Ice Drilling Program

LONG RANGE DRILLING TECHNOLOGY PLAN




June 30, 2020

Sponsor: National Science Foundation

Contents

Cover photos: (upper left) Foro 3000 assembly at the IDP warehouse in Madison, WI (photo credit: Jay Johnson); (upper right) Borehole logging at South Pole Station with the IDP Intermediate Depth Logging Winch (photo credit: Jim Koehler); (lower right) Blue Ice Drilling at Allan Hills, Antarctica (photo credit: Ian van Coller); (lower left) Winkie Drilling on Thwaites Glacier (photo credit: Brent Goehring).

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 drills and technologies needed to successfully implement the Science Plan. Much of the equipment mentioned is already being developed or maintained by IDP as part of its inventory of NSF equipment. This plan also describes the latest development projects at IDP. Finally, this plan briefly addresses the funding allocated for its implementation.

Highlights/Changes for this 2020-2030 Update:

General highlights and changes:

- Expanded list of Recommended Technology Investments as proposed by the IDP Science Advisory Board and other community members. Many of the proposed investments focus on defining requirements for desired technology to meet emerging science goals. IDP-WI anticipates having increased capacity for this type of work in the near-term, with field work in both the Arctic and Antarctic postponed due to COVID-19.

Additions:

- Added plans to pursue formulation of a number of IDP Science Requirements documents for new technologies.
- Plan to purchase additional ASIG Drill components to complete fulfillment of the original system science requirements.
- Plan to discuss an approach to evaluating the condition of boreholes, fluid levels over time, and bailing or removing fluid from boreholes.

Deletions:

- None.

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 2020-2030.

Recommended Technology Investments

The following investments in drilling technologies are expected to be needed to accomplish science goals envisioned for the next decade. Investments prioritized by time, from discussions of the IDP Science Advisory Board, include:

Priority 1 (needed this year):

- Maintain and upgrade agile equipment in inventory, including: Hand Augers, Sidewinders, the 4” Electromechanical Drills, the 3” Electrothermal Drill, the 3.25” Badger-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 Drill.

- Implement Foro 400 Drill system modifications following the recent first deployment of the system.
- Finish fabrication of a second ice-ready Winkie Drill.
- Develop the IDP Conceptual Design for clean sample acquisition from a hot water ice coring drill for sediment-laden basal ice samples.
- Develop the IDP Conceptual Design for retrieving rock, basal ice, sediment, and water from West Antarctic (e.g., Mt. Resnik) and East Antarctic sites (e.g., within Wilkes Basin) (consider suite of existing or new drills, e.g. large hole with hot water drill, then deploy sediment core or rock core, retrieve basal ice)
- Develop IDP Science Requirements for collecting a small amount (e.g. chips or up to 10 cm) of sub-ice rock using a lightweight tethered ice core drill, for example the Eclipse and Stampfli drills.
- Develop IDP Science Requirements for collecting a small amount (e.g. less than 1 meter) of sub-ice rock using an intermediate or deep ice core drill in a fluid-filled hole, for example the Foro 3000 drill.
- Develop IDP Engineering Design for the 700 m drill.
- Develop the updated IDP Conceptual Design and Engineering Design for a clean Scalable Hot Water drill that minimizes its logistical footprint including fuel supply.
- Purchase remaining ASIG Drill components to allow for depth capability of 700 m.
- Establish the IDP Science Requirements for replicate coring for the Foro 1650 and Foro 3000 drill.
- Establish the IDP Science Requirements for identification and planning of borehole maintenance and fluid control over time.
- Establish the IDP Science Requirements for removing (or lowering) drilling fluid from a borehole (for example for freezing in a sensor).
- Evaluate options for new drilling fluids for Herc Dome and other ice and rock drilling projects
- Investigate a lighter weight source of power to replace generators for drilling systems, in order to ease demand on logistics, including renewable energy.

Priority 2 (needed within the next three years):

- Continue investigation and modifications of the RAM 2 Drill to achieve the 100 m depth goal reflected in the system Science Requirements.
- Finish building a stand-alone Foro 3000 Drill as per the IDP Science Requirements.
- Acquire components to extend the depth of the Foro 1650 (IDD) to 1850 m, including an updated control system, so that it can be deployed at the same time as the Foro 3000.

- Based on the updated IDP Science Requirements, Conceptual Design, and Engineering Design, build a Scalable Hot Water Access drill for creating access holes in ice with modular capability to be used for clean access.
- Identify procurement source and cost for potential purchase of a rapid hole qualifier (temperature and caliper) for field staff use in borehole logging applications.
- Resolve logging winch electrical noise issues.

Priority 3 (needed within three to five years):

- Continue to evaluate options for exploring/testing shallow drill fluid columns.
- Finish building a second Blue Ice Drill for wide-diameter drilling to 200 m.

IDP will address these priorities either by the maintenance and modification of equipment already in its inventory or by developing or procuring new equipment. 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 things such as its transportability (i.e. weight, size), its condition, and the availability of documentation such as component specifications, fabrication drawings, operating instructions, maintenance manuals, etc. Major component inter-changeability and logistical agility is now 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 the scientific investigators.

One of the guiding principles for development of drilling technology expressed in the U.S. Ice Drilling Program Long Range Science Plan 2020-2030 prescribes that *"Major drilling systems (e.g. sondes, winches, control 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 recent 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 past 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 m 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 has been used on one funded project (for which it was designed) at Pakitsoq, West Greenland, in 2003 and 2004, for exploratory work at the South Pole in 2013, and for several demonstrations of ice coring for the public in the U.S.

Current Status

The drill is functional, but improvements are needed.

Technical Issues

Wobbling witnessed during operation due to the looseness of the bayonet mount. Stronger springs should be implemented to hold the barrel in place on the mount, and a new attachment method should be designed for the bayonet pins, as one of the three pins tends to pop out.

Plans

While IDP receives many requests for use or purchase of this drill from private sector groups, there have been few requests for polar field use of the drill for NSF-funded projects since the original project. Improvements to the drill will be made when required for an NSF field project.

Hand Augers

The hand auger is the most basic of mechanical drills and is driven from the surface by extensions that are added as drilling proceeds into the ice. IDP primarily deploys two types of hand augers: SIPRE (3-inch core) and a more recently developed IDDO system (3 and 4-inch cores). The SIPRE system takes half-meter cores, while the IDDO systems can be configured to take either half-meter or one-meter cores. IDP also has PICO hand auger kits in inventory (3 and 4-inch cores), though most components have aged beyond their useful life. 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 individually packed by IDP and sent to the BFC (Berg Field Center) for distribution to the specified field project. Drills for use elsewhere are shipped directly to the individual investigators or to the field sites. Existing PICO hand augers in inventory are aging, and parts that have reached the end of their useful life are being removed from inventory over time. IDP maintains eight copies of the new 3-inch IDDO hand auger and three copies of the 4-inch IDDO hand auger. The IDDO model is now being regularly used by investigators in both Greenland and Antarctica.

Technical Issues

In 2019, an issue with cutter head fatigue and failure was witnessed during two field projects in Greenland. IDP is now fabricating cutter heads out of stainless steel instead of aluminum, though the aluminum heads can still be utilized as spares.

The PICO hand auger models employed carbide cutters to enable drilling through very small pebbles or dirty, silty or sandy ice, but carbide cutters are not currently available with the IDDO hand auger models.

Plans

1. Improve hand augers based on feedback from users – Ongoing.
2. Fabricate steel cutter heads for all IDDO hand auger kits – PY 2020.
3. Continue to phase out aging PICO equipment – Ongoing.
4. Maintain hand auger inventory – Ongoing.
5. Improve documentation, potentially including a training video – Contingent upon available budget and NSF approval; will be completed as community priorities dictate.

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 component can also be used to help spin the hand auger barrel itself 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.

Technical Issues

An assessment of the units by IDP engineers in PY 2018 showed that the cleat setup could pose a personnel safety hazard, even though the system has been used extensively in the field with no reported incidents. The cleat components were also integrated with the braking system of the unit. In PY 2018, IDP completed minor modifications to the locking brake components and removed the cleats from the stem. Performance in the field, however, was inadequate. Field team feedback noted the nylon disks that replaced the cleats were inadequate and were more difficult to use. The new brake also experienced a failure, and the new braking technique proved to be slower than with the original configuration. In late 2019, IDP conducted a careful analysis of all Sidewinder components. The prototype brake and nylon disks have been removed from service and all systems are back in the original configuration. IDP is reviewing potential improvements and modifications in 2020. IDP also recently purchased a Kovacs Sidewinder for testing.

Plans

1. Maintain Sidewinder systems – Ongoing.
2. Improve Sidewinders based on feedback from users and test – A Kovacs Sidewinder has been purchased for testing; if it works well, additional units will be purchased for the IDP inventory.
3. Review and update documentation – Ongoing.
4. Purchase or fabricate additional Sidewinders – As needed.
5. Improve documentation, potentially including a training video – Contingent upon available budget and NSF approval; will be completed as community priorities dictate.

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.

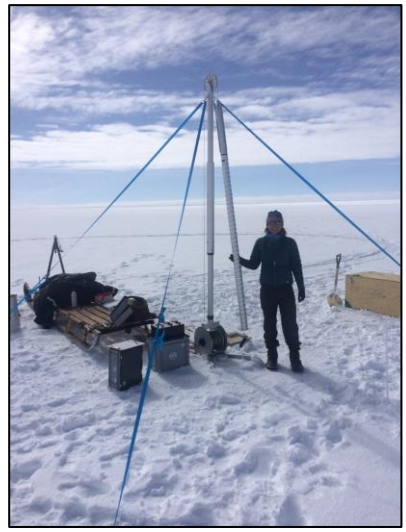
Technical Issues

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, IDP and community scientists formulated science requirements for a lightweight coring drill, able to be transported by backpack, named the Portable Firn Coring Drill. Following that discussion, IDP researched commercially-available systems and also considered designing a new tool. In the end, a commercially-available drilling system was evaluated and 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 some preliminary in-field testing in conjunction with another funded NSF field project being supported by IDP near Summit Station, Greenland. Two equipment operators were able to put the small, solar-powered system through its paces and subsequently drafted a comprehensive test report. In late 2017, IDP completed minor maintenance and repairs, identified and procured a number of spare parts, and procured shipping cases and bags for modularity and very 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. 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. The team collected 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 is working to replace the aluminum cutter heads with a stainless steel head to prevent deformation and procure a spare anti-torque section. 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 and separation technique.

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 9-1/2 inches (241 mm) 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 deeper coring to 200 m depth at the request of the scientific community. A new cable winch and tower were implemented in the design as well as several new down-hole components. In 2015, IDP further implemented and tested new step cutters during a Greenland deployment. Depth capability is still largely influenced by site/ice characteristics. The current equipment is likely reaching its design limits, and assuring depths of 200 m would require a re-design of the system. 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 continued in 2017 but was temporarily suspended in late 2017 due to budget constraints and decisions on the funding of field projects.

Current Status

The BID continues to be one of IDP's most requested drills. A recently fabricated drill tent has allowed operations to continue in poor weather conditions. A new tower was designed and fabricated in 2019 to more adequately bear the loads of the tent and allow for safer tent erection than the original BID tripod design. IDP also continues to make critical modifications to the sonde sections in an attempt to improve core quality at depth and to aid in servicing of the drill in the field.

Technical Issues

Collecting good core quality at greater depths has proven to be an issue as IDP attempts to extend the BID's depth capability. 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 temperature and 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 for over a decade, many original BID components are aging beyond their useful life and require replacement or redesign.

Plans

1. Maintain the BID and BID-Deep components – Ongoing.
2. Replace aging components – PY 2020, PY 2021.
3. Complete fabrication of a second BID-Deep – Initiated in PY 2016; 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 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 particularly 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, where drilling progress would have been halted had the tents not been available. In 2017, IDP completed a full redesign of the aging control boxes and readout boxes to provide for 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 and tested to make the load sense circuit more robust. Beneficial updates were made to the Operator's 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. In late 2016 and early 2017, IDP performed a thorough assessment of the Eclipse Drills and has since implemented numerous minor, but very beneficial modifications to the drills. An improved winch cable termination has been built and will be tested prior to field use with the drills.

Technical Issues

Improvements to 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 testing and integration of the new cable terminations – PY 2021.
3. Complete documentation and enter into database – Ongoing.
4. Ready third existing Eclipse Drill system for issue – 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 drills. Depending on the configuration, the drill can be transported by light aircraft or helicopter.

The 4-Inch Drill was most recently 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.

Current Status

IDP currently has two 4-Inch Drill systems ready for issue. A new set of core barrels was fabricated with flight geometry similar to that of the Foro drills. The barrels were tested during recent Antarctic field seasons. IDP is still working to determine which geometry will provide for the best results. To meet continued demand for a drill of this type, IDP has designed and fabricated a drill known as the Foro 400 Drill (see below). A 4-Inch Drill system will still be maintained; however, the Foro 400 Drill will offer new capabilities and substantial weight savings. A new chips bailer was designed for use with the 4-Inch Drill system in 2019 for clearing cuttings from the bottom of holes drilled with the ASIG Drill augers. The bailer was successfully tested in holes augered with the RAID system during the Antarctic Field Trial (AFT-3) at Minna Bluff during the 2019-2020 field season.

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. A number of repairs were recommended by the field engineers following recent deployments. 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 supplements the 4-Inch Drills and 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 a 76 mm (3-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 from melting and refreezing of the surrounding ice. The Thermal Drill has performed well in British Columbia, Alaska and in southeastern Greenland. The drill was most recently used to drill through firn aquifer layers in SE Greenland during spring 2013 and spring 2015. In 2019, three IDP personnel traveled to Alaska in conjunction with the Juneau Icefield Research Program (JIRP) to perform drill testing.

Current Status

IDP has one Thermal Drill ready for issue. At the request of the science community, IDP began exploring upgrades to the Thermal Drill 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 a prototype ethanol delivery mechanism were implemented. Preliminary testing of the upgrades was conducted near Madison and were further tested by IDP in Alaska in July 2019 with the Juneau Icefield Research Program (JIRP).

Technical Issues

Inasmuch as the cable winch sleds are the 4-Inch Drill sleds, they are very heavy, making the drill not optimal for transport by small aircraft if depths beyond approximately 30 m are desired. The new Foro Design (see below) will offer weight savings and should eventually be compatible with the Thermal Drill sonde. With minimal design and fabrication work, the Thermal Drill could also be adapted for use with the Badger-Eclipse Drill winch and tower.

Plans

1. Make minimal additional modifications following 2019 JIRP testing – PY 2020.
2. Complete/update drawings to the extent practicable and enter into database – Ongoing.
3. Update Drill Operations and Maintenance Manual – PY 2020 and as needed.
4. Perform maintenance and repairs – As needed.
5. Upgrade for weight reduction and compatibility with Foro drill system – Contingent upon available budget and NSF approval; will be completed as community priorities dictate.

Foro 400 Drill

In PY 2015, improvements for the 4-Inch Drill, based on driller feedback and utilizing more recent and proven designs from other IDP drill systems, were initiated through design of the Foro 400 Drill. IDP expects the new design will eventually replace most components of the aging 4-Inch Drill equipment, however one full 4-Inch sonde will be retained for use on science projects requiring the larger 104 mm diameter core. The Foro Drill produces a 98 mm (3.9-inch) diameter core, the same as IDP's Intermediate Depth Drill and the currently in development Foro 3000 Drill. In addition, the new sonde design is submersible and watertight. The drill also incorporates a new tower, winch and control system, largely based on the current 4-Inch Drill equipment, but offering generous weight savings. Using the IDD sonde design spreads design costs over multiple projects, strengthens component availability, and promises to reduce future operations and maintenance costs (by reducing the number of different parts).

Current Status

The new system was fabricated and tested in-house during summer 2019. It was deployed to Antarctica for its first field project during the 2019-2020 field season at Allan Hills, Antarctica.

Technical Issues

The IDP operators at Allan Hills noted a number of challenges with the new system, most notably with chip transport. IDP engineers are currently working to fabricate a new barrel set with modified geometry in addition to other modifications.

Plans

1. Complete drill system drawings and enter into database – Ongoing.
2. Make modifications and complete repairs following recent Antarctic field work – PY 2020.
3. Perform maintenance and repairs – As needed.
4. Complete the Operations and Maintenance manual – PY 2020.
5. Complete engineer and driller hands-on training – Contingent upon available budget and NSF approval; will be completed as community priorities dictate.

Small Hot Water Drill

The IDP Small Hot Water Drills (SHWD) use hot water to create shallow holes in the 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. Feedback on system performance is continuously collected from users of the system. In recent years, 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 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. In the past, the small hot water drills were typically operated by investigators without assistance from IDP equipment operators. 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 2019-2020 field season.

Current Status

IDP has two small hot water drills in inventory. One system was shipped to Antarctica in 2018 and components were briefly tested at WAIS Divide in January 2020. It will serve as a backup for the planned RAM Drilling efforts in 2021-2022. Related to IDP's SHWD capability, it is envisioned that the Scalable Hot Water Drill (see section below), for which IDP engineers completed a Conceptual Design, would serve as IDP's scalable and deep hot water drilling system.

Technical Issues

The system is reliable and efficient to a depth of 25-30 m. PY 2016 modifications were lab tested in Madison, but capability to 60 m has not yet been field-tested.

Plans

1. Complete small purchases based on January 2020 testing – PY 2020.
2. Update completed operating procedures as needed – Ongoing.

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. It was used three times in West Antarctica, where it routinely achieved depths of 90 m. The Askaryan Radio Array (ARA) project borrowed the drill for the 2010-2011 Antarctic field season 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, IDP and community scientists finalized science requirements which drove substantial modifications and upgrades to the drill system to reduce its logistical requirements. IDP completed a conceptual design for the modified system known as the RAM 2, with scalable components for either shallow (~40 m) deployments or for full 100 m deployments. The modifications will serve to dramatically reduce the system weight from approximately 24,000 lbs. to about 10,000 lbs. and will allow for easier assembly and operations in remote areas. IDP also supported a student project at the Colorado School of Mines, where a student team worked to characterize necessary air flow and design downhole tooling.

Current Status

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. On Thwaites Glacier, beginning in 2021-2022, the system will use the large compressors from the original RAM Drill to help ensure project success. 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 the upcoming Thwaites field work. The smaller RAM 2 compressors will eventually be optimized to provide the necessary airflow for future projects.

Technical Issues

Optimization of the small compressors is required to meet the revised science requirements for RAM 2.

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 2020 and PY 2021.
2. Complete modifications identified during the Greenland 2018 test – PY 2020 and PY 2021.
3. Complete drill system drawings and enter into database – PY 2020.
4. Update operating procedures and other procedural documents – PY 2020.

Agile Sub-Ice Geological (ASIG) Drill

The Agile Sub-Ice Geological (ASIG) Drill was the first sub-glacial access rock coring drill in the IDP inventory. The drill system design 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. In PY 2014, IDP began designing auxiliary systems and then received the base minerals exploration rig purchased from Multi-Power Products Ltd. In early 2016, IDP conducted an extensive North American (NA) Test of the complete system just outside of Madison. Minor modifications and upgrades were made following that test. The drill system deployed to Pirrit Hills, Antarctica for the 2016-2017 field season. The ASIG Drill system was successfully used to drill through approximately 150 m of ice and collected 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, however, the core quality was poor. For information on another sub-glacial rock coring drill in the IDP inventory, see the Winkie Drill section.

Current Status

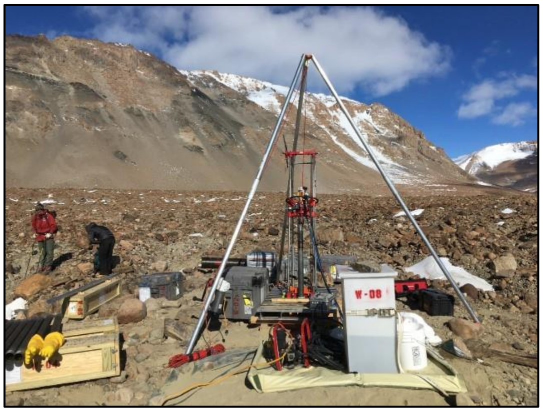
Following the 2016-2017 field season, IDP engineers are completing necessary modifications and upgrades as time allows. In spring 2019, IDP engineers completed air drop testing in a prototype well near Madison to quantify parameters that may create a hydrofracking situation in ice. In such situations, borehole fluid circulation would be lost, halting drilling. This was experienced in one of the two holes drilled at Pirrit Hills and a number of times with the RAID Drill at Minna Bluff. IDP intends to complete modifications and ship the system to Greenland in 2021 for a field project requiring augering of fifteen holes to depths of 100 m. The drill is also planned for use in northern Greenland beginning in 2022.

Technical Issues

Site conditions where this drill will be deployed may vary dramatically. Factors such as firn depth and ice fabric and dynamics will likely affect drilling parameters. Throughout the development of the ASIG Drill, IDP worked closely with industry experts as well as with the team that developed the RAID system (see section below) to share knowledge of benefit to both teams. A comprehensive list of technical issues and general recommendations is contained in the End of Season Report for the 2016-2017 season.

Plans

1. Modify and repair components – PY 2020.
2. Purchase additional components to fulfill science requirements – PY 2020 and PY 2021.
3. Enter documentation for the drill system into the documentation database – Ongoing.



Winkie Drill

In 2015, IDP purchased a commercially-available rock coring Winkie Drill system from Minex (since then the rights to the drill have been sold to PHQ Inc). IDP worked to upgrade the system to add ice augering and ice coring capabilities. The system has a depth capability of 120 m with AW34 sized drill rods, and creates ice core 33.4 mm in diameter and rock core 32.5 mm in diameter. The ice augering capability of the system was initially tested outside of McMurdo Station, Antarctica in February 2016. The system then underwent testing in Madison before shipment back to Antarctica in September 2016 for a funded field project in 2016-2017. The drill performed well during that initial season, drilling 8 holes between 12-54 m depth. Rock cores between 28-67 cm in length were collected in five of the holes and a semi-consolidated sediment core was retrieved from one hole. Modifications were subsequently made to accommodate a request for larger core diameter (71.7 mm) as well as the replacement of the gas engine wtih an electric motor, for improved reliability and to allow for operation within a tent. The drill was again used successfully during the 2017-2018 season in Ong Valley, Antarctica, where two continuous mixed-media cores were collected to a depth of 9.45 m and 12.36 m. In 2018, IDP engineers made repairs and incorporated modifications to allow the system to be utilized in areas where surface firn covers the ice and bedrock below. Borehole casing was procured to seal the bottom of the casing to the ice. Models of packer components were developed, and benchtop testing was conducted for compressed air inflation. The modifications proved successful during the 2019-2020 season during the first year of a two-year Thwaites Glacier project, with the drilling of six access holes and collection of three bedrock samples between 34-41 m depth.

Current Status

A limited number of components used during the 2019-2020 season have been returned to Madison for repair prior to the second season of the Thwaites Glacier project in 2021-2022. IDP is also building up a second Winkie Drill system to accommodate a second funded field project for the 2021-2022 season.

Technical Issues

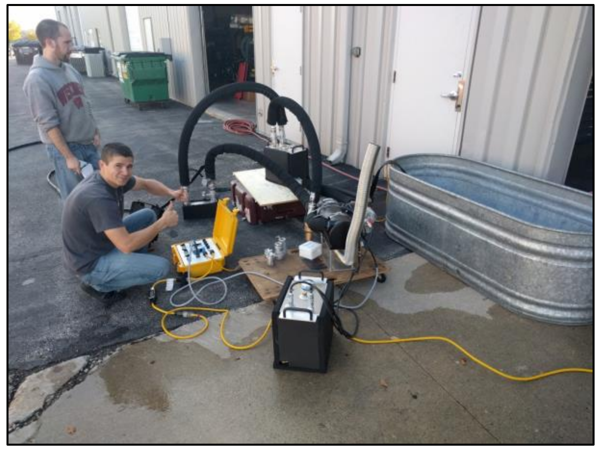
No major issues are known. A comprehensive account of the drill's performance is contained in the equipment operators' End-of-Season reports for the 2016-2017, 2017-2018 and 2019-2020 seasons.

Plans

1. Enter completed documentation into the documentation database – PY 2020 and ongoing.
2. Make repairs to the system following the 2019-2020 field season – PY 2020.
3. Fabricate a second Winkie Drill system – PY 2020.

4. Repair and maintain the Winkie Drill system(s) – Ongoing.
5. Complete engineer and driller hands-on training – PY 2021.
6. 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 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 small field camps 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 previous 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 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 2021 or beyond.

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. To maintain field operations, the system includes a surface-based mechanical and electrical maintenance and repair shop built in a Mobile Expandable Container Configuration (MECC) ISO container. The drill was utilized for six production seasons at WAIS Divide from 2007-2013 and completed the deepest U.S. ice core ever drilled at 3,405 m depth. Replicate coring operations were also successfully completed onsite (see Replicate Coring section below). In PY 2015, IDP worked with community scientists to complete revised science requirements for the DISC Drill. This iterative process included discussion of the feasibility of reducing the drill's logistical footprint.

Current Status

Disassembly and packing of the equipment was completed at WAIS Divide in 2015-2016. In spring 2020, all remaining DISC Drill components were finally returned to Madison. Per discussions between IDP, the NSF and community scientists, the next deep U.S. drilling project is likely planned for Hercules Dome. 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 drilling at Hercules Dome. The community consensus was that IDP should pursue development of the Foro 3000 Drill.

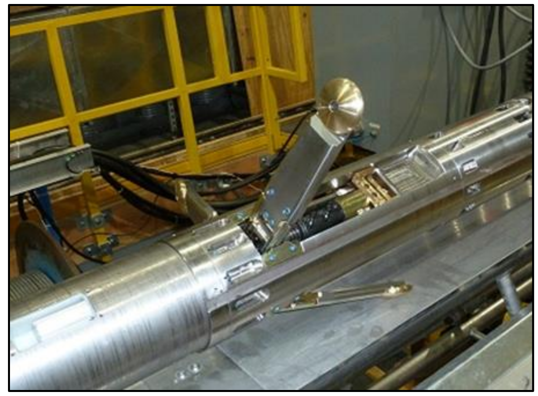
Technical Issues

The obsolescence and the resulting inability to source replacement components, particularly electronics, was an ongoing challenge throughout operation of the drill at WAIS Divide. This challenge will persist throughout the useable life of the drill. A new drill fluid would need to be selected prior to the next field project (see Drill Fluid section).

Plans

1. Clean and store DISC Drill components until a future deployment of the system – Ongoing.

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; 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 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, in turn, the Foro 3000 Drill. 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, similar to those used in the oil and gas industry. IDP believes this concept shows promise for successful implementation at Hercules Dome with the Foro 3000 Drill.

Current Status

The replicate coring-specific equipment of the DISC Drill system was returned to IDP in Madison in 2013 where it was dried, re-packed and remains in storage.

Technical Issues

Similar concerns exist as with the DISC Drill. The obsolescence and the resulting inability to source replacement components, particularly electronics, is expected to be a challenge during the useable lifetime of the replicate coring components.

Plans

1. Store DISC Drill Replicate Coring components until a future system deployment – Ongoing.

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. In 2017 and early 2018, IDP iterated with community scientists on requirements for such a drill. The resulting requirements were finalized 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 1650 and the Foro 400. IDP subsequently completed a Conceptual Overview of the system, and a 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. In early 2020, following further consultation with the science community on reducing the logistical burden of a new design, the IDP Science Requirements were updated in spring 2020 based on an even smaller-diameter core than the Foro Drills or the Badger-Eclipse Drills. Currently IDP-WI is calling this the 700 m Drill, but that name may change over time.

Current Status

IDP and the science community have evaluated the logistics associated with sonde and ice core size. Currently, a core diameter as small as 64 mm shows promise in keeping the drill system and associated fuel and drilling fluid needs small while still meeting science needs for quantity of core. Updated IDP Science Requirements were finalized in spring 2020. The anticipated design will use readily-available small diameter tubing for the sonde and will integrate many of the auxiliary components (e.g. winch, tower, tent) outlined in the original Foro 700 Conceptual Design. Pending an IDP request for NSF approval, IDP will pursue the Detailed Design of such auxiliary equipment as well as the new reduced-diameter sonde.

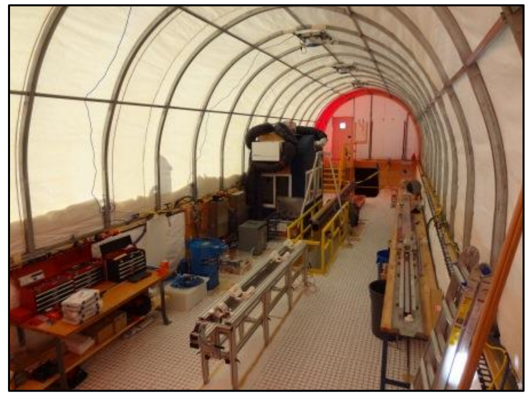
Technical Issues

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

Plans

1. Update the Conceptual Design for the 700 m Drill and hold an IDP community review – PY 2020.
2. Complete Detailed Design of 700 m drill system – PY 2021.
3. Complete fabrication of 700 m system – Will be completed as NSF and community priorities dictate.

Foro 1650 Drill



In PY 2014, IDP completed the design and fabrication of a new Intermediate Depth Drill (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. Per the Science Requirements, the IDD was 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 IDD 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. Beginning in 2019, the drill is now referred to as the Foro 1650, 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 SPICEcore project.

Current Status

The IDD system is currently being stored in Madison, WI. Between 2016 and 2018, IDP engineers worked with Makar Technologies Ltd. and then with Mage Controls Ltd. to redesign the drill system electronics and implement beneficial sensors (e.g. temperature, pressure, inclination). In the end, a number of issues were found with components provided to IDP. The design also did not allow IDP to change the motor set up or tune the system, greatly limiting IDP’s ability to repair components in the field. In late 2018, this approach was abandoned and IDP initiated an in-house custom design for IDD and Foro 3000 electronics which will make use of proven, off-the-shelf parts wherever possible.

Technical Issues

Substantial additional effort and resources are being required to resolve the control system issues to result in a robust, reliable design.

ESTISOL 140 was used as a drilling fluid for both the drill test in Greenland and SPICEcore project, but IDP equipment operators experienced irritating side effects from the fluid. See section on Drilling Fluid.

Plans

1. Fabricate and test new control system electronics – This is being completed as part of the Foro 3000 Drill development continuing in PY 2020 and PY 2021.

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 Intermediate Depth Drill (formerly IDD, now Foro 1650), now referred to as the Foro 3000 Drill. In May 2017, IDP completed a Conceptual Overview document outlining necessary changes to the IDD to enable drilling to 3,000 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 outlines the size and weight of each system, transport options for moving each system to the next proposed 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 report ultimately helped inform IDP, NSF, and the science community's decision to move forward with fabrication of the Foro 3000 Drill in advance of the next deep drilling project.

Current Status

Based on community consensus and support, the NSF has directed IDP to proceed with the fabrication of a Foro 3000 drill for the next deep drilling project, tentatively anticipated to occur at Hercules Dome. Fabrication is in progress and is expected to continue through PY 2022.

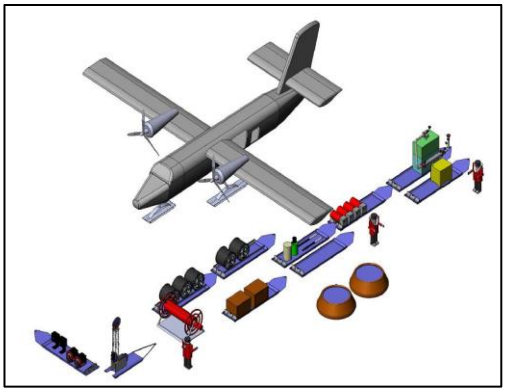
Technical Issues

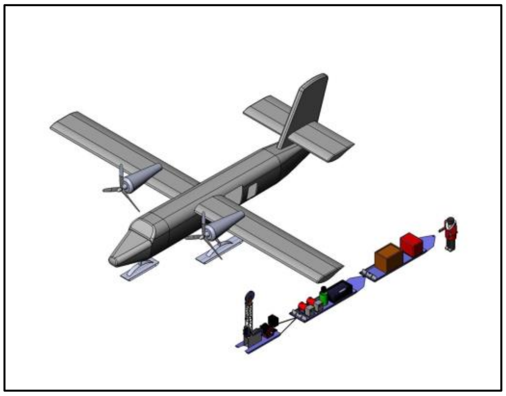
The Foro 3000 Drill is expected to be a relatively simple and straightforward expansion of the Foro 1650 (Intermediate Depth Drill) currently in IDP inventory. The Foro 3000 Drill makes use of a majority of the Foro 1650 component designs, and implementation of Foro 3000 components would be reverse compatible, enabling the drill to revert to a more agile 1,650 m system as needed. As mentioned in the Foro 1650 Drill section, additional effort and time is required to complete a re-design of the Foro 3000 and Foro 1650 control system electronics. IDP plans to complete a majority of the electronics work in PY 2020 and PY 2021 and final in-house testing in PY 2021 and PY 2022.

Plans

1. Complete re-design and fabrication of control system – PY 2020 and PY 2021.
2. Complete fabrication of the Foro 3000 Drill – PY 2020 through PY 2022.
3. Deploy the drill to Antarctica – Future field project needs and funding will determine availability; currently anticipated in fall 2022.

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 multiple 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 building a modular hot water drill with the 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).

Current Status

In May 2016, a joint proposal was submitted by the University of Tennessee-Knoxville, Dartmouth College and the University of Wisconsin-Madison to the NSF for funding and approval to develop and fabricate the ScHWD system. The proposers responded to reviewer feedback and questions between November 2016 and June 2017. In March 2018, NSF notified the proposers that the proposal was being declined, however, future development of the system is not unrealistic.

In May 2017, IDP initiated a conceptual design for a sanitation unit for use with the ScHWD, in accordance with the IDP Science Requirements for the sanitation unit 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.

Technical Issues

Not applicable; system is not yet built.

Plans

1. Initiate fabrication of the ScHWD – Contingent upon available budget and NSF approval; will be completed 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 performed by DOSECC Exploration Services, LLC (DES). Subsequent test activities were managed directly by UMD and UCSD. 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 team, 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) outside of Salt Lake City. In May 2015, a review was held for each system. Another IDP engineer was invited to attend a post-NAT RAID review in Salt Lake City, while IDP invited the lead DES engineer on the RAID project to attend the ASIG Drill review via web and teleconference. Additionally, IDP and DES personnel jointly supported the RAID Auger & Packer Test field project 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 the first deployments 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 planned. 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, or the 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 was ultimately unable to complete their objective to drill through 700 m of firn at the site and to collect bedrock core below, stemming from the creation of a larger amount of chips than planned and lack of a technique to remove those cuttings. 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 the 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 hydrofracture events. Bedrock was reached successfully in the second hole, resulting in the first rock core collection using the RAID system. While a number of challenges were encountered during the season, 1 m of near-basal material was collected as well as 3 m of bedrock core from just below the ice-bedrock interface.

Current Status

Following the AFT-3, the RAID PIs are in discussion with the NSF to plan for return of certain RAID components to the U.S. for maintenance and modification. The RAID PIs are also in discussion with IDP management to possibly have some of the work completed at IDP-WI. If approved, and following maintenance and modification of the drill, 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 has made them available for use by the science community. The first, the Intermediate Depth Logging Winch (IDLW), is a 1.5 km winch that is very portable and is used for logging shallow and intermediate depth holes. 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 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 has been used extensively for logging boreholes in both Greenland and Antarctica and was most recently used during the 2014-2015 Antarctic season for logging at WAIS Divide. Following arrival of the winch in Madison, IDP invited Gary Clow, a USGS employee and the former predominant operator of the winch, to Madison in summer 2015 to help train the IDP-WI staff on the setup, operations, crating, maintenance and troubleshooting of the winch.

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 has also arranged for the transfer of the IceCube logging winch to IDP. This winch has the capability of logging to depths of more than 2,500 m. The winch was used for logging operations at NEEM in

Greenland during summer 2012 and will be transferred to IDP when it is no longer in use with the WISSARD system.

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 the last several Antarctic seasons and has undergone minor maintenance following each deployment. In late 2018 and early 2019, IDP worked to implement a number of potential fixes for the electromagnetic interference (EMI) issues witnessed with the DLW. Resolution of the issues will require additional time and effort and should be implemented before the winch is deployed again. IDP also periodically works with PIs to test communications and compatibility of their logging tools with the logging winches at IDP-WI's off-campus warehouse facility. Depending on the availability of funds and labor, IDP also plans to investigate the design or purchase a rapid hole qualifier unit for use in borehole logging applications.

Technical Issues

The current IDLW cable, owned by the IceCube project, sustained some damage during recent field seasons in 2017-2018, 2018-2019 and 2019-2020. In each instance, IDP engineers unspooled the cable and provided an initial assessment. 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 drill 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. The IDP engineer onsite at Minna Bluff removed, cut, re-spooled and re-terminated the longer section of the cable back onto the winch with the assistance of two other IDP personnel who flew out for the day from McMurdo.

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 will require maintenance prior to any future deployments.

Plans

1. Maintain and upgrade the IDLW, the DLW and the USGS logging winch systems – Ongoing.
2. Investigate and design or purchase a rapid hole qualifier unit for use in RAID and other borehole logging applications – PY 2021 or beyond.
3. Receive IceCube logging winch following use with the WISSARD system on the SALSA project – As NSF priorities dictate.
4. Refurbish and modify, if necessary, the IceCube logging winch – As NSF priorities dictate.

3.0 DECOMMISSIONED SYSTEMS

In recent years and with NSF approval, IDP has retired the following equipment in light of operational/technical issues, components having aged beyond use or the systems' function having been replaced by newer technology in the IDP inventory. Equipment is either being cannibalized and useful components kept for future testing and development efforts, or the systems are being disposed of per the proper channels.

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. IDP engineers assembled and inspected the drill in late 2015 and prepared a status report of the equipment in inventory. The system would have required extensive repair and/or redesign to be made into a useful tool. IDP has decommissioned this system, as its function has now been replaced by the purchase of a 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 system included cutters with replaceable carbide inserts for drilling in mixed media ice. A non-coring rock bit and auger was used for penetrating through larger segments of rock and gravel. The drill bit was rotated via a rigid drill string by a surface-mounted electric motor mounted to a tower. Drill penetration was controlled by a feed system on the drill tower to account for varying ice conditions. The drill produced 76-mm (3-inch) diameter cores a few tenths of a meter long. The drill sustained significant damage during its last deployment in 2009-2010. Community interest remains in collecting 'dirty ice', however, community enthusiasm has now been directed to sub-glacial rock coring. To that end, IDP has purchased off-the-shelf rock coring drills (see Winkie Drill section) and has modified them to drill through ice and to collect rock cores below. The Koci Drill system has been retired as its function has now been replaced by the Winkie Drill.

Miscellaneous Equipment

A number of other stand-alone components have also been decommissioned including a winch used with the former 5.2-Inch Drill system and various tooling and support equipment. 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.

4.0 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 is a necessity for the continuation of intermediate and deep coring projects. A few possible substitutes have been 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 was used in the deep drilling at NEEM, in Greenland, and is again being used at East GRIP 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 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.

Based on positive experiences in using ESTISOL 140 by drilling colleagues in Denmark, ESTISOL 140 was chosen as the drilling fluid for the Greenland test of IDP's Foro 1650 (IDD) as well as for the SPICEcore drilling project completed at the South Pole Station.

After IDP equipment operators experienced mild headaches, minor lung and throat irritation, skin irritation and other side effects when working with the ESTISOL 140, IDP and SSEC Quality Assurance & Safety personnel initiated an investigation into the fluid's composition. IDP-WI/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 decreasing the amount of fluid that ends up on the equipment operators' work suits and identifying a glove that is more chemically resistant to the ESTISOL 140.

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 used 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 air monitoring sensor that had been shown to work down to -40 °C was identified through RAECO, a distributor of detection instrumentation, and after further discussion with the UW Health and Safety professionals, an Ion Science PhoCheck Tiger detection unit was procured for use with the ESTISOL 140.

IDP completes safety assessments for all of its drill systems. For large field drilling projects such as the WAIS Divide Ice Core Project and the SPICEcore Project, IDP also institutes seasonal startup, daily and weekly safety checks of equipment and operations while in the field. This includes the measuring of fluid vapor levels and recording of the results. 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. For future drilling projects where the borehole needs to remain open, IDP would like to identify an alternative fluid to use in place of ESTISOL 140. A good replacement has not yet been identified, however, IDP continues to discuss this issue with its international colleagues. ESTISOL 140 is currently being used with the RAID system.

In 2014, under the direction of former IDP Industry Liaison Bill Eustes, student Benton Ellis at the Colorado School of Mines (CSM) conducted a study of potential ice core drilling fluids, analyzing temperature versus viscosity and density from minus 60 °C to 10 °C. Seven candidate fluids were tested, many of which are used in the petroleum mining industry, and Ellis presented the results at the 2014 IDP TAB meeting. Results of the study showed that viscosity is highly dependent upon temperature, getting thicker with lower temperatures, that there is a temperature at which the viscosity rises nonlinearly and that density generally varies linearly with temperature. The international ice drilling community also continues to actively pursue good candidate drilling fluids. Several papers in the Annals of Glaciology Vol 55, No 68, 2014, discuss the pursuit of identifying new fluids. SSEC Quality Assurance & Safety, along with UW Environmental Health and Safety (EHS) and IDP engineering, also conducted an evaluation of three candidate fluids for use with the ASIG Drill. The three fluids tested included EFC Crystal 180, EFC Crystal 205ST, and Isopar K. The two EFC Crystal fluids are refined mineral oil and would be new to this application for the IDP group. Isopar K is a naphtha and was used with HCFC 141b by IDP for the DISC Drill project at WAIS Divide. The three chemicals were evaluated to assess the impact to the health and safety of the equipment operators as well as the logistical issues with shipping the chemicals. During this evaluation, no red flags were identified that would rule out the use of any of these chemicals for this application. Safety Data Sheets were reviewed, odor testing was conducted, packing and shipping requirements were researched, and chemical compatibility testing was conducted on various types of gloves. Overall, none of the possible replacements were found to raise concerns in polar drilling applications. The fluids were also found to present less of an odor issue than the ESTISOL 140 mentioned above. For more information on this testing, interested parties may contact IDP. IDP used Isopar K, without the addition of a densifier, for the first deployment of the ASIG Drill in 2016-2017 and with the recent deployments of the Winkie Drill in 2016-2020, as there was no requirement that the holes needed to remain open (i.e. hydrostatically balanced).

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 and CSM 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, including a summary issued in 2011 by the Chinese Polar Research Center (Pavel G. Talalay, *Drilling Fluids for Deep Coring in Central Antarctica*, Technical Report PRC 02-23011, Jilin University, China, December 2011) and several articles published in the Annals of Glaciology, Vol 55, No. 68, 2014. 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 look to alternative fluids for future projects. IDP remains in discussion with its international colleagues on this matter. In April 2018, IDP-WI shipped samples of three fluids to CSM for further testing, including Isopar K, Crystal 205ST and Crystal 200. CSM also planned to test a number of new Calsia drilling fluids manufactured by Calumet Specialty Products Partners, L.P. The CSM team investigated the suitability of a solid based density increasing agent for ice coring and drilling fluids. Micromax is an Elkem ASA product used in maintaining drilling fluid density. It consists of microspherical manganese tetraoxide particles with a SG of 4.7 to 4.9 and an average particle size of 1 micron. The CSM team tested the premise that microsized particles of colloidal size would stay in suspension in the viscous cold fluids. The team tested the Micromax weighting agent in Calsia 62 and Calsia 100 (from Calumet), Crystal 205ST and Crystal 200 (identified and sent to CSM by IDP-WI for testing), and the currently used Estisol 140 (also from IDP-WI) and Isopar K (from the National Science Foundation Ice Core Facility or NSF-ICF). Tests were made with clean fluid for temperature related rheology and density effects. A second set of tests were made with a batch of the Micromax mixed into the six fluids to meet a SG of 0.92 for temperature related rheology and density effects.

The CSM team noted challenges in getting the mixture to shear even with a drilling fluid company-donated wetting agent. Upon intense shearing for two hours, the mixtures were allowed to sit at room temperature. The Micromax fell out of suspension within a day, leaving the test tubes indelibly stained. A conjecture was that colder fluids would be more viscous and hold the particles in suspension. The team took the six samples with the Micromax and six without Micromax to the NSF-ICF in Lakewood, CO, for testing in the -22 °C lab. Within a day, the same settling was observed. Therefore, the team concluded that this particular material was not shearing small enough to affect a non-settling suspended state and therefore failed to meet the premise. Solid based density agents still show potential, but the right material must be identified. A solid based material is logistically more easily transported and likely of smaller volume than drilling fluid (A. Eustes, personal communication, April 23, 2020).

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 to investigate alternative drilling fluids – Ongoing.
2. Provide proper Personal Protective Equipment (PPE) for drill system deployments and operator safety – Ongoing.

5.0 RESPONSES TO TECHNOLOGY PRIORITIES FROM THE LONG RANGE SCIENCE PLAN 2020-2030

IDP notes the following guiding principles for development of drilling technology expressed in the U.S. Ice Drilling Program Long Range Science Plan 2020-2030:

- 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 clearly defined and transparent at the initial stage of planning. Scientists and engineers working together through IDP must assess the impact of changes as they arise during the engineering design and fabrication 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, control 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.
- Engineering design teams must include individuals with field experience using appropriate ice drilling technology and/or other relevant field experience.

These principles have been and are being adhered to in the course of IDP's development and maintenance/upgrade projects – most recently in the substantial redesign of the RAM Drill, modification and upgrade of the Winkie Drill system, fabrication of the Foro 3000 design 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 U.S. Ice Drilling Program Long Range Science Plan 2020-2030

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 4-6). 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 a number of 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 2020-2030, 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 4" Electromechanical Drills, the 3" Electrothermal Drill, the 3.25" Badger-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 Drill.*

   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 above as well as in other points of this section below.

2. *Implement Foro 400 Drill system modifications following the recent first deployment of the system.*

   IDP action: Modifications in process. Addressing chip transport issues witnessed during the drill's first use in the 2019-2020 Antarctic field season. New barrels in fabrication. Drafting the Operations and Maintenance Manual.

3. *Finish fabrication of a second ice-ready Winkie Drill.*

   IDP action: Fabrication in process. The IDP Winkie Drill system builds upon a commercially-available drill rig. In the remainder of PY 2020, IDP plans to complete sub-system assembly of the Winkie 2. A full-face ice bit has been designed and will be tested in late 2020 or early 2021, pending access to the ice well facility. Fluid chiller equipment is also being researched and specified, as warm fluid temperatures caused drilling issues during the 2019-2020 Antarctic season. The system is largely being constructed as a copy of the current Winkie Drill (Winkie 1) in IDP inventory, incorporating the latest modifications and upgrades made to the original system.

4. *Develop the IDP Conceptual Design for clean sample acquisition from a hot water ice coring drill for sediment-laden basal ice samples.*

   IDP action: Pending completion of the IDP Science Requirements in PY 2020, IDP engineers will prepare a Conceptual Design document for review by the NSF and the science community.

5. *Develop the IDP Conceptual Design for retrieving rock, basal ice, sediment, and water from West Antarctic (e.g., Mt. Resnik) and East Antarctic sites (e.g., within Wilkes Basin) (consider suite of existing or new drills, e.g. large hole with hot water drill, then deploy sediment core or rock core, retrieve basal ice)*

   IDP action: Pending completion of the IDP Science Requirements in PY 2020, IDP engineers will prepare a Conceptual Design document for review by the NSF and the science community.

6. *Develop IDP Science Requirements for collecting a small amount (e.g. chips or up to 10 cm) of sub-ice rock using a lightweight tethered ice core drill, for example the Eclipse and Stampfli drills.*

   IDP action: Beginning in PY 2021, IDP will iterate with community scientists on formulation of the applicable Science Requirements.

7. *Develop IDP Science Requirements for collecting a small amount (e.g. less than 1 meter) of sub-ice rock using an intermediate or deep ice core drill in a fluid-filled hole, for example the Foro 3000 drill.*

   IDP action: Beginning in PY 2021, IDP will iterate with community scientists on formulation of the applicable Science Requirements.

8. *Develop IDP Engineering Design for the 700 m drill.*

   IDP action: In 2017 and early 2018, IDP iterated with community scientists on requirements for such a drill. The resulting requirements were finalized in March 2018. IDP subsequently completed a Conceptual Overview of the system and a 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 for a 700 m deployment of the Foro 700 versus modification and deployment of a smaller-diameter drill such as the Badger-Eclipse Drill. In early 2020, following IDP coordination of scientists and engineers in discussion to reduce the logistical burden of a new design, IDP identified commercially-available tubing that would produce a 64 mm core. The IDP Science Requirements for the 700 m Drill were finalized in spring 2020, and the Conceptual Design will be updated for the 700 m Drill in summer/fall 2020. In PY 2021, IDP engineers will complete a Detailed Engineering design for an agile 700 m drill for review by the NSF and the science community.

9. *Develop the updated IDP Conceptual Design and Engineering Design for a clean Scalable Hot Water drill that minimizes its logistical footprint including fuel supply.*

   IDP action: In PY 2014, science requirements for a Scalable Hot Water Drill (ScHWD) were formalized. IDP subsequently completed engineering requirements for the system, completed a conceptual design and conducted both internal and external reviews of the concept in PY 2014. In May 2016, a proposal was submitted to the NSF for construction of the ScHWD system. In late

2017, IDP engineers drafted a report outlining a preliminary evaluation of how a hot water sanitation unit could be adapted to the ScHWD design. The ScHWD proposal was declined by the NSF in March 2018, however future development of the drill is still anticipated, due to community interest. Pending updating of the Science Requirements following the 2020 SAB meeting, and beginning in PY 2021, IDP will update the existing Conceptual Design for the ScHWD system. Following review of the Conceptual Design by the science community and approval by the NSF, IDP engineers will complete the Detailed Engineering Design for the ScHWD system. In conjunction with this work, IDP will also discuss recent success of the BEAMISH Drill with the British Antarctic Survey to incorporate beneficial technologies and lessons learned.

10. *Purchase remaining ASIG Drill components to allow for depth capability of 700 m.*

    IDP action: Procurement of additional rod and casing planned for early 2021.

11. *Establish the IDP Science Requirements for replicate coring for the Foro 1650 and Foro 3000 drill.*

    IDP action: Beginning in PY 2021, IDP will iterate with community scientists on formulation of the applicable Science Requirements.

12. *Establish the IDP Science Requirements for identification and planning of borehole maintenance and fluid control over time.*

    IDP action: Beginning in PY 2021, IDP will iterate with community scientists on formulation of the applicable Science Requirements.

13. *Establish the IDP Science Requirements for removing (or lowering) drilling fluid from a borehole (for example for freezing in a sensor).*

    IDP action: Beginning in PY 2021, IDP will iterate with community scientists on formulation of the applicable Science Requirements.

14. *Evaluate options for new drilling fluids for Herc Dome and other ice and rock drilling projects.*

    IDP action: Discussion on drilling fluid research and use is regularly included at the IDP Technical Advisory 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. IDP remains in contact with Professor Bill Eustes at the Colorado School of Mines, who recently conducted tests of candidate fluids and weighting agents. Consideration of fluid cost, availability, conductivity, viscosity, etc. remains part of the ongoing conversation. Former IDP Driller and PhD chemist Dave Ferris also provided IDP with notes from his research on potential new drill fluids.

15. *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 will initiate discussion on this topic with its Technical Advisory Board and with others in the drilling community and will pursue the design or purchase of power sources with low logistical demand as resources, funding and NSF approval permit.

Priority 2 (needed in the next 3 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: Based on 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, additional component modifications are being made. IDP will review a range of options. These will include small engine options that can provide higher air flow, casing options that can reduce airflow demand, and a review of vacuum as an alternative to compressed air.

17. *Finish building a stand-alone Foro 3000 Drill as per the IDP Science Requirements.*

    IDP action: Fabrication in process. IDP anticipates the system will be ready for issue in 2022.

18. *Acquire components to extend the depth of the Foro 1650 (IDD) to 1850 m, including an updated control system, so that it can be deployed at the same time as the Foro 3000.*

    IDP action: Through design and fabrication of a stand-alone Foro 3000 Drill, IDP will then have a stand-alone IDD capable of 1650 m depth and the Foro 3000 Drill, capable of 3000 m depth in its inventory. This will allow for simultaneous operation of the systems in the Arctic and Antarctic if desired. IDP will pursue design and implementation of modifications to allow the Foro 1650 to reach 1850 m if tasked by the NSF. To extend the depth to 1850 m, IDP anticipates having to purchase a new cable and new winch drum. Most other components of the Foro 1650 should not require modification.

19. *Based on the updated IDP Science Requirements, Conceptual Design, and Engineering Design, build a Scalable Hot Water Access Drill for creating access holes in ice with modular capability to be used for clean access.*

    IDP action: In PY 2014, science requirements for a Scalable Hot Water Drill (ScHWD) were formalized. IDP subsequently completed engineering requirements for the system, completed a conceptual design and conducted both internal and external reviews of the concept in PY 2014. In May 2016, a proposal was submitted to the NSF for construction of the ScHWD system. In late

2017, IDP engineers drafted a report outlining a preliminary evaluation of how a hot water sanitation unit could be adapted to the ScHWD design. The ScHWD proposal was declined by the NSF in Mach 2018, however future development of the drill is still anticipated, due to community interest. Per number 10 above, the next step is to update the previous Conceptual Design and then complete a detailed Engineering Design, following updating of the Science Requirements by the science community.

20. *Identify procurement source and cost for potential purchase of a rapid hole qualifier (temperature and caliper) for field staff 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.

21. *Resolve 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 a number of minor changes to the equipment but did not observe any noticeable improvement. Efforts will continue as resources allow to further investigate and mitigate this issue.

Priority 3 (needed in 3 to 5 years):

22. *Continue to evaluate options for exploring/testing shallow drill fluid columns.*

    IDP action: IDP discussed the practice of drilling with shallow drill fluid columns during the recent 8th International Ice Drill Symposium as well as at the 2019 IDP Technical Advisory 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. IDP has also purchased off-the-shelf devices to record vibration downhole during drilling and is working with the Colorado School of Mines to analyze some initial vibration data collected with the Eclipse Drill during the 2019-2020 Antarctic season. Such data could help inform drill design or modifications that may reduce the stress induced in the ice during cutting.

23. *Finish building a second Blue Ice Drill for wide-diameter drilling to 200 m.*

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. While the second BID is largely a replica of the original and very successful BID design, minor beneficial modifications and upgrades will be made in conjunction with building of the second system. The majority of the cost in fabricating a second system lies in the purchase of capital equipment and materials, however engineering effort is also needed for re-initiating contact with the component manufacturers, as the original BID was built several years ago back in 2009-2010. 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 required for upcoming field work. IDP will complete fabrication of the second BID-Deep system as NSF and community field work priorities dictate.

6.0 FIELD SUPPORT OF SCIENCE PROJECTS

In addition to the development of new drilling equipment and the maintenance and upgrade of existing ice drilling, rock drilling and related equipment, IDP will continue to provide support for science projects in the field. This support generally consists of assisting PIs with planning the field activities, providing equipment for the project, and providing a field crew for the operation of the equipment.

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 six to ten projects being actively supported with half of them actually in the field and the other half in the planning/preparation phase of the project. 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

7.0 EXPENDITURES

In spring 2018, the NSF encouraged IDPO to submit a proposal for another 5-year Cooperative Agreement. The proposal was non-competitive but underwent a full review by NSF and community representatives. The NSF subsequently awarded Dartmouth a new 5-Year Cooperative Agreement. Under the new agreement, IDPO and IDDO combined under one name of the U.S. Ice Drilling Program, or IDP. 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 2020-2030. Appendix 2 outlines current and near-term development and maintenance and upgrade expenditures for PY 2020 and PY 2021.

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 consider decommissioning equipment that is no longer desired by the science community.

Annual expenditures for operations supporting field projects vary depending upon 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.

8.0 CUTTING EDGE TECHNOLOGY OPPORTUNITIES

IDP is committed to continuous improvement and streamlining of operations with regard to 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 technologies (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 accelerators 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 each season.
8. 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.
9. 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.
10. Packaging – Research into lightweight packaging technologies appropriate for IDP applications could reduce system weight and improve portability.
11. 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.
12. 3-D Printing – Implementing a 3-D printer at IDP would allow engineers quick-turnaround on prototype parts and in some cases production parts. Quick and inexpensive printing of such parts would also aid in evaluation of component potential for field use.
13. SLLID – Further design and modifications are required to optimize the recently developed Sediment Laden Lake Ice Drill, but doing so could remove the need for bulky, oversized, inefficient Hotsy Drill systems currently in use by science teams.
14. 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.
15. 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.
16. 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.

9.0 REFERENCES

Pavel G. Talalay, Drilling Fluids for Deep Coring in Central Antarctica, Technical Report PRC 02-23011, Jilin University, China, December 2011.

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
CFM	Cubic Feet per Minute (of airflow)
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
ETFE	Ethylene Tetrafluoroethylene
FEP	Fluorinated Ethylene Propylene
HCFC	Hydrochlorofluorocarbon
ICDS	Ice Coring & Drilling Services
IDD	Intermediate Depth Drill
IDDO	Ice Drilling Design and Operations (now IDP-WI)
IDLW	Intermediate Depth Logging Winch
IDP	Ice Drilling Program (formerly IDPO-IDDO)
IDPO	Ice Drilling Program Office (now IDP)
IDP-WI	Ice Drilling Program at the University of Wisconsin-Madison (formerly IDDO)
IH	Industrial Hygienist
ISO	International Organization for Standardization
ITASE	International Trans-Antarctic Scientific Expedition
MECC	Mobile Expandable Container Configuration
NSF	National Science Foundation
NSF-ICF	National Science Foundation Ice Core Facility
OPP	Office of Polar Programs
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
SALSA	Subglacial Antarctic Lakes Scientific Access
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
TAB	Technical Advisory Board
USGS	United States Geological Survey
WAIS	West Antarctic Ice Sheet
WISSARD	Whillans Ice Stream Subglacial Access Research Drilling

Appendix 1 – Long Range Project Schedule

Legend:

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

	PY 2020	PY 2021		PY 2022		PY 2023		PY 2024		PY 2025
Equipment	**2020 Arctic**	**2020-2021 Antarctic**	**2021 Arctic**	**2021-2022 Antarctic**	**2022 Arctic**	**2022-2023 Antarctic**	**2023 Arctic**	**2023-2024 Antarctic**	**2024 Arctic**	**2024-2025 Antarctic**
4-Inch Drill 1										
4-Inch Drill 2										
Agile Sub-Ice Geologic Drill	*Funded project postponed				1 funded; 2 proposed		1 funded; 2 proposed			
Badger-Eclipse 1 [1]		*Funded project postponed								
Badger-Eclipse 2 [1]										
Badger-Eclipse 3	TBD									
Blue Ice Drill/Blue Ice Drill-Deep 1		*Funded project postponed	1 funded; 2 proposed	Re-scheduled from 2020-2021						
Blue Ice Drill/Blue Ice Drill-Deep 2	TBD									
Chipmunk Drill										
DISC Drill	In storage									
DISC – Replicate Coring System	In storage									
Drill Fluid Development										
Foro Drill - 400 m		*Funded project postponed	1 funded; 1 proposed	Re-scheduled from 2020-2021						
700 m Drill [2]	TBD									
Foro 1650 Drill (Intermediate Depth Drill)										
Foro Drill - 3000 m										
Hot Water Corer [3]	TBD									
Logging Tower										
Logging Winch - IDP Intermediate Depth										
Logging Winch - IDP Deep										
Logging Winch - USGS [4]										
Logging Winch - IceCube [5]	TBD									
Prairie Dog										
Pressure Vessel										
Rapid Hole Qualifier	TBD									
RAM (Rapid Air Movement) Drill	Staged in ANT	*Funded project postponed	Staged in ANT	Re-scheduled from 2020-2021		Re-scheduled from 2021-2022				
Scalable Hot Water Drill	TBD									
Sediment Laden Lake Ice Drill										
Small Hot Water Drill 1	Staged in ANT	*Funded project postponed	Staged in ANT	Re-scheduled from 2020-2021		Re-scheduled from 2021-2022				
Small Hot Water Drill 2										
Stampfli 2-Inch Drill										
Thermal Drill	*Funded project postponed		1 funded; 2 proposed							
Winkie Drill 1		*Funded project postponed		Re-scheduled from 2020-2021						
Winkie Drill 2		*Funded project postponed		1 funded; 1 proposed						
Sidewinder (5 available)			1 funded; 1 proposed	1 proposed	1 proposed		1 proposed			
Hand Auger, 3” PICO (7 available)	*Funded project postponed		Phasing out							
Hand Auger, 4” PICO (2 available)			Phasing out							
Hand Auger, 3" IDDO (8 available)			1 funded	2 proposed		1 proposed				
Hand Auger, 4" IDDO (3 available)			1 proposed		1 proposed		1 proposed			
Hand Auger, SIPRE (6 available)	*Funded project postponed	*Funded project postponed	1 proposed		1 proposed		1 proposed			

[1] Solar/wind power capabilities available.
[2] Conceptual Design completed in PY 2019. Science community and IDP iterating on potential for reduced-diameter sonde and logistics.
[3] Science Requirements initiated in PY 2019. Will be pursued as NSF and community priorities dictate.
[4] Winch transferred from USGS to IDP inventory in 2014.
[5] Expect winch will be added to IDP inventory after use by the University of Nebraska with the WISSARD system.
*Funded projects postponed due to COVID-19.

Appendix 2 – Current and Near-Term Estimated Budgets for Development and Maintenance & Upgrade Work

PY 2020 - PY 2021

Development or Maintenance & Upgrade Project	PY 2020 (Current)	PY 2021
4-Inch Drill	38,000	38,500
ASIG Drill	34,200	70,200
Badger-Eclipse Drill	26,300	61,100
Blue Ice Drill	79,700	75,500
Foro 400 Drill	42,900	75,900
Foro 1650 Drill	23,300	
Foro 3000 Drill	674,000	377,000
Hand Augers	46,700	50,700
Logging Winches	35,700	57,300
RAM Drill Upgrades	119,400	78,600
Detailed Design (e.g. 700 m Drill) [1]		78,000
Feasibility Study (e.g. Mt. Resnick)		15,500
Stampfli Drill	65,300	50,000
Thermal Drill	21,500	51,300
Winkie Drill [2]	139,400	94,500
TOTAL COSTS	**1,346,400**	**1,174,100**

[1] Conceptual Design completed in PY 2019; the concept is being further reviewed by IDP and the science community for potential downsizing of the sonde/core and associated logistics.
[2] PY 2020 costs include Winkie 1 repairs and modifications as well as final fabrication of a Winkie 2. PY 2021 costs include repairs and modifications for both Winkie 1 and Winkie 2.
NOTE: Estimates are subject to change based on levels of NSF funding and the number of deployments/associated required maintenance for each system.

NOTE: Individual project totals are highly subject to change due to COVID-19 impacts.

Equipment Development	(blue)
Maintenance & Upgrade	(green)