by envisioning and initiating fabrication of the Foro Drill series. Through the design of similar drill systems with varying depth capabilities and the implementation of interchangeable components, IDP is committed to pursuing the efficient deployment of systems, a reduction in the level of logistics required, and lower overall design and maintenance costs. Some of these systems, such as the Foro 400, will replace aging drills that are nearing the end of their useful life (e.g. 4-Inch Drill), while others like the Foro 3000 will dramatically decrease the amount of logistics required to collect cores to a certain depth. Finally, others will fill a void where capability does not currently exist but is highly desired by the science community (e.g. 700 Drill).

The following sections provide a brief history of each piece of equipment in the IDP inventory, outline the current status of each system, note any technical issues with the equipment and outline plans for the near future.

Chipmunk Drill

The Chipmunk Drill is a hand-held, motor driven drill that collects 41 mm (1.6-inch) diameter cores in solid ice. It has two barrels, one 15 cm long and one 50 cm long. The drill was first used for a funded project (for which it was designed) at Pakitsoq, West Greenland, in 2003 and 2004. It was later used for exploratory work at the South Pole in 2013 and for several demonstrations of ice coring for the public in the U.S. More recently, the drill was used to collect shallow cores in the Sierra Nevada range in fall 2021 and in Wyoming in fall 2022. During winter/spring 2022, the drill was used by an investigator at UW-Madison for testing highly strained ice created in a campus lab.

Photo credit: Joe McConnell, DRI

Current Status

The drill is functional, and improvements were made in late 2021 and 2022. The coupler on the top of the longer barrel was turned down to allow it to fit inside the borehole. Chip windows like those on the short barrel were added to the long barrel, and the drive adapter was re-designed, simplified, and fabricated. Couplers were redesigned for use with both the current barrels and for adaptation of an off-the-shelf barrel, such as a barrel from the Stampfli Drill. The two systems would then use interchangeable heads and cutters designed by IDP, thereby standardizing parts inventory, and reducing maintenance costs. In 2022, IDP shortened a damaged Stampfli barrel for use with the Chipmunk Drill, but this has not been tested in the field. Chip separator plugs were fabricated and foam was reworked in the shipping case. Additional improvements are needed to optimize performance, pending successful testing of the Stampfli barrel.

Technical Issues

The current two drill barrels have different cutter attachment styles and should be standardized. Few drawings exist for the original design, but drawings are being completed for any newly designed parts.

Plans

1. Test operation with a Stampfli barrel – PY 2023 or PY 2024.
2. Purchase/fabricate a second Stampfli barrel – PY 2024 or PY 2025.
3. Fabricate cutter head assemblies for use with the Stampfli barrels – PY 2024 or PY 2025.
4. Decommission specific Chipmunk Drill components – To follow successful implementation of the new barrels.

Hand Augers

The hand auger is the most basic of the mechanical drills and is driven from the surface by extensions that are added as drilling proceeds into the ice. IDP traditionally deploys two types of hand augers: SIPRE (3-inch core) and IDDO (3 and 4-inch cores), but has recently taken custodianship of Kovacs hand augers formerly maintained by the Berg Field Center (BFC) at McMurdo Station. The SIPRE, Kovacs, and short IDDO systems take half-meter cores, while the long IDDO systems take one-meter cores. IDP also has two remaining PICO 3-inch hand auger kits in inventory, which are occasionally requested for drilling in blue ice. Much of the PICO equipment has aged beyond its useful life and several PICO drill kits were decommissioned in early 2022. The maximum depth to which hand augers can be used without power assistance (see Sidewinder section) is approximately 20 m. Hand augers are typically operated by investigators without assistance from IDP equipment operators.

Current Status

Hand augers are individually packed and assigned to investigators, depending on project needs. Augers for users traveling through McMurdo Station are sent to the BFC for distribution to the specified field project. Drills for use elsewhere are shipped directly to the investigators or to the field sites. IDP maintains eight copies of the 3-inch IDDO hand auger, three copies of the 4-inch IDDO hand auger and nine copies of the SIPRE hand auger. IDP will also maintain one Kovacs Mark V kit (14 cm/5.5 in core) and approximately five Kovacs Mark II kits (9 cm/3.5 in core). The PICO hand augers employed carbide cutters to enable drilling through very small pebbles or dirty, silty or sandy ice. Carbide cutters have now been designed and fabricated for the IDDO Hand Augers, but have not yet been used in the field.

Technical Issues

An issue with delaminated flights occurred during use of an IDDO hand auger in Greenland in 2022. New tape, epoxy and mechanical fasteners were purchased, and the procedure for installing flights was documented. The flight tape was also tested in cold and various fluids. **While ethanol can be used to free a stuck SIPRE or Kovacs hand auger, only glycol should be used with the IDDO hand augers.** This is noted to users in the IDP Letters of Support, and noted in the Operations and Maintenance Manuals that accompany each drill into the field.

Plans

1. Improve hand augers based on feedback from users – Ongoing.
2. Maintain hand auger inventory – Ongoing.

Sidewinder

The Sidewinder is not a drill but is a drive/lifting system used in conjunction with the hand augers. It is driven by an electric motor (power hand drill) and a winching system to help in both lowering and retrieving the drill string. The power hand drill is also used to spin the hand auger barrel during drilling. The Sidewinder extends the maximum practical depth of coring with a hand auger to about 40 m. Like the hand augers, the Sidewinders are typically operated by investigators without assistance from IDP equipment operators.

Current Status

Five working systems are available, but many parts are aging. In late 2022, IDP worked with Mechanical Engineering students at UW-Madison on a Senior Design Project. The goal of the project was to mitigate safety risks posed by the current Sidewinder design, reduce the transport weight, and optimize operations, for example, by removing the need to stand on a Hardigg case to operate the unit. The students evaluated different braking system and platform designs, ran Finite Element Analysis (FEA) on components, and created a Bill of Materials and CAD models. IDP engineers and undergraduate student interns will complete remaining design tasks and specify and source components. IDP plans to build a prototype of this new design in late PY 2023 or PY 2024. The prototype would be tested before it would be sent into the field for use by a science team.

Technical Issues

An assessment of the units by IDP engineers in PY 2018 showed that the cleat setup on the rope spool could pose a personnel safety hazard. The cleat components were also integrated with the braking system of the unit. A modified brake and nylon disks, which replaced the cleat components, were tried in 2018, but performance in the field was inadequate, slower, and experienced a failure. In 2019, IDP conducted a thorough analysis of all Sidewinder components. The prototype brake and nylon disks were then removed from service and all systems are back in the original configuration. IDP also purchased a Kovacs Sidewinder for testing. During testing, the Kovacs system did not appear to have enough gear reduction to hold the weight of the auger stem. Concerns with the braking system were also witnessed with both the Kovacs and IDP units.

Plans

1. Maintain Sidewinder systems – Ongoing.
2. Build and test a prototype based on the IDP redesign – PY 2023 and PY 2024.
3. Improve documentation, potentially adding a training video – Contingent upon available budget.

Prairie Dog

A modification of the hand auger, the Prairie Dog includes a stationary outer barrel that allows operations in solid ice as well as firn. The depth limit is approximately 40 m (with a Sidewinder). The system is commonly used in warm ice conditions where the two-barrel design aides in chip transport during coring. The system was used in both Wyoming and Montana in 2013 for ice patch coring and again near the Wyoming/Montana border in 2016 and 2018.

Current Status

The drill system is complete and is ready for issue. The Prairie Dog is typically operated by one IDP equipment operator with assistance from the science team.

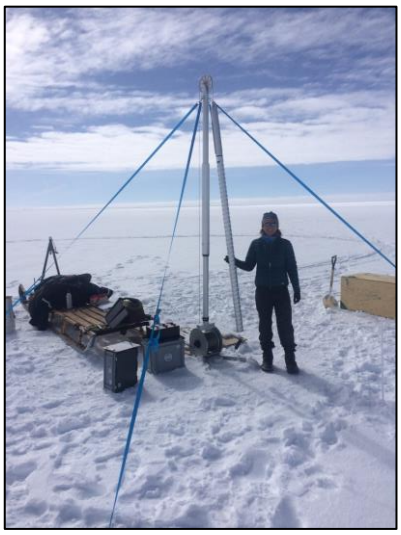
Technical Issues

During operation in Wyoming/Montana in 2018, a drive stem broke on the Prairie Dog anti-torque section, suspending drilling for the short nine-day project. IDP subsequently completed a Finite Element Analysis (FEA) study on the aluminum shaft, essentially reproducing the failure. The aluminum part was re-fabricated from hardened stainless steel, increasing its strength.

Plans

1. General maintenance and modification – Ongoing as needed.

Stampfli Drill



In 2015, community scientists identified the need for a lightweight coring drill, able to be transported by backpack. IDP researched commercially available systems and considered designing a new tool. In the end, a commercially available drilling system was purchased from Icedrill.ch in Switzerland in 2016. IDP customized the order to include a winch for depth capability to 100 m.

In May 2017, IDP conducted preliminary in-field testing of the drill at Summit Station, Greenland. In late 2017, IDP completed minor maintenance, procured several spare parts, and procured shipping cases and bags for modularity and lightweight deployment. IDP also purchased a lightweight Tentipi Safir tent for use with the system. IDP engineers also designed a new aluminum cutter head with removable steel cutters, as the original manufacturer's design employed a one-piece aluminum head with cutters machined in. IDP has since implemented steel cutter heads with removable cutters. The system was deployed for an NSF-funded field project in summer 2018 in the Yukon Territory, Canada, where it was operated by the science team to collect one firn core to 10 m depth and another to 20 m depth. In 2019, a science team successfully collected a 50 m core from Mt. Hunter in Denali National Park, Alaska.

Current Status

The Stampfli Drill is ready for issue.

Technical Issues

In early March 2019, IDP sought to determine if the Stampfli Drill could be utilized to drill pilot holes in firn and ice, in advance of subglacial rock coring with the IDP Winkie Drill. IDP tested Stampfli Drill operation in a prototype ice well near Madison, WI. Chip transport was found to be inefficient when drilling in solid ice. In 2020, IDP worked to replace the aluminum cutter heads with stainless steel heads to prevent deformation. In 2021, IDP performed minor maintenance on the drill system, including replacement of a circuit board in the control box, re-termination of the cable, and procurement of field tools and spare brushes for the slip ring. In 2022, a new core barrel was procured to replace a warped barrel, the winch motor was tuned and a cutter grinding fixture was designed. Future modifications to improve chip transport may include the addition of shoes with varying pitch and the addition of a ribbed outer barrel, though this would require wider kerf cutters and a taller tower.

Plans

1. General maintenance and modification – Ongoing as needed.
2. Make modifications to improve drilling capabilities in solid ice – Will be completed as NSF and community priorities dictate.

Blue Ice Drill (BID)

The Blue Ice Drill (BID) is an agile drill capable of retrieving cores of approximately 241 mm (9-1/2 inches) in diameter. The BID system had a depth capability of 30 m in solid ice in its original design and has been used successfully in both Greenland and Antarctica for many years. In PY 2014, the system was modified to allow for attempts at deeper coring to 200 m depth at the request of the science community. A new cable winch and tower were implemented in the design as well as several new down-hole components. Depth capability is still largely influenced by site/ice and firn depth characteristics. The standard BID typically utilizes a ropes setup for coring to shallow depths, and the cable winch is used for achieving greater depths. In 2016, IDP initiated fabrication of a second BID-Deep system (BID-Deep 2), based on user demand and as outlined in the U.S. Ice Drilling Program Long Range Science Plan. Fabrication was temporarily suspended in late 2017 due to budget constraints and decisions on the funding of field projects.

Current Status

The BID is one of IDP's most requested drills. A recently fabricated drill tent (see MAST Tent section) has allowed operations to continue in poor weather conditions. A new tower was fabricated in 2019 to bear the loads of the tent and allow for safer tent erection than the original BID tripod. IDP made additional modifications to the drill including painting the outer barrels white to reduce solar gain, redesigning the cable termination, fabrication of scoop cutters and work on the crown sheave.

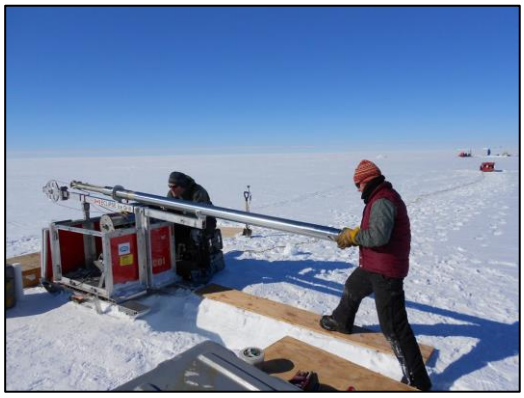
Technical Issues

Collecting good core quality at greater depths in attempts to extend the BID's depth capability has proven challenging. The drill can easily drill through at least 80 m of firn, and deeper through another 70 m of solid ice. The drill has only reached 187 m in practice in Greenland. Site-specific ice properties such as firn depth, temperature and ice structure as well as the large core diameter and/or mechanical aspects of the drill are all potential factors that may impact core quality. After prolonged use, many original components are aging and require replacement or redesign. IDP is discussing with the science community several approaches for drilling good quality ice core in blue ice, which may include design and fabrication of a modified BID or the development of a large-diameter thermal drill.

Plans

1. Maintain the BID and BID-Deep components – Ongoing.
2. Re-design/fabricate a second BID-Deep – Initiated in PY 2016; discussing best course of action with science community. Will be completed as NSF and community priorities dictate.

Badger-Eclipse Drill



The Badger-Eclipse Drills are modified Eclipse Drills originally manufactured by Icefield Instruments, Inc. The drill is an electromechanical system capable of collecting 81 mm (3.2-inch) diameter cores to depths of approximately 300 m. The drill system is transportable by small aircraft or helicopter. IDP has two Badger-Eclipse Drill systems that it regularly deploys and a third, partial Eclipse Drill that was transferred from the University of New Hampshire to IDP at the University of Wisconsin in 2010.

In 2013, IDP designed and fabricated a solar and wind power system for use with the drill, which has proven useful at field sites where environmental impact is of concern and where use of a generator is not desirable or permitted. IDP also owns two Mountain Hardwear Space Station tents for use with the Badger-Eclipse Drill systems. The tents have allowed drilling operations to continue safely and reliably during inclement weather in Alaska, Greenland, and Antarctica. In 2017, IDP completed a redesign of the aging control boxes and readout boxes to provide simplified operation, weight reduction and new sealed cases. In 2018, new cover panels were implemented for the traversing system. New cases were also procured for the motor section and tower frame. New load pins and load pin amplifiers were implemented to make the load sense circuit more robust. Beneficial updates were made to the Operations and Maintenance Manual and minor maintenance is performed between field seasons.

Current Status

Two Badger-Eclipse drills are available for use. One is referred to as the ‘standard’ Badger-Eclipse Drill and the other as the ‘traversing’ Badger-Eclipse Drill, since it is sled-mounted. An improved winch cable termination has been built and is ready for field testing. IDP is also working to ensure complete drawings and documentation are available for the drills.

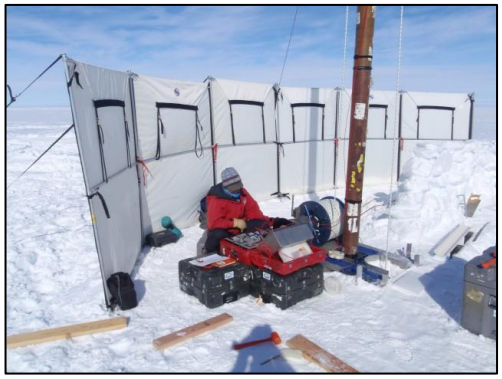
Technical Issues

Improvements to the instrumentation and the control system have been implemented to increase operational flexibility and reliability. Aging components are being replaced as necessary.

Plans

1. General maintenance and repairs – Ongoing.
2. Complete field testing of the new cable termination – PY 2024.
3. Complete documentation and enter into database – Ongoing.
4. Ready a third Eclipse Drill system for issue, either by completing/upgrading the unit from UNH or through the purchase of a new Eclipse Drill – As needed.

4-Inch Drill



The 4-Inch Drill is an electromechanical ice coring drill that takes a 104 mm (4-inch) diameter core. Cores can be retrieved from depths to approximately 400 m. Winches with 100, 200, and 400 m 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 that produced by the Badger-Eclipse or Foro 400 drills. Depending on the configuration, the drill can be transported by light aircraft or helicopter.

The 4-Inch Drill was used at Law Dome Antarctica during the 2018-2019 season and with the Rapid Access Ice Drill (RAID) project near Minna Bluff, Antarctica during the 2019-2020 season. Two 4-Inch Drill winches and a tower were also deployed to Thwaites Glacier during 2019-2020 for use by a science team for instrument installation in a hot water hole. A 4-Inch Drill is currently being used with the GreenDrill project in Greenland for drilling pilot holes and for bailing fluid from the ASIG Drill holes.

Current Status

IDP currently has two 4-Inch Drill systems ready for issue. To meet continued demand for a drill of this type, IDP has designed and fabricated a drill known as the Foro 400 Drill (see Foro 400 section). A 4-Inch Drill system will still be maintained. However, the Foro 400 Drill offers new capabilities and substantial weight savings, albeit with a smaller (3.9-inch) diameter core. A new chips bailer was designed for use with the 4-Inch Drill system in 2019 for clearing cuttings from pilot holes drilled by ASIG Drill augers. The bailer was successfully tested in holes augered with the RAID system during the third Antarctic Field Trial (AFT-3) at Minna Bluff during the 2019-2020 field season. In late 2020, new winch crates were implemented, and the readout and control boxes were re-calibrated.

Technical Issues

The current 4-Inch Drills are repaired as needed, however, the systems are aging. In some cases, replacement parts may no longer be available. The cable winch sleds are very heavy, making the drill not optimal for transport by small aircraft. Improvements to the instrumentation and control system for the drill have also been noted as desirable to improve reliability and to reduce weight. All of these considerations have been taken into account with regard to the new Foro 400 Drill design.

Plans

1. Perform general maintenance and repairs – Ongoing.
2. Maintain at least one each of the 100, 200, and 400-meter winches – Ongoing.

Electrothermal Drill

The Electrothermal Drill (aka Thermal Drill) melts an annulus around the ice cores it collects. It can be substituted for the 4-Inch Drill sonde, using the same winch system, for use in ice warmer than about minus 10°C. The drill collects an 86 mm (3.4 inch) core and has been used to drill to nearly 300 m. For depths shallower than 30 m, a simpler tripod assembly for operation of the drill has been used with good success. The sonde is particularly useful in ice close to the pressure melting point, where electromechanical drills are at risk of getting stuck. The Thermal Drill has performed well in Alaska, British Columbia, southeastern Greenland, and Peru. In 2019, three IDP personnel traveled to Alaska in conjunction with the Juneau Icefield Research Program (JIRP) to perform drill testing. The drill was used in September 2022 to successfully drill 128 m to bedrock at a high-altitude site on the Quelccaya Ice Cap in Peru.

Current Status

IDP has one Thermal Drill ready for issue. At the request of the science community, IDP pursued upgrades in PY 2018 to allow for coring to 300 m. New heat rings, a new 300 m water-shedding cable, a magnetic tool to aid in core removal and an ethanol deployment system were implemented. In 2021, a new debris vacuum was designed, fabricated, and tested to remove debris from the borehole that might impede melting and forward progress. A new core processing tray was also developed. In PY 2022, a second aluminum sonde was fabricated to replace the heavier steel barrel.

Technical Issues

4-Inch Drill cable winch sleds used with the Thermal Drill are very heavy, making the drill not optimal for transport by small aircraft. The new Foro 400 Design (see Foro 400 section) offers weight savings and should eventually be made compatible with the Thermal Drill sonde. The Thermal Drill could also be adapted for use with the Badger-Eclipse Drill winch and tower.

Plans

1. Complete documentation and enter into database – Ongoing.
2. Perform maintenance and repairs – As needed.
3. Upgrade for weight reduction and compatibility with Foro 400 Drill system – Contingent upon available budget and NSF approval; will be completed as community priorities dictate.

Foro 400 Drill

Design of the Foro 400 Drill was initiated in PY 2015 based on driller feedback with the aging 4-Inch Drill, and to utilize more recent and proven designs from other IDP drill systems. The drill is expected to largely replace use of the 4-Inch Drill equipment; however at least one full 4-Inch sonde will be retained for use on science projects requiring the larger 104 mm diameter core. The design is largely based on the current 4-Inch Drill equipment but offers generous weight savings. The Foro Drill produces a 98 mm (3.9-inch) diameter core, the same as IDP's Foro 1650 Drill (Intermediate Depth Drill) and Foro 3000 Drill. In addition, the Foro 400 sonde design is submersible and watertight. Using a common sonde design across several drills spreads design costs over multiple projects, strengthens component availability, and promises to reduce future maintenance costs. During a lull in fieldwork caused by the pandemic, IDP conducted beneficial hands-on training for several IDP Engineers at the UW Physical Science Lab (PSL) test well. The system was deployed to Antarctica for its first field project during the 2019-2020 field season at Allan Hills, Antarctica. The system was used again on Tunu Glacier in Greenland in spring 2022 and again at Allan Hills during the 2022-2023 Antarctic field season.

Current Status

Minor modifications have been made following each of the drill's field deployments. Fishing tools were fabricated and drill recovery loops procured in 2021. Slam Stick mounts were also fabricated to allow for collection of vibration data during coring. In 2022, scoop cutter shoes and sonde stands were procured. In 2023, IDP is pursuing the specification and purchase of aluminum outer tubes to replace the fiberglass tubes, as it is believed the fiberglass is creating heat, chip transport issues and poor core quality starting at depths as shallow as 150 m. A collet cutter head was also designed and fabricated.

Technical Issues

Operators at both Tunu Glacier and Allan Hills noted several challenges with the new system, most notably with chip transport. New outer barrel tubing was procured and modifications were made to existing tubing in 2020. The modifications were successfully tested in an ice well outside of Madison in February 2021 but did not perform as well in Greenland or Antarctica.

Plans

1. Complete drill system drawings and enter into database – Ongoing.
2. Perform maintenance and repairs – As needed.
3. Fabricate aluminum outer barrels – PY 2023.

Small Hot Water Drill

The IDP Small Hot Water Drills (SHWD) use hot water to create shallow holes in ice. They are non-coring and are typically used to produce holes 100-200 mm in diameter down to a maximum practical depth of 60 m. Primary use is for shot holes for seismic work, but they have also been used for access holes through a thin ice shelf. These drills are transportable by light aircraft and helicopter. Between 2014 and 2016, IDP implemented substantial modifications to the drills, with assistance from UW-Madison Physical Sciences Lab (PSL) personnel. IDP refurbished the heaters, evaluated the hose, specified and procured a new nozzle kit, and tested and verified all modifications prior to shipping the system to Antarctica in fall 2015. Additional modifications and upgrades were made to the drills in late PY 2016, and IDP built up a fully operational second unit. One of the two systems has a 30 m depth capability, and the second system has a depth capability to 60 m. All identified maintenance and upgrades were completed in 2016, including implementation of lightweight Siglin sleds and system covers for protection from the elements. Following upgrades to the system and upon review of user feedback, IDP now recommends that a trained IDP operator deploy with each system. The system was most recently tested in West Antarctica by two IDP personnel during the 2022-2023 field season and was operated by an experienced PI in northern Greenland in spring 2023.

Current Status

IDP has two small hot water drills in inventory. One system was shipped to Antarctica in 2018 and was tested at WAIS Divide in January 2023. It will serve as a backup for the planned RAM Drilling effort in 2023-2024. Based on the testing in Antarctica, IDP made a few modifications to the second system in Madison in early 2023. The system was then shipped to Greenland for fieldwork in May 2023.

Technical Issues

The system is generally reliable and efficient to a depth of 25-30 m. Most of the modifications made have been either tested in the lab or the field, but capability to 60 m has not yet been field-tested. During the May 2023 deployment, the science team reported an issue with the water temperature not reaching the setpoint. IDP provided remote troubleshooting support and will investigate the issue further once the system returns to Madison.

Plans

1. Update documentation and operating procedures – As needed.
2. Investigate the temperature setpoint issue – PY 2023.

Rapid Air Movement (RAM) Drill

The Rapid Air Movement (RAM) Drill was developed for creating shot holes for seismic geophysical exploration. It is a system in which high-velocity air drives rotating cutters and blows the ice chips from the hole. The cutting drill motor hangs on a hose that carries the air from the surface and is reeled out as the hole deepens. The original RAM Drill was used three times in West Antarctica, where it routinely achieved depths of 90 m. The Askaryan Radio Array (ARA) project used the drill in 2010-2011 to test methods of producing holes for radio antennae at South Pole but could not get deeper than 63 m at that location.

In 2017, substantial modifications and upgrades were made to reduce the system's logistical requirements. IDP designed and built the modified RAM 2 system. The modifications serve to dramatically reduce the system weight and will allow for easier assembly and operations in remote areas. A field test of the modified system was conducted near Raven Camp in Greenland in July 2018. Repairs and additional modifications were made prior to the drill's deployment to Antarctica in September 2018. The system was tested by two IDP personnel at WAIS Divide during the 2019-2020 field season. The drill routinely achieved between 50-55 m, the requirement for planned field work on Thwaites Glacier. The smaller RAM 2 compressors will eventually be optimized to provide the necessary airflow for future projects.

Current Status

During an abbreviated 2022-2023 Antarctic season, the RAM 2 Drill was used to drill 27 holes on a line starting at WAIS Divide camp and extending ~32 km grid west towards Thwaites glacier, and operational data for the RAM 2 Drill system was collected.

Technical Issues

Optimization of the compressors (small or large) and the hose and sonde are required to meet the revised science requirements for RAM 2. Even with the large compressors, however, the drill system is not reaching the 90 m depth range of the original RAM Drill.

Plans

1. Continue work to address the need for more compressed air with modular units to meet the science requirements. Work to identify and test a solution – PY 2024 or PY 2025.
2. Complete drill system drawings and enter into database – As needed.
3. Update operating procedures and other procedural documents – As needed.

Agile Sub-Ice Geological (ASIG) Drill

The Agile Sub-Ice Geological (ASIG) Drill is based on a commercially available minerals exploration rig, which IDP adapted for drilling through ice and for ice coring. The system is designed to drill access holes through ice less than 700 m thick and subsequently collect bedrock cores from beneath glaciers. A minerals exploration rig was purchased from Multi-Power Products Ltd., and IDP designed auxiliary systems for fluid handling. In 2016, IDP conducted a North American Test of the complete system just outside of Madison, WI. The drill system was deployed to Pirrit Hills, Antarctica for the 2016-2017 field season where it was successfully used to drill through approximately 150 m of ice and collect 8 m of 39 mm (1.5-inch) diameter excellent quality rock core. Nearly 5 m of ice core was also collected near the ice-bedrock transition, but the core quality was poor. In 2019, IDP engineers completed air drop testing to quantify parameters that may create a hydro fracture situation in ice. System maintenance was subsequently conducted, and an electronic pressure relief valve and a shaker table for separating ice chips and drill fluid were recently implemented.

Current Status

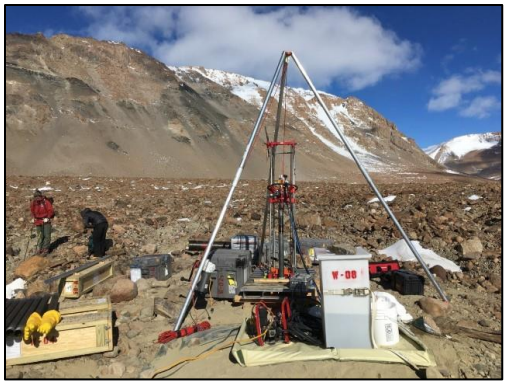
The system was shipped to Thule Air Base (now known as Pituffik Space Base) in Greenland in July 2022 via military vessel. In April 2023, four IDP Engineers/Drillers deployed to Greenland for the GreenDrill project. One borehole was successfully drilled to 516 m depth, where 7.4 m of subglacial material was retrieved, including 4.5 m of bedrock core. A second season for the project is planned for 2024.

Technical Issues

Drill site factors such as firn depth, ice fabric and composition of the subglacial environment will affect drilling parameters. Despite implementation of an electronic pressure relief valve and no indication of an over-pressure occurrence, a hydro fracture occurred near the packer in May 2023 when drilling had reached approximately 400 m depth. Drill rod and casing clearances are tight, necessitating higher pumping pressures. New downhole tooling may need to be specified and procured to alleviate this issue. While the drill operates inside a tent, poor weather prevented running the engines outside, resulting in downtime. A comprehensive list of technical issues is contained in the End of Season Reports.

Plans

1. Make necessary repairs/modifications following the GreenDrill seasons – PY 2023 and PY 2024.
2. Specify and procure new downhole tooling – Pending evaluation of the 2023 GreenDrill season.
3. Procure and implement a tent for engines.
4. Enter documentation for the drill system into the documentation database – Ongoing.



Winkie Drill

The Winkie Drill is a commercially-available rock coring system originally purchased by IDP in 2015. IDP has implemented upgrades to add ice augering and ice coring capabilities. The system has a depth capability of 120 m and creates ice and rock cores 33.4 mm (1.3-inch) in diameter. The system successfully collected subglacial mixed media and bedrock cores during its first three deployments beginning in the 2016-2017 season. Modifications were subsequently made to accommodate a request for larger core diameter (71.7 mm) as well as replacement of the gas engine with an electric motor, for improved reliability and to allow for operation inside a tent. In 2018, IDP engineers incorporated modifications for use of the drill in areas where surface firn covers the ice and bedrock below. In 2020 and 2021, IDP built a second Winkie Drill, referred to as Winkie 2, to meet funded field project demands. In early 2021, IDP engineers tested a new ice bit outside of Madison, WI. A new fluid chiller was also designed and fabricated to mitigate warm temperatures and drilling challenges witnessed on Thwaites Glacier. A slip-style foot clamp assembly was also implemented in 2021 and 2022 to improve safety when tripping drill rod and casing into and out of the borehole, and an electronic pressure relief valve (PRV) was implemented to reduce the potential for a hydro fracture event while drilling through ice.

Current Status

Both Winkie Drills are deployed regularly to the Arctic and Antarctic. An Eclipse Drill is currently sent with each system to drill pilot holes.

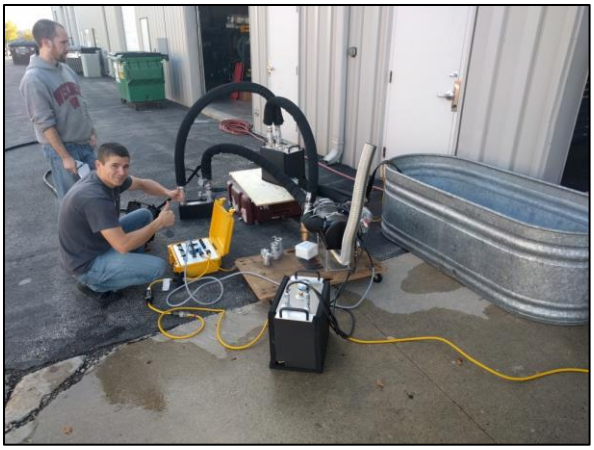
Technical Issues

During the 2022-2023 Antarctic season and the 2023 Greenland season, the Winkie Drill was unable to successfully drill past thick layers of clay and unconsolidated debris. This issue was discussed during the 2023 IDP Technical Assistance Board meeting and drag bits and tumbler media were procured in an attempt to drill through clay. Following additional challenges in Greenland, it is believed the clearances in the downhole tooling may be too tight for drilling, clearing and transporting clay. IDP will evaluate this further upon the drill's return from Greenland. Drill performance details are contained in the End-of-Season Reports.

Plans

1. Repair, maintain and upgrade the Winkie Drill system(s) – Ongoing.
2. Investigate clearances for downhole tooling and procure new tooling if needed – PY 2023 or PY 2024.
3. Develop a weight-reduced firn access hole system – Contingent upon available budget and NSF approval; will be completed as community priorities dictate.

Sediment Laden Lake Ice Drill (SLLID)



Per the recommended technology investments in the Long Range Science Plan, IDP worked with representatives of the science community to finalize science requirements for a small, portable hot water drill system. The requirements were completed in 2015, and in 2016, IDP initiated the conceptual design of the system. In early 2017, the detailed design was completed and reviewed by community scientists as well as external technical personnel from the polar ice drilling community. Following a successful review in April 2017, IDP made minor adjustments to the design and iniated fabrication of the system. Basic requirements include a drilling speed of less than 30 minutes for a 5-inch hole through a 6 m ice cover. Drill components are small, lightweight and are able to be lifted by a maximum of two people. The drill has stand-alone capability for operation at remote sites with no heavy equipment and is intended to be operated by the science team. Components that allow for clean access drilling were also incorporated in the design. Fabrication, final assembly and in-house testing of the drill were completed in fall 2017. The system was first deployed in the Dry Valleys of Antarctica during the 2018-2019 field season.

Current Status

Following use of the new system in 2018-2019, IDP solicited feedback from the science team who had operated the drill. The team noted several advantages of the SLLID system over the typical Hotsy/Jiffy Drill setup, including safer operation when starting holes to free cables and a substantially improved glycol heater. The team also provided beneficial recommendations needed to make the drill more agile, including less cumbersome fittings and hoses, new module support bracketry, a pump to accommodate pressure loss through smaller hoses and fittings and an IDP functional test on ice.

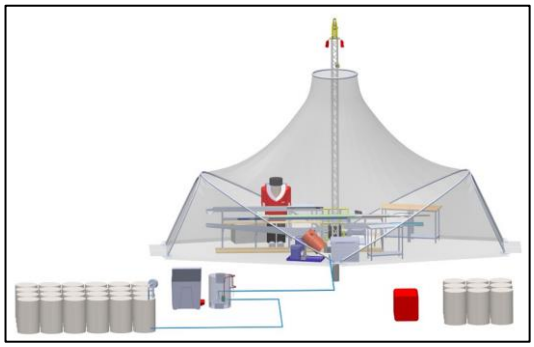
Technical Issues

A comprehensive account of the drill's performance is contained in PI feedback collected by IDP, teleconference notes and in a project/task tracking list maintained by IDP.

Plans

1. Implement modifications to optimize performance and ease of use – Contingent upon available budget and NSF approval; will be completed as community priorities dictate.
2. Develop operating procedures and other procedural documents – PY 2025 or beyond.

700 M Drill



Per the Long Range Science Plan, a mid-range drill (700 m) is desired for use in remote areas such as mountain glaciers in the Arctic. Science Requirements were completed in March 2018 for a drill originally referred to as the Foro 700 Drill, as the idea was to utilize the current sonde design of the Foro 400, 1650 and 3000 Drills. IDP subsequently completed a Conceptual Overview of the system, and a conceptual design review was held in August 2019 with members of the science community. Following the review and in response to reviewer questions, IDP completed an analysis of the quantity of drill fluid and ice core boxes needed. IDP also evaluated designing around a smaller diameter sonde such as that of the Badger-Eclipse Drill. Following further consultation with the science community on reducing the logistical burden of a new design, the IDP Science Requirements were updated based on an even smaller-diameter core than the Foro Drills or the Badger-Eclipse Drills. IDP subsequently updated the Conceptual Overview for the drill, now referred to as the 700 Drill, and held another review with science community representatives in January 2021. Following positive feedback from that review, IDP sought and gained NSF approval in March 2021 to move forward with the Detailed Design of the 700 Drill. The Detailed Design was completed and reviewed in November 2021, and NSF approval to move forward with fabrication of the drill was granted in February 2022. The final IDP Science Requirements for the 700 Drill, finalized in January 2021, identify a core diameter of 70 mm, with the drill to be designed in a way that a possible future core barrel that produces 64 mm diameter core would be a minor adaptation.

Current Status

Design drawings have largely been completed and fabrication and assembly of the drill are well underway. The system is expected to be ready in spring 2024 and may be field tested by IDP at that time, pending NSF support and approval.

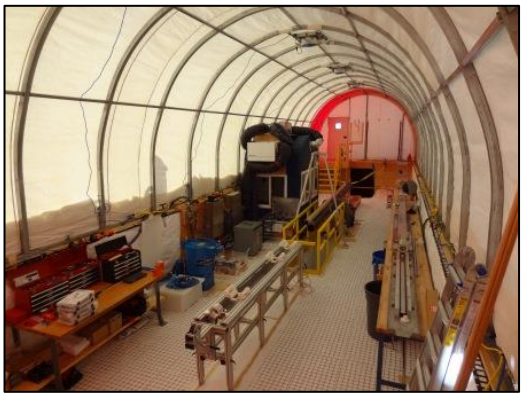
Technical Issues

Not applicable; system is not yet built. While a system of these specifications does not yet exist, the design, particularly for auxiliary sub-systems, relies heavily on proven concepts from the Foro Drill series.

Plans

1. Continue fabrication and procurement of system components – PY 2023 and PY 2024.
2. Complete fabrication of 700 m system – PY 2024.

Foro 1650 Drill



In PY 2014, IDP completed the design and fabrication of a Foro 1650 Drill (previously referred to as the Intermediate Depth Drill or IDD). With assistance from international colleagues, IDP modified the existing design of the Hans Tausen Drill and built a new system. The system was field-tested outside of Summit Station, Greenland, in spring 2014 and was used in the successful completion of the SPICEcore project near South Pole Station from 2014-2016, where a total of 1,751 m of core was collected. The drill was originally designed to reach a depth of 1,500 m. Following a post-project analysis of the SPICEcore project, IDP has set the cable limit for the current winch drum at 1,700 m capacity, which allows for drilling to approximately 1,650 m depth. This maintains adequate safety margins for the drum flanges and mitigates the risk of system damage should the level wind not spool the cable perfectly every time. While the system was originally called the Intermediate Depth Drill or IDD, the name was updated in 2019 to signify the shared sonde design of other IDP drill systems (e.g. Foro 400, Foro 3000). IDP also procured new 4-conductor cables following the SPICEcore project to mitigate operational issues experienced during the project. IDP also pursued a resign of the drill system electronics to implement beneficial sensors for temperature, pressure, and inclination. The drill system electronics design is now shared between the Foro 1650 and the Foro 3000, making use of proven, off-the-shelf parts wherever possible.

Current Status

Electronics assembly and testing was completed in 2022 in conjunction with Foro 3000 Drill system in-house testing. The Foro 1650 system was subsequently shipped to Port Hueneme, CA in November 2022 for transport to McMurdo Station on the resupply vessel. The drill is currently being stored in McMurdo in anticipation of intermediate coring at Allan Hills for the COLDEX project (year TBD).

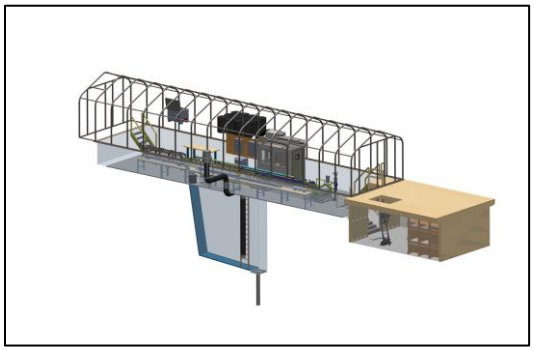
Technical Issues

Repairs and modifications were made prior to the drill's shipment to Antarctica in 2022, but field testing and use of the new electronics has not been completed.

Plans

1. Repair, maintain and upgrade the Foro 1650 Drill – Ongoing.

Foro 3000 Drill



Beginning in PY 2016, IDP began working with science community representatives and Antarctic Support Contract (ASC) personnel to conduct an analysis of using the DISC Drill for the next U.S. deep ice coring project versus using an adaptation of the Foro 1650 (formerly the Intermediate Depth Drill or IDD), now referred to as the Foro 3000 Drill. In May 2017, IDP completed a Conceptual Overview document outlining necessary changes to the Foro 1650 to enable drilling to 3000 m. In early June 2017, a Concept Review was held with IDP and several community scientists. During the remainder of PY 2017, IDP researched the adaptation of whipstock technology to allow for replicate coring on the downhill side of the borehole with the Foro 1650 and potentially other systems. IDP subsequently completed a DISC Drill vs. Foro 3000 Drill Analysis report in October 2017, which outlined the size and weight of each system, transport options for moving each system to the next deep drill site, quantity of fuel and drilling fluid needed for each system, the number of IDP personnel required for operations, the number of ASC camp staff required, and other logistical concerns. The Foro 3000 design offers a dramatic reduction in system weight when compared to the DISC Drill (120,000 lbs. versus 52,000 lbs.). The report ultimately helped inform IDP's, NSF's, and the science community's decision to move forward with fabrication of the Foro 3000 Drill.

Current Status

Final control system testing and troubleshooting was completed in PY 2022. IDP is currently conducting an inventory of all tools contained within the MECC (Mobile Expandable Container Configuration) machine shop, a 20-foot shipping container with expandable wings that was used with the DISC Drill and will be used with the Foro 3000. The drill system is now ready for issue and is slated for use on the next U.S. deep drilling project at Hercules Dome, Antarctica. The drill will likely be shipped to Antarctica in 2024 or 2025, with drilling operations currently anticipated to begin no sooner than the 2025-2026 field season.

Technical Issues

The Foro 3000 Drill is a relatively straightforward expansion of the Foro 1650 (Intermediate Depth Drill) currently in IDP inventory. The Foro 3000 Drill makes use of a majority of the Foro 1650 component designs.

Plans

1. Complete inventory of the MECC machine shop contents – PY 2023.
2. Deploy the drill to Antarctica – Tentatively anticipated for fall 2024.

BASE (Basal Access and Subglacial Exploration) Drill

Through iterative discussion between IDP and science community members, it has become clear that the drills in IDP inventory for retrieving rock cores from under 100 m and under 700 m of glacial ice are not optimal logistically for retrieving cores from under 200 m of ice, which is an important depth for understanding the first two feet of estimated sea level rise from current melting of the Greenland Ice Sheet. The IDP Long Range Science Plan 2022-2032 prioritized acquisition of a drill rig with increased agility and safety for retrieving rock core from beneath 200 m of ice. IDP worked with community scientists and IDP engineers to develop the IDP Science Requirements for the BASE (Basal Access and Subglacial Exploration) Drill, which were finalized in April 2022. With community enthusiasm and NSF support from both the Arctic and Antarctic sections, IDP was given approval in February 2022 to pursue the purchase of a 200 m rock coring rig.

Current Status

IDP worked with University of Wisconsin Purchasing Services in summer 2022 to release a Request For Proposal (RFP) solicitation to rock coring drill vendors. A vendor was selected and a purchase order was submitted in early March 2023. IDP will work closely with vendor Multi-Power Products Ltd. as they work to modify a commercial rig to meet IDP operational, polar and logistics requirements. IDP engineers will review and approve the Conceptual Design from Multi-Power, and will sign off on the final design before the start of fabrication. IDP will also conduct monthly virtual meetings with Multi-Power through fabrication or project completion. Prior to shipment of the drill rig from Kelowna, BC, Canada, IDP engineers will visit the manufacturer to ensure all requirements and specifications such as weight have been met. In conjunction with commercial fabrication of the primary rig, IDP engineers will design and fabricate auxiliary systems and components for drilling through ice, similar to equipment used with the ASIG Drill, such as an electronic pressure relief valve and equipment for processing ice chips and drilling fluid. IDP will also specify and procure all downhole tooling.

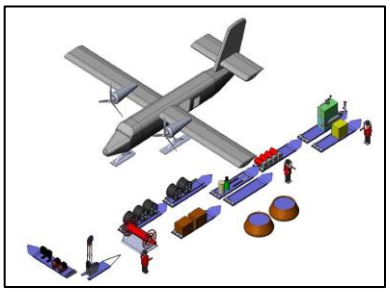
Technical Issues

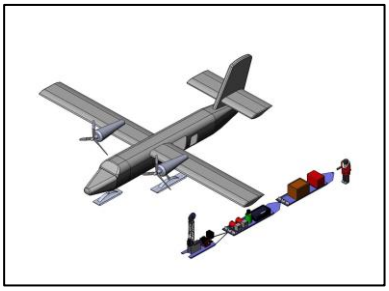
Not applicable; system is not yet built.

Plans

1. Conduct meetings, reviews and a site visit with vendor Multi-Power – PY 2023.
2. Receive commercial rock drilling rig – PY 2024.
3. Design rig modifications and auxiliary subsystems for polar coring operations – PY 2023 and PY 2024.
4. Specify and procure downhole tooling – PY 2023 and PY 2024.
5. Fabricate, assemble, and test BASE Drill equipment – PY 2024.

Scalable Hot Water Drill (ScHWD)





When an ice core is not needed, a hot water drill can provide fairly rapid access to the base of an ice sheet. Such a drill is particularly useful for drilling through an ice shelf, to enter the ocean beneath or for creating holes for the installation of scientific instruments within the ice, and for seismic studies. IDP does not at present have a deep hot water access drill. Based on science requirements established in 2014, IDP developed a conceptual design for a modular hot water drill with flexibility to create holes of various sizes to depths between 50 and 1,000 m. This design is known as the Scalable Hot Water Drill (ScHWD).

In May 2016, a joint proposal was submitted to the NSF by the University of Tennessee-Knoxville, Dartmouth College and the University of Wisconsin-Madison to fabricate the ScHWD system. That proposal was declined.

In May 2017, IDP initiated a conceptual design for a sanitation unit for use with the ScHWD, in accordance with the IDP Science Requirements developed in collaboration with science community representatives. Such a unit would allow for operation at field sites where environmental impact is of special concern. In September 2017, IDP engineers drafted a *Preliminary Evaluation of Hot Water Sanitation Unit for Application to Scalable Hot Water Drill (ScHWD)* report.

Current Status

PI Britney Schmidt at Cornell University and her colleagues were invited to submit a Round 2 Mid-scale Research Infrastructure (MSRI) proposal to the NSF for fabrication of a hot water drill. Design and fabrication of the drill may ultimately be carried out by engineers at the British Antarctic Survey (BAS), but IDP has provided the team with a letter of support outlining IDP's willingness to provide advice and design input for the project. In addition, following development and successful testing of the drill, IDP is committed to helping ensure integration of the drill with the IDP inventory for use by the broader U.S. science community, if recommended by NSF. The Cornell MSRI proposal was submitted in early May 2023. IDP has also discussed with PI Schmidt the possibility of testing drill components at the ice well located at the UW Physical Sciences Lab campus in Stoughton, WI.

Technical Issues

Not applicable; system is not yet built.

Plans

1. Provide support for the MSRI proposal/project – Contingent upon NSF approval; will be pursued as NSF and community priorities dictate.

Rapid Access Ice Drill (RAID)

The Rapid Access Ice Drill (RAID) is a University of Minnesota-Duluth (UMD) and University of California-San Diego (UCSD) project funded by the National Science Foundation. Design, fabrication, and initial test activities were completed by DOSECC Exploration Services, LLC (DES). Subsequent test activities were managed directly by UMD and were carried out by Timberline Drilling Inc. IDP did not directly participate in the design or fabrication of the RAID, however, throughout the process of designing, building, and fielding the RAID, ASIG and Winkie Drills, the RAID PIs, the DES and Timberline teams, and the IDP engineering and management team developed a synergistic relationship of benefit to all. While the drill systems differ in scope, size and capability, they share many common characteristics. In March 2015, two IDP engineers and the IDP Program Manager were able to participate in the RAID North American Test (NAT) in Utah. Additionally, IDP and DES personnel jointly supported the RAID Auger & Packer Test conducted outside of McMurdo Station in February 2016. During the brief test, IDP and DES engineers worked to successfully test both the RAID and ASIG Drill packer devices.

This collaborative relationship continued through deployment of the systems to Antarctica during the 2016-2017 field season, with each organization providing troubleshooting support to the other via phone. The RAID system completed its first Antarctic Field Trial (AFT-1) at Minna Bluff during the 2016-2017 field season. The system was successfully traversed to the Minna Bluff site, set up and operated. However, the firn-ice transition at the site proved to be over twice as deep as expected. This resulted in an insufficient length of augers onsite, and the team was unable to successfully set and seal the packer device. During the following 2017-2018 field season (AFT-2), an IDP engineer was onsite for related coring and logging projects nearby and was invited to view the RAID operations and testing. The RAID team made important progress in sealing the firn-ice transition but was ultimately unable to complete their objective to drill through 700 m of ice at the site and to collect bedrock core below, stemming from the creation of a larger amount of firn cuttings than anticipated, which overwhelmed the fluid circulation system. In early January 2019, an IDP engineer deployed to McMurdo Station to lead planned RAID maintenance efforts. The team of five set up the drill rig and completed modifications and test objectives including repair and testing of the hydraulic system, testing of the Fluid Recirculation System, documentation of operation and winterization procedures, installation and testing of new components, and deployment of a new conductor casing. In addition, the team developed procedural efficiencies to reduce rig set up and take down time.

The RAID system completed its third Antarctic Field Trial (AFT-3) at Minna Bluff during the 2019-2020 field season. UMD contracted with Timberline Drilling Inc. for primary operation of the drill system. The IDP engineer who deployed for the previous maintenance season was again onsite to provide ice drilling

expertise and general consultation. Three holes were drilled. The first and third holes were abandoned following hydro fracture events (the second of which was planned in order to measure pressure at hydro fracture). Bedrock was reached successfully in the second hole, resulting in the first rock core collection using the RAID system. While several challenges were encountered during the season, 1 m of near-basal material was retrieved as well as 3 m of bedrock core from just below the ice-bedrock interface. A summary report of AFT-3 activities and results is provided by Goodge et al. (2021, *Annals of Glaciology*).

Current Status

Following the AFT-3, the RAID project obtained supplemental funding from the NSF to carry out further upgrades and maintain system readiness for future deployment. A subset of the drilling equipment, including the Fluid Recirculation System (FRS), was returned to the U.S. for maintenance and modification. Much of this work is being carried out by Matrix Drilling Products in Lewisburg, TN. Upgrades and modifications to the FRS and related equipment include: (a) design and fabrication of a new fluid swivel and diverter; (b) design and installation of a new automation system; (c) refinement of the shaker; (d) upgrade to the glycol loop in the melting tank; (e) re-routing of hose lines and installation of sight glasses; (f) addition of a centrifugal pump for reverse-circulation drilling; (g) installation of a new door and partition between cold and warm rooms; (h) installation of new ventilation; and (i) acquisition of new firn augers. The refurbished FRS is scheduled to arrive in Port Hueneme, California by the end of 2023 for eventual staging in Antarctica. Through IDP's Cooperative Agreement and with NSF approval, an IDP engineer familiar with the RAID system is providing periodic advice, feedback and evaluation of engineering proposals. The IDP engineer also periodically visits Matrix Drilling Products to provide feedback on the modifications being made. Ultimately, the RAID team envisions drilling on the polar plateau in search of the oldest ice and bedrock samples.

Logging Winches

Following a SAB recommendation articulated in the U.S. Ice Drilling Program Long Range Science Plan, IDP purchased and modified two logging winches and made them available for use by the science community. The first, the Intermediate Depth Logging Winch (IDLW), is very portable and is used for logging shallow and intermediate depth holes to 1,750 m. This IDLW has been used during several Antarctic seasons for logging the SPICEcore borehole at South Pole. The second logging winch, the IDP Deep Logging Winch (DLW), is capable of logging to 4,000 m. The DLW was first deployed to WAIS Divide during the 2016-2017 Antarctic season for logging of the WDC06A borehole and later to Minna Bluff in support of RAID during the 2017-2018 field season. IDP engineers implemented several user-recommended upgrades for the IDLW in PY 2017, including the addition of a cable grip and means of shifting gears under load, as well as a re-design of the encoder scraper to allow it to function in both directions (i.e. descent and ascent). Repairs and upgrades for the DLW were also implemented and include the addition of LabVIEW program instructions, adjustment of the tension reading (calibration, noise, and oscillation), addition of a cable grip, troubleshooting of a knocking sound witnessed in the field, creation of a reference guide for operation of the LCI-90i display (tension settings, depth zeroing, field calibration), and determination of a method to record tension from the LCI-90i.

In PY 2014, the United States Geological Survey (USGS) gifted its 4,000 m logging winch to the University of Wisconsin-Madison for continued use by the polar logging community. The winch was used extensively for logging boreholes in both Greenland and Antarctica and was last deployed during the 2014-2015 Antarctic season for logging at WAIS Divide.

Through consultation with the borehole logging community, IDP plans to require at least one IDP operator deploy with the systems, as equipment damage has been witnessed in recent seasons when a dedicated IDP operator did not deploy. When slow speed, multi-shift logging is required, IDP will work to train a member of the science team to assist with winch operation.

IDP routinely inspects, repairs and implements minor but beneficial upgrades to the logging winches upon their return from the field.

Current Status

The IDLW has deployed for several Antarctic seasons and has undergone minor maintenance following each deployment. IDP is investigating electromagnetic interference (EMI) issues experienced with the Deep Logging Winch (see Technical Issues below). IDP periodically works with PIs to test communications and compatibility of their logging tools with the winches at the IDP facility in Madison, WI. Depending on the availability of funds and labor, IDP also plans to investigate the design or purchase of a rapid hole qualifier for borehole logging applications.

Technical Issues

An IDLW cable, owned by the IceCube project, sustained some damage during recent field seasons. In each instance, IDP engineers unspooled the cable and provided an initial assessment following each field season. IceCube had the cable repaired by a qualified vendor after the 2017-2018 season; no additional repairs were necessary after the 2018-2019 season. During the 2019-2020 season, operators noticed the strength members of the cable were frayed at 1,245 m depth. The cable and payload were safely and successfully removed from the borehole, and the winch was transferred to Minna Bluff for its next planned assignment with RAID. IDP personnel onsite at Minna Bluff removed, cut, re-spooled and re-terminated the longer section of the cable back onto the winch. A new cable was purchased for the IDLW and was spooled on the winch in May 2021.

In late 2018 and early 2019, IDP worked to implement several potential fixes for electromagnetic interference (EMI) issues witnessed with the DLW, including switching to proper VFD type cabling, and implementation of improved cable shielding and noise filtering. Some small improvements were made, but not enough to reduce the EMI to an acceptable level. IDP is revisiting this issue again in 2023 and has discovered that the physical installation of the drive is not compliant with the manufacturer's specifications for EMI shielding. A part has been ordered to install this correctly. IDP has also tested application of a filter on the communications line, which appears to reduce the amplitude of the noise considerably. If these mitigation efforts prove ineffective, IDP is also considering replacing the current AC motor with a DC motor and drive option. Initial investigations into a motor swap in 2018 identified a motor and controller that would require minimal modifications to implement.

Comprehensive lists of technical issues and general recommendations for the IDLW and the DLW are contained in the End of Season Reports. IDP has not deployed the USGS winch since it was transferred to IDP. It would require maintenance prior to any future deployments.

Plans

1. Maintain and upgrade the IDLW, the DLW and the USGS logging winch systems – Ongoing.
2. Evaluate and mitigate EMI issues with the DLW – PY 2023.
3. Investigate and design or purchase a rapid hole qualifier unit for use in RAID and other borehole logging applications – PY 2024 or beyond.

3.0 AUXILIARY EQUIPMENT

Mast Anchored, Suspended & Tensioned (MAST) Tents

In 2018, IDP worked with Fabricon LLC in Missoula, MT, to design and fabricate a tent for use with IDP's Blue Ice Drill. The tent was first deployed to Law Dome during the 2018-2019 Antarctic season and greatly improves IDP's ability to continue operations during inclement weather. In 2019, PI John Higgins from Princeton University purchased a second tent of this design for use with IDP's Foro 400 Drill at Allan Hills, Antarctica, during the 2019-2020 season. The tent was subsequently added to IDP's equipment inventory for use on future projects. IDP refers to the tents as the MAST (Mast Anchored, Suspended & Tensioned) Tents. The MAST Tents can currently be used with the BID and Foro 400 systems. The 700 Drill will also utilize a tent of this design. Minor modifications to the 4-Inch Drill would make it compatible as well.

Cargo Ramp

In 2020, IDP worked to design a ramp for safer and easier loading and unloading of cargo at polar field sites. IDP consulted with Kenn Borek Air Ltd. to ensure the design would meet flight crew requirements and be easily adapted to Twin Otter and Basler aircraft. The ramp was assembled in early 2021 in Madison and preliminary load testing was conducted. The ramp was first deployed to the field for testing with the Tunu project in NE Greenland in spring 2022 and was again used at Allan Hills during the 2022-2023 Antarctic season. Minor delamination (seen in photo at right) was repaired, and the ramp was used in Greenland with the GreenDrill project spring 2023. IDP is designing minor modifications for the two-piece ramp connection point and then plans to build a second ramp.

4.0 SYSTEM DECOMMISSIONING

In instances where substantial operational or technical issues are identified with equipment or in cases where components have aged beyond their useful life or have been replaced by newer technology in the IDP inventory, IDP seeks NSF approval to decommission and retire the equipment. Equipment is either cannibalized and useful components kept for future testing and development efforts, or the systems are disposed of per the proper channels. IDP does, however, retain certain smaller components that might be of interest for Education and Outreach work.

Items Recently Decommissioned

In September 2022, a subset of Deep Ice Sheet Coring (DISC) Drill components on loan to artist Anna McKee since 2016 were officially removed from the NSF/IDP inventory. These items are part of an art exhibit, and both UW-Madison and the National Science Foundation (NSF) agreed to permanently transfer ownership, rights, and interest in the equipment items to the Nevada Museum of Art.

Description of equipment items:

- Quantity 4, 8505D376, Core Barrel Section
- Quantity 1, 8505D959, Cutter Head, L-version
- Quantity 4, 8505C962, Cutter Inclined Blade
- Quantity 4, 8505C961, Core Dog Cage
- Quantity 4, 8505B132, Core Dog – 122mm

Items Slated for Decommissioning

IDP will soon pursue decommissioning of the DISC Drill system and its associated Replicate Coring components.

Deep Ice Sheet Coring (DISC) Drill

The Deep Ice Sheet Coring (DISC) Drill is a tilting-tower electromechanical drill designed to take 122 mm (4.8-inch) diameter ice cores to a depth of 4,000 m. The drill recovers cores up to 3.5 m long per run. The drill was utilized for six production seasons at WAIS Divide, Antarctica, from 2007-2013 and completed the deepest U.S. ice core ever drilled at 3405 m depth. Replicate coring operations were also successfully completed onsite (see Replicate Coring section).

Current Status

In spring 2020, all remaining DISC Drill components were returned to Madison. In 2017, IDP worked with science community representatives to complete a DISC Drill vs. Foro 3000 (see Foro 3000 section) analysis, to help determine which system should be used for the next deep U.S. ice drilling project at Hercules Dome, Antarctica. The community consensus was that IDP should pursue development of the Foro 3000 Drill. As much of the functionality of this drill is being replaced by the new Foro 3000 Drill, IDP initiated a discussion with the science community in spring 2021 regarding decommissioning of the DISC Drill. A survey was also distributed to the science community in August 2021 to gauge interest in future use of the drill. Following these efforts and with the approval of the NSF, IDP will soon decommission the DISC Drill and remove it from inventory. The MECC (Mobile Expandable Container Configuration) machine shop would not be decommissioned as it is planned for use with the Foro 3000 Drill.

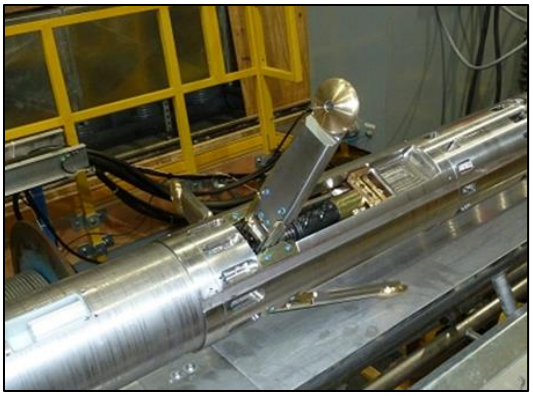
Technical Issues

The obsolescence and the resulting inability to source replacement components, particularly electronics, was an ongoing challenge throughout operation of the drill at WAIS Divide, though the project was successfully completed.

Plans

1. Pursue decommissioning and removal of the DISC Drill from inventory – PY 2023.

Replicate Coring



Collecting a single deep ice core from a given region makes verification of the validity and spatial representativeness of key results difficult. Furthermore, scientific demand for ice samples is unevenly distributed versus depth and the inventory of existing cores is being depleted in depth intervals of high scientific interest. The ability to obtain additional volumes of samples at selected intervals, termed replicate coring, addresses these concerns and adds value to the scientific return from ice coring.

The IDP replicate coring system for the DISC Drill functions by tilting and forcing the sonde against the drill hole wall with 'actuators' that push against the wall upon command from the surface. This gradually deviates the drilling out of the main borehole into the side wall and eventually into the new replicate hole. The replicate coring system was constructed in 2011. The system was tested at WAIS Divide, Antarctica, during the 2011-2012 field season. No core was obtained, but using insight from that test, IDP engineers made modifications to the sonde and carried out further testing in Madison. During the 2012-2013 field season at WAIS Divide, the system produced five azimuth and depth-controlled deviations at four target depths. A total of 285 m of excellent quality replicate ice core was recovered.

At the urging of the science community, IDP engineers undertook evaluation of a less complex replicate coring method that might be applied with the Foro 1650 and Foro 3000 Drills. A *Replicate Coring System for 98mm Electromechanical Drill – Whipstock Conceptual Documentation* report was completed, describing a more passive replicate coring approach through implementation of a whipstock device, like those used in the oil and gas industry. IDP believes this concept shows promise for successful implementation with future intermediate depth and deep drilling projects.

Current Status

The replicate coring-specific equipment of the DISC Drill system was returned to IDP in Madison in 2013. IDP will soon decommission the DISC Drill and Replicate Coring components and remove them from inventory.

Technical Issues

See DISC Drill section.

Plans

1. Pursue decommissioning and removal of the DISC Drill replicate coring components from inventory – PY 2023.

Items Previously Decommissioned

In recent years, the following equipment has been decommissioned and scrapped or cannibalized:

5.2-Inch Drill - In 2018, IDP received approval from the NSF to decommission the winch used with the 5.2-Inch Drill system. The winch was sold in an online auction in September 2020 by UW SWAP (Surplus With A Purpose). In March 2021, IDP received approval from the NSF to scrap/cannibalize the remaining components of the 5.2-Inch Drill. In June 2021, the remaining components were sold in a UW SWAP online auction.

2-Inch Drill - The 2-Inch Drill system was developed and manufactured by Glacier Data in Fairbanks, AK for rapid, near-surface core collection on the U.S. ITASE project. The maximum depth the drill reached is 42 m. A number of performance issues were noted with the drill. The system was last used in 2003. The system would have required extensive repair and/or redesign to be made into a useful tool. IDP decommissioned this system, as its function has now been replaced by the 2-inch Stampfli Drill system (see Stampfli Drill section).

Koci Drill - The Koci Drill, named after the late drill engineer Bruce Koci, was an electromechanical, single-barrel coring drill that was designed to operate in ice containing limited amounts of sand, silt and very small sedimentary rocks. The drill sustained significant damage during its last deployment in 2009-2010. Community enthusiasm is now focused on sub-glacial rock coring. To that end, IDP purchased two shallow off-the-shelf rock coring drills (see Winkie Drill section) and has modified them to drill and core clean ice, mixed media and bedrock. The Koci Drill system has been retired as its function has now been replaced by the Winkie Drills.

Miscellaneous Equipment - A number of other stand-alone components, various tooling and support equipment have also been decommissioned.

- A 1000-gallon tank used at WAIS Divide for drill fluid storage and transport with the DISC Drill system was re-purposed in 2019 for fuel transport at a McMurdo Station airfield.
- Original RAM Drill hose reel and related components
- P05 cable spooler – Title transferred to the NSF-sponsored IceCube program at the University of Wisconsin-Madison, NSF Award #1719277
- Blue A-frame double girder gantry crane
- Qty. 3 Dell desktop computers
- DISC Drill control room (destroyed by a storm in McMurdo Station)
- Pengo cable tensioner

5.0 DRILLING FLUID

With the phase-out and banning of the production of ozone-depleting substances such as chlorofluorocarbons, a good substitute for the two-part Isopar K and HCFC 141b drilling fluid used at WAIS Divide and on several European drilling projects was a necessity for the continuation of intermediate and deep coring projects. A few possible substitutes were identified: n-butyl acetate, dimethyl siloxane (silicone) oil, and an ESTISOL-COASOL mixture. Butyl acetate has been used by both the U.S. and the Japanese programs in the past, and is currently being used by the Chinese program, but because of the health risks associated with the chemical, IDP and the U.S. science community have decided not to use this fluid. ESTISOL-COASOL is routinely used by Danish drill projects in Greenland. The mixture has a disadvantage in that ESTISOL 240, a coconut extract, could compromise biological experiments because it is a nutrient. Silicone oils have been suggested as a possible ice drilling fluid but have not been used by the U.S. community, as the oils are difficult to remove from surfaces, are expensive and may not be available in the required quantity. Both the silicone oils and the ESTISOL-COASOL mixture also have the major disadvantage of being significantly more viscous at low temperatures than fluids successfully used in the past. In 2013 and 2014, a new drilling fluid emerged called ESTISOL 140, made by a company in Denmark. ESTISOL 140 is dense enough to balance the borehole without a densifier and also has only a modest increase in viscosity at temperatures as low as -55°C. ESTISOL 140 was used for testing of the Foro 1650 (IDD) in Greenland as well as for the SPICEcore drilling project completed at the South Pole Station. It is also slated to be used for proposed COLDEX intermediate depth drilling and planned drilling at Hercules Dome. ESTISOL 140 is also used with the RAID system. IDP uses Isopar K, without the addition of a densifier, for ASIG Drill and Winkie Drill deployments, as there has been no requirement that the holes need to remain open (i.e. hydrostatically balanced).

After IDP equipment operators experienced mild headaches, minor lung and throat irritation, skin irritation and other side effects when working with the ESTISOL 140 in Greenland, IDP and SSEC Quality Assurance & Safety personnel initiated an investigation into the fluid's composition. IDP/SSEC worked with the manufacturer of the fluid, Esti Chem A/S in Denmark, on acquiring the latest Safety Data Sheet (SDS). The main ingredient in ESTISOL 140 is 2-ethylhexyl acetate, and evidence based on review of the Safety Data Sheet (SDS) suggests that this fluid has low toxicity. In addition, available literature on the fluid was reviewed by a UW Safety Chemical Hygiene Officer (CHO) and a University Health Services Industrial Hygienist (UHS IH). Additional improvements to Personal Protective Equipment (PPE) were recommended and implemented through the purchase of protective eyewear and new gloves and aprons to be worn over the drilling suits. These efforts primarily focused on reducing the amount of fluid that ends up on the equipment operators' work suits. Following the Greenland field test in 2014, IDP

also made substantial modifications to the Foro 1650 ventilation system, including the addition of active ventilation components for the driller control room to ensure continuous air flow and to induce an air flow pattern that pulls room air down and away from the occupants' breathing area and workspace. The system uses an energy recovery ventilator (ERV) and two inline duct heaters to circulate enough air to replace the volume of air inside the control room every 67 seconds (53 times/hour). An Ion Science PhoCheck Tiger air monitoring sensor that had been shown to work down to -40°C was identified and procured for use with the ESTISOL 140.

Following improvements to the drill structure's ventilation system and to the available PPE, side effects from use of the fluid abated a bit but were still present during operations at the South Pole. IDP continued its discussions with UW Health & Safety personnel, the fluid manufacturer, and the equipment operators, but all sources indicate that while the fluid is an irritant, it is not toxic. A good replacement has not yet been identified, however, IDP continues to discuss this issue with its international colleagues.

With deep (i.e. >1,000 m) drilling in very cold regions in East Antarctica likely in the future, IDP will continue to work with its international colleagues on cold temperature drilling fluids.

Current Status

While there are currently available drilling fluids, none are ideal for drilling at very cold sites. Several papers have been published about potential fluids and can be found on IDP's Icedrill.org website at: https://icedrill.org/library/drilling-fluids. While use of ESTISOL 140 is advantageous for maintaining the borehole, the fluid's strong odor and tendency to readily vaporize in warmer areas, such as the drilling control room and facilities used to dry driller clothing, will lead IDP to continue looking for alternative fluids. IDP remains in discussion with its international colleagues on this matter. In 2022, a representative from Battelle who is familiar with polar drilling operations, extended an offer to research potential drilling fluids. IDP engineers provided Battelle with information on desired specifications and previous fluids used to aid in Battelle's research.

Technical Issues

Drilling fluids should, among other things, be non-hazardous, have low viscosity at very low temperatures, and not inhibit or complicate biological studies.

Plans

1. Continue to work with U.S. and international colleagues and with Battelle to investigate alternative drilling fluids – Ongoing.
2. Provide proper Personal Protective Equipment (PPE) for drill system deployments and operator safety – Ongoing.

6.0 RESPONSES TO TECHNOLOGY PRIORITIES FROM THE LONG RANGE SCIENCE PLAN 2023-2033

IDP notes the following guiding principles for development of drilling technology expressed in the U.S. Ice Drilling Program Long Range Science Plan 2023-2033:

- Designs require that the supporting logistical needs do not impede execution of the science.
- While developing the science requirements, logistical issues such as weight, size, costs, and time for development must be defined and transparent at the initial stages. Scientists and engineers working together through IDP must assess the impact of changes as they arise during the development process.
- Drills, major drilling subsystems, and accompanying technology must be developed with consideration of potential use in future projects. The drills and technology must be versatile and well documented so that they can be used, maintained, and repaired by other engineers.
- Major drilling systems (e.g., sondes, winches, controls and other major electronics systems) should be fungible to the maximum extent possible. Major component interchangeability and logistical agility should be essential deliverables for all new drilling technology projects.
- Engineering design teams must include individuals with field experience using appropriate ice drilling technology and/or other relevant field experience.
- Increased medium and heavy scientific traversing infrastructure are urgently needed to improve access to many scientifically important regions of the Antarctic and Greenland Ice Sheets.

These principles have been and are being adhered to during IDP's development and maintenance/upgrade projects – most recently in the modification and upgrade of the Winkie 1 Drill system, building of the Winkie 2 Drill system, fabrication of the Foro 3000 Drill, design and fabrication of the 700 Drill and in iterations between IDP and community scientists in establishing new or updated Science Requirements for a variety of systems. IDP also works closely with both the Arctic and Antarctic logistics providers to ensure that ease in transport of IDP equipment and logistical support of IDP projects is achievable. Through IDP’s collaboration with the science community and IDP’s Science Advisory Board, IDP ensures that the drilling systems and technologies it develops will directly support the priorities outlined by the NSF and by the community. IDP has on staff several project managers, engineers and field support personnel with extensive field experience. This allows for the pursuit of practical and polar-ready designs and equipment.

Recommended technology investments in the U.S. Ice Drilling Program Long Range Science Plan 2023-2033

The IDP Science Advisory Board and the broader polar science community have identified high-priority investments in drilling technology that are needed to achieve the science goals planned for the next decade (see pages 4-5). IDP works to plan its investments in technology within the time frames listed in

the Long Range Science Plan, however, NSF ultimately determines the timelines for such investments. IDP's annual scope of work and schedule are influenced by several factors, including:

- Timing of funded and planned proposals
- Definition of science requirements
- State of the technology to meet the requirements
- Availability of personnel
- Availability of funding

The following are the recommended technology investments, as listed in the U.S. Ice Drilling Program Long Range Science Plan 2023-2033, together with the corresponding IDP action taken or to be taken.

Priority 1 (needed this year):

1. *Maintain and upgrade agile equipment in inventory, including: Hand Augers, Sidewinders, the Foro 400 Drill, the 4" Electromechanical Drills, the 3" Electrothermal Drill, the 3.25" Eclipse Drills, the Stampfli Drill, Logging Winches, the Small Hot Water Drills, the Blue Ice Drill, the Prairie Dog, the Agile Sub-Ice Geological Drill (ASIG), the Rapid Air Movement Drill (RAM) Drill, and the Winkie Drills.*

   IDP action: These systems will be maintained and upgraded as a high priority. This is a major focus of this Plan – see related content for each drill system in section 2.0 above as well as in other points of this section below.

2. *Adapt the commercial BASE Drill rig for retrieving rock core from beneath 200 m of ice (BASE Drill).*

   IDP action: IDP awarded a build contract in March 2023 to Multi-Power Products Ltd. for the fabrication of a rock drilling rig capable of drilling to 200 m depth. IDP expects to receive the rig in November 2023. In PY 2023 and PY 2024, IDP plans to design and fabricate a rig platform, a circulation system, an electronic pressure relief valve system, and procure drill rod and downhole tooling.

3. *Develop the Conceptual Design for collecting a small amount (chips to 10 cm) of sub-ice rock/mixed media/mud in a frozen regime using an intermediate or deep ice core drill in a fluid filled hole, for example, with the Foro 3000 Drill.*

   IDP action: IDP plans to iterate with community scientists on formulation of applicable Science Requirements. IDP will then use that information to develop a Conceptual Design document for review by members of the science community. This document may be initiated in PY 2024, but may be delayed due to IDP's support of a backlog of field projects following two years of COVID-related field work delays.

4. *Finish construction of the 700 Drill.*

   IDP action: Hardware and software designs are nearly complete and procurement and receipt of components is well under way. Assembly of major subsystems such as the winch and sonde are also in progress. IDP anticipates the drill will be ready for field testing or for the first, untested field use on a science project in spring 2024.

5. *Develop the updated IDP Conceptual Design and Detailed Design for a clean Scalable Hot Water Drill that minimizes its logistical footprint including fuel supply.*

   IDP action: Further work on clean Scalable Hot Water Drill actions are pending NSF approval.

6. *Investigate a lighter weight source of power to replace generators for drilling systems, in order to ease demand on logistics, including renewable energy.*

   IDP action: Two of the drills in IDP inventory currently have solar operation capability, including the Badger-Eclipse Drills and the Stampfli Drill. It is possible that this technology could be adapted to run other equipment in the IDP inventory. IDP conducted an initial analysis of lighter weight power sources and generator alternatives as part of the 700 Drill Detailed Design. IDP plans to conduct research into current technology in either PY 2023 or PY 2024. In fall 2023, a short-term student project at IDP-Dartmouth will also focus on preliminary research into current technology.

7. *Finish the Conceptual Design and begin the Detailed Design for replicate coring for the Foro 3000 Drill.*

   IDP action: In 2018, IDP completed an initial analysis of replicate coring methods suitable for an electromechanical drill. Summary of the research and a description of use of a whipstock device were outlined in a report titled *Replicate Coring System for 98mm Electromechanical Drill – Whipstock Conceptual Documentation.* As staffing allows, IDP would revisit that paper and flesh out details for how to implement these concepts with the Foro 3000 Drill. The Detailed Design would be reviewed by science community members and the NSF prior to any equipment fabrication taking place.

8. *Develop the Detailed Design for a clean hot water basal ice coring mechanism for a hot water drill.*

   IDP action: In 2020, the University of Nebraska-Lincoln (UNL), under a subaward from IDP-Dartmouth, developed the Conceptual Design for such a hot water coring sonde. The Conceptual Design was reviewed, and several improvements were identified. UNL intends to pursue the Detailed Design and construction of the sonde through a future NSF proposal they will submit.

9. *Conduct an engineering feasibility study to evaluate and recommend longer-term drilling approaches to retrieve ice with good core quality down to 400 m depth in blue ice areas. Possible approaches include: replicate coring for Foro 400, large-diameter thermal drill (diameter < 241 mm TBD), complete re-design of the BID, and others. For each approach, estimate the anticipated improvement in core quality, impacts on associated logistics, and the time required to complete the resulting drill. Identify the most promising approach that could be implemented not later than 2028, but earlier if possible.*

   IDP action: Through an iterative process with IDP and community scientists, IDP engineers will evaluate a number of known and promising technologies and approaches and will outline the pros and cons of each. A report will be drafted to help inform future development of the appropriate technology.

10. *Resolve Deep Logging Winch electrical noise issues.*

    IDP action: In response to recommendations noted by IDP equipment operators in the 2016-2017 WAIS Divide End-of-Season Report and the 2017-2018 Minna Bluff End-of-Season Report, IDP initiated an investigation into the electrical noise issues experienced when borehole logging tools are attached to the IDP Deep Logging Winch. IDP engineers drafted a Deep Logging Winch EMI Mitigation Report, outlining the background of the situation, previously implemented mitigation efforts, further testing required and initial estimates for additional modifications. IDP implemented and tested several minor changes to the equipment but did not observe any noticeable improvement. The IDP Electrical Engineer hired in 2022 is currently taking a fresh look at the EMI issues and is working to properly install the winch drive, as the current physical installation of the drive is not compliant with the manufacturer's specifications for EMI shielding. A noise filter tested on the communications line is also showing promise for reducing the noise considerably.

Priority 2 (needed in the next 3 years):

11. *Build a Scalable Hot Water Access drill for creating access holes in ice that has modular capability for clean access.*

    IDP action: PI Britney Schmidt at Cornell University and her colleagues were invited to submit a Round 2 Mid-scale Research Infrastructure (MSRI) proposal to the NSF for fabrication of a hot water drill. Design and fabrication of the drill may ultimately be carried out by engineers at the British Antarctic Survey (BAS), but IDP has provided the team with a letter of support outlining IDP's willingness to provide advice and design input for the project. In addition, following development and successful testing of the drill, IDP is committed to helping ensure integration of the drill with the IDP inventory for use by the broader U.S. science community, if recommended by NSF. The Cornell MSRI proposal was submitted in early May 2023. IDP has also

discussed with PI Schmidt the possibility of testing drill components at the ice well located at the UW Physical Sciences Lab campus in Stoughton, WI.

12. *Identify procurement source and cost for potential purchase of a rapid hole qualifier (temperature and caliper) for field scientist use in borehole logging applications.*

    IDP action: IDP does not currently maintain any borehole logging tools within its inventory. Investigation into the design or purchase of a hole qualifying tool for use with IDP drill systems would be pursued in conjunction with IDP's maintenance and upgrade of the logging winches in inventory. IDP's international colleagues in both Denmark and Australia have designs for rapid qualifiers that they are willing to share with IDP.

13. *Establish the IDP Science Requirements for identification and planning of borehole maintenance and fluid maintenance over time, including removing (or lowering) drilling fluid from a borehole (for example for freezing in a sensor).*

    IDP action: IDP will iterate with community scientists on formulation of the applicable Science Requirements.

14. *Create a second, updated Blue Ice Drill.*

    IDP action: Due to increased interest in use of the Blue Ice Drill (BID), IDP initiated fabrication of a second BID-Deep system in late PY 2016 and made continued progress throughout PY 2017. A few additional equipment purchases were made in early PY 2018, but the project was subsequently put on hold to redirect personnel and funds to other higher priority systems. Recent requests to use the BID have been accommodated with the existing system. IDP is discussing with the science community several approaches for drilling good quality ice core in blue ice, which may include design and fabrication of a modified BID or the development of a large-diameter thermal drill. Further discussion with the science community and the NSF will determine the nature of a possible second, updated Blue Ice Drill.

15. *Evaluate options for new drilling fluids for future ice and rock drilling projects.*

    IDP action: Discussion on drilling fluid research and use is regularly included at the IDP Technical Assistance Board (TAB) Meetings and at other drilling community meetings. Discussion also occurred at the 8th International Ice Drill Symposium in fall 2019 in Copenhagen, Denmark. Consideration of fluid cost, availability, conductivity, viscosity, etc. remains part of the ongoing conversation. Related research papers are available at https://icedrill.org/library/drilling-fluids. In 2022, a representative from Battelle who is familiar with polar drilling operations, extended an offer to research potential drilling fluids. IDP engineers provided Battelle with information on desired specifications and previous fluids used to aid in Battelle's research.

Priority 3 (needed in 3 to 5 years):

16. *Continue investigation and modifications of the RAM 2 Drill to achieve the 100 m depth goal reflected in the system Science Requirements.*

    IDP action: Following IDP testing of the new RAM 2 Drill components at Raven Camp, Greenland in summer 2018 and at WAIS Divide during the 2019-2020 field season, several component modifications were made. During an abbreviated 2022-2023 Antarctic season, the RAM 2 sonde, winch and tower were used with the larger compressors from the original RAM Drill for drilling near WAIS Divide Camp. Even with the large compressors, the drill was unable to reach the 80-90 m depth range achieved by the original RAM Drill. IDP intends to review a range of additional options. These will include small engine options that can provide higher air flow and a review of vacuum as an alternative to compressed air. In the near term, the RAM 2 components will continue to be used with the original RAM air compressors to complete the GHOST project on Thwaites Glacier in Antarctica.

17. *Establish the Science Requirements for retrieving sidewall ice samples at specific depths in an existing borehole without using an ice coring drill.*

    IDP action: IDP will iterate with community scientists on formulation of the applicable Science Requirements.

18. *Draft a feasibility paper outlining the potential for using shallow drill fluid columns for ice coring.*

    IDP action: IDP discussed the practice of drilling with shallow drill fluid columns during the 8th International Ice Drill Symposium as well as at the 2019 IDP Technical Assistance Board Meeting. IDP's international colleagues note limited success in practice and have provided IDP with field data. There are limits to benefits of engineering analysis given the wide range of variables and unknowns with ice conditions. Actual field testing is a logical next step.

7.0 FIELD SUPPORT OF SCIENCE PROJECTS

IDP-supported field work was largely postponed by the COVID-19 pandemic between March 2020 and April 2022. During the pandemic, IDP remained active in planning future field work with the NSF, PIs, ASC and Battelle ARO. IDP continues to provide researchers with Letter of Support/Scope of Work (LOS/SOW) documents for inclusion in their proposals to the NSF. IDP field support generally consists of assisting PIs with planning field activities, providing equipment for the projects, and providing a field crew for the operation of the equipment. In early 2022, field project planning and execution ramped back up and IDP is working to support a backlog of project postponed by COVID as well as newly-funded projects.

Field projects are typically one to three seasons long and are usually defined only a year or two prior to their execution. Typically, during a fiscal/program year, IDP might have 8-12 projects being actively supported with half of them in the field and the other half in the planning/preparation phase of the project. The backlog of field projects created by COVID-19 delays may require the deployment of additional personnel over the next several years. A summary of planned and potential equipment assignments can be found in Appendix 1. Additional detail on completed, current and upcoming field projects supported by IDP can be found in the Fieldwork section of the IDP website, located at: https://icedrill.org/fieldwork.

8.0 EXPENDITURES

The Ice Drilling Program currently operates under a 5-year Cooperative Agreement with the NSF. The prime award is to Dartmouth College, with subawards to the University of New Hampshire and the University of Wisconsin. Annual budgets are estimated based on the proposal budgets tentatively approved by the NSF but are subject to annual negotiation. Final determination of the IDP annual budgets will determine how much funding is available for equipment development and maintenance and upgrade of ice drilling and related equipment associated with the science outlined in the U.S. Ice Drilling Program Long Range Science Plan 2023-2033. Appendix 2 outlines current development and maintenance and upgrade expenditures for PY 2023 (November 1, 2022 – October 31, 2023).

Once equipment is ready for use on science projects, routine maintenance and incremental upgrades are required as the equipment becomes damaged or worn or modifications are identified that will improve performance. Annual expenditures for this maintenance and upgrade function have increased each year, as the number of drills in the IDP inventory increases. IDP is cognizant of this issue and continues to decommission equipment that is no longer desired by the science community.

Annual expenditures for operations supporting field projects vary depending on the science projects funded by the NSF. Preparation and shipping of equipment for very simple projects typically only require IDP expenditures of $3,000-$5,000. Large, multi-year projects have historically required IDP expenditures of $400,000-500,000 per field season. Labor for deploying in-house staff and for an agreed

upon number of part-time equipment operators is included under the IDP base subaward funding. In PY 2024 and PY 2025, supplemental funding is anticipated to help support a backlog of field projects and the deployment of additional equipment operators.

9.0 CUTTING EDGE TECHNOLOGY NEEDS

IDP is committed to continuous improvement and streamlining of operations regarding the design of new equipment, the maintenance and upgrade of existing equipment and the operation of drilling and logging equipment in the field. IDP routinely works to consider and evaluate cutting edge technologies that could minimize downtime and reduce component and system weights and footprints, fuel consumption and logistical requirements. IDP engineers have identified the following potential technology needs (in no priority order), that could have positive impacts on NSF-funded science programs, if pursued.

1. Ice Well – A shallow, prototype ice well was established by IDP engineers near Madison, WI. A larger, deeper and easily accessible ice well would prove extremely valuable during the design and testing of equipment. This would help ensure designs are vetted and field deployments are successful.
2. Cold Room – Similar to an ice well, a cold room or freezer lab would prove invaluable for component testing. IDP occasionally rents a small, portable freezer unit when necessary. In addition, the use of clear ice blocks combined with a high-speed camera would allow IDP to clearly evaluate cutter head geometry as well as any flexion in the drill barrels and heads. The addition of strain gauges and/or accelerometers with data acquisition would provide for even more comprehensive testing.
3. Composites – Further investigation and testing of the feasibility of using composites, such as fiberglass and carbon fiber, for chips chambers, core barrels, or structural components could expand design options and reduce drill system weight and cost.
4. Drill Fluids – Lab and field testing of potential new drilling fluid options could simplify drill system design (e.g. ventilation) and the need for PPE.
5. Battery Power – Research into the application of onboard battery power for downhole equipment could reduce system complexity, cable diameter and weight of associated surface infrastructure. Battery powered augers could also be explored. IDP briefly considered battery power to reduce weight and simplify implementation of the ASIG Drill chips bailer, but implementation falls outside of the current scope of system maintenance.
6. Wireless – Research into the feasibility of wireless communication between the surface and drill sondes could reduce system complexity.
7. Drill Tents – Development/procurement of a more robust version of the Mountain Hardwear tents for use with the Eclipse Drills could reduce tent maintenance required after drilling

seasons. IDP is currently looking into this based on information from international colleagues on tent options that have worked well for their programs.

8. Automation - A large portion of required cargo for field campaigns is to support personnel in the field. Automation of certain drill system functions could reduce the number of operators required and thus dramatically reduce required field logistics.
9. Packaging – Research into lightweight packaging technologies appropriate for IDP applications could reduce system weight and improve portability.
10. Power Sources – Research into the following areas:
    - Engines – Research into the latest-technology engines that are lightweight and efficient with potential applications as prime movers for hydraulic and compressed air systems could reduce system weights and footprints.
    - Solar Power Generators – This technology is advancing quickly, and research could prove very useful for reducing logistical footprints, fuel consumption and emissions. While the current power output does not quite meet the requirements of the larger drills in IDP inventory, this lightweight option should be further evaluated for the dramatic reduction in fuel it could provide.
    - Hybrid Power Sources – The drilling process inherently requires uneven power loads i.e. high loads during tripping to the surface but low loads during descent/coring. A hybrid power source utilizing a battery to meet power spikes could reduce the overall size of a generator and therefore fuel requirements and weight. This infrastructure also easily lends itself to renewable energy sources such as wind or solar for energy production.
11. SLLID – Further design and modifications are required to optimize the Sediment Laden Lake Ice Drill to make it more portable.
12. Microturbines – Research into microturbine generators as heat and electrical sources for hot water drilling operations could provide lightweight options when compared to traditional diesel generators.
13. Thermal Regulation – Research into the latest technology for implementation of thermal regulation for the IDP Thermal Drill could reduce burnout of heat rings and could also reduce the need for IDP operators to deploy with the system, thereby reducing field project logistics.
14. Rapid Access – Research into lightweight, mechanical rapid access drilling leveraging the latest technology developed by the British Antarctic Survey could prove beneficial for the U.S. science community.
15. Lasers – The use of lasers for extracting ice samples from borehole walls is being explored by the community. This technology could be implemented for coring, replicate coring, directional drilling, etc. in the future.
16. Shallow Wet Drilling – Procuring wet drilling components from Icefield Instruments for the IDP Eclipse Drills or designing and fabricating wet drilling components for the IDP Foro 400 Drill could allow for the collection of higher quality cores at greater depths (e.g. 300-400 m).

10.0 ACRONYMS

AFT	Antarctic Field Trial
ARA	Askaryan Radio Array
ASC	Antarctic Support Contract (Antarctic logistics provider)
ASIG	Agile Sub-Ice Geological (Drill)
BID	Blue Ice Drill
BFC	Berg Field Center, located in McMurdo Station, Antarctica
CHO	Chemical Hygiene Officer
CSM	Colorado School of Mines
DES	DOSECC Exploration Services, LLC
DISC	Deep Ice Sheet Coring (Drill)
DLW	Deep Logging Winch
EFC	Environmental Fracking Compound
EMI	Electromagnetic Interference
ERV	Energy Recovery Ventilator
HCFC	Hydrochlorofluorocarbon
IDD	Intermediate Depth Drill
IDDO	Ice Drilling Design and Operations (now IDP-WI)
IDLW	Intermediate Depth Logging Winch
IDP	Ice Drilling Program
IDP-WI	Ice Drilling Program at the University of Wisconsin-Madison (formerly IDDO)
IH	Industrial Hygienist
ITASE	International Trans-Antarctic Scientific Expedition
MECC	Mobile Expandable Container Configuration
NSF	National Science Foundation
NSF-ICF	National Science Foundation Ice Core Facility
PI	Principal Investigator
PICO	Polar Ice Coring Office
PPE	Personal Protective Equipment
PY	Program Year (formerly ‘FFY’ for Federal Fiscal Year; term used after Nov. 1, 2014 to signify that the IDP fiscal year does not sync with the Federal Fiscal Year)
RAID	Rapid Access Ice Drill (University of Minnesota-Duluth and University of California-San Diego)
RAM	Rapid Air Movement (Drill)
SAB	Science Advisory Board
ScHWD	Scalable Hot Water Drill
SDS	Safety Data Sheet
SHWD	Small Hot Water Drill
SIPRE	Snow, Ice and Permafrost Research Establishment
SLLID	Sediment Laden Lake Ice Drill
SPICEcore	South Pole Ice Coring Project

SSEC	Space Science and Engineering Center
SWAP	UW Surplus With A Purpose (program)
TAB	Technical Assistance Board
USGS	United States Geological Survey
WAIS	West Antarctic Ice Sheet

11.0 REFERENCES

Goodge JW, Severinghaus JP, Johnson J, Tosi D, Bay R (2021). Deep ice drilling, bedrock coring and dust logging with the Rapid Access Ice Drill (RAID) at Minna Bluff, Antarctica. Annals of Glaciology, 62, 324-339, https://doi.org/10.1017/aog.2021.13.

Appendix 1 – Long Range Project Schedule

View this table at: https://icedrill.org/equipment/availability

Legend:

Planned Field Project
Proposed Field Project
System In Development
Planned Maintenance/Upgrade (Equipment Not Available)
System Available
System Not Available

	PY 2023	PY 2024		PY 2025		PY 2026		PY 2027		PY 2028
Equipment	**2023 Arctic**	**2023-2024 Antarctic**	**2024 Arctic**	**2024-2025 Antarctic**	**2025 Arctic**	**2025-2026 Antarctic**	**2026 Arctic**	**2026-2027 Antarctic**	**2027 Arctic**	**2027-2028 Antarctic**
4-Inch Drill 1										
4-Inch Drill 2										
Agile Sub-Ice Geologic Drill										
Badger-Eclipse 1 - Standard [1]										
Badger-Eclipse 2 - Traversing [1]										
Badger-Eclipse 3	TBD									
BASE Drill										
Blue Ice Drill/Blue Ice Drill-Deep 1										
Blue Ice Drill/Blue Ice Drill-Deep 2	TBD									
Chipmunk Drill										
DISC Drill	Planned for decommissioning and removal from inventory.									
DISC – Replicate Coring System	Planned for decommissioning and removal from inventory.									
Drill Fluid Development	TBD									
Foro Drill - 400 m										
700 m Drill										
Foro 1650 Drill (Intermediate Depth Drill)										
Foro Drill - 3000 m				Shipping to ANT						
Hot Water Corer	TBD									
Logging Tower										
Logging Winch - IDP Intermediate Depth										
Logging Winch - IDP Deep										
Logging Winch - USGS										
Prairie Dog										
Pressure Vessel										
Rapid Hole Qualifier	TBD									
RAM (Rapid Air Movement) 2 Drill										
Scalable Hot Water Drill	TBD									
Sediment Laden Lake Ice Drill										
Small Hot Water Drill 1										
Small Hot Water Drill 2										
Stampfli 2-Inch Drill										
Thermal Drill 1										
Thermal Drill 2										
Winkie Drill 1										
Winkie Drill 2										
Sidewinder (5 available)	2 funded		1funded	1funded	1funded		1funded			
Hand Auger, 3" IDDO (8 in inventory)	2 funded	1proposed	1funded	1funded; 1proposed	1funded	1funded; 1proposed	1funded			
Hand Auger, 4" IDDO (3 in inventory)	1funded									
Hand Auger, SIPRE (6 in inventory)	1funded		1funded							
Hand Auger, 9 cm Kovacs Mark II (2 in inventory)										
Hand Auger, 14 cm Kovacs Mark V (1 in inventory)										

[1] Solar/wind power capabilities available.

Appendix 2 – PY 2023 Estimated Budgets for Development and Maintenance & Upgrade Work

Development or Maintenance & Upgrade Project	PY 2023 [2]
700 m Drill	978,000
4-Inch Drill	0
ASIG Drill	43,495
Badger-Eclipse Drill	39,331
BASE Drill (Basal Access and Subglacial Exploration) [1]	192,000
Blue Ice Drill	94,986
Drilling Fluid Research	0
Environmental Impact Reduction Projects	24,500
Foro 400 Drill	91,290
Foro 1650 Drill	25,937
Foro 3000 Drill	37,000
Hand Augers	83,102
Logging Winches	3,320
RAM Drill Upgrades	24,592
Stampfli Drill	24,551
Thermal Drill	15,890
Winkie Drill	52,505
TOTAL COSTS	**1,730,500**

[1] Commercial rig ordered in March 2023; IDP to design and fabricate auxiliary subsystems in PY 2023 (and PY 2024) for drilling in the polar regions.
[2] Budgets reflect baseline PY 2023 project budgets set in November 2022; subsequent change requests are not reflected.

Equipment Development	
Maintenance & Upgrade	