Ice Drilling Design and Operations

LONG RANGE DRILLING TECHNOLOGY PLAN




Prepared by the Ice Drilling Design and Operations group in collaboration with the Ice Drilling Program Office

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Contents

Cover photos: (upper left) ASIG Drill at Pirrit Hills, Antarctica; (upper right) Winkie Drilling in the Ohio Range, Antarctica; (lower right) Testing of Small Hot Water Drill upgrades in Madison, WI; (lower left) Rock cores collected with the ASIG Drill in Antarctica

1.0 INTRODUCTION

The U.S. Ice Drilling Program 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 IDDO as part of its inventory of NSF equipment. This plan also describes the latest development projects at IDDO. Finally, this plan briefly addresses the funding allocated for its implementation.

Highlights/Changes for this 2017-2027 Update:

General highlights and changes:

- Added highlights/changes section
- Refreshed formatting/layout for easier reading

Additions:

- Added a text section for the Foro 3000 system, for which IDDO plans to complete the detailed design in PY 2018
- Plan to complete the conceptual design for Foro 700, either based on the Foro/IDD systems or on an Eclipse Drill
- Plan to complete the conceptual design of the sanitation unit for the proposed ScHWD system
- Plan to iterate with IDPO and community scientists on completion of science requirements for a new hot water coring device, capable of drilling to 200 m at warm sites
- Plan for a replica of the Intermediate Depth Drill in the future, based on a new Priority 3 recommended technology investment in this year's Long Range Science Plan
- Plan to have one IDDO engineer participate in the RAID field trials at Minna Bluff, Antarctica during the 2017-2018 field season
- Plan to have one IDDO engineer participate in the ARA hot water drilling activities at South Pole Station during the 2017-2018 field season

Deletions:

- Deleted consideration of the Modular 2,500 m Clean Hot Water Drill; mention was removed from this year's Long Range Science Plan update after a discussion on the Thwaites Glacier initiative and available British Antarctic Survey (BAS) drill systems
- Deleted plan to design in situ probes for observation and sampling; mention was removed from this year's Long Range Science Plan update

The high priority tasks and investments identified by the IDPO Science Advisory Board (SAB) are shown below as listed in the U.S. Ice Drilling Program Long Range Science Plan 2017-2027.

Recommended technology investments

The following investments in drilling technologies are needed to accomplish science goals planned for the next decade. Investments, prioritized by time, and from consensus of the IDPO 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 Shot Hole Drills, the Blue Ice Drill, the Prairie Dog, the ASIG Drill and the Winkie drill.
- Maintain and upgrade the Intermediate Depth Drill.
- Finish building a second Blue Ice Drill for wide-diameter drilling to 200 m.
- Finish building the Sediment Laden Lake Ice Drill.
- Finish cost estimate, construction schedule and detailed design for upgrading the Intermediate Depth Drill to 3,000 m ('Foro 3000').
- Finish the RAM Drill modifications for modularity, weight reduction and ease of logistics based on existing IDPO Science Requirements for rapidly creating shot holes.
- Conduct Antarctic field trials of the Rapid Access Ice Drill (RAID)[1].

Priority 2 (needed within the next three years):

- Finish building the Foro Drill system.
- Modify the Badger-Eclipse (or Foro) drill for drilling to 700 m under conditions of limited logistics based on established science requirements.
- Build a Scalable Hot Water Access drill for creating access holes in ice from 50 m up to approximately 1,000 m depth with modular potential to be used for clean access.
- Upgrade the Electrothermal Drill to allow for coring to 300 m through temperate and poly-thermal firn and ice. The drill needs to be agile and light weight (transportable by helicopter).
- Build Foro 3000 components (i.e. IDD add-on components).
- Develop science requirements for a hot water drilling system that can be used to recover ice core samples from warm sites (e.g. Chile, NZ, Asia) to 200 m depth.
- Investigate a rapid hole qualifier (temperature and caliper) for use with RAID and other borehole logging applications.

Priority 3 (needed within three to five years):

- Build replicate components of the IDD drill to enable same-year use in both the Arctic and Antarctic.
- Continue to evaluate options for new drilling fluids, and exploring/testing shallow drill fluid columns.

[1] Development of the RAID system was completed by the University of Minnesota-Duluth and the University of California-San Diego, with design, fabrication, and test activities being performed by DOSECC Exploration Services, LLC (DES).

IDDO 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 IDDO 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. In the continuing maintenance and upgrade of existing equipment, IDDO will undertake, to the extent permitted by availability of resources and funding, a systematic program of defining the baseline performance of each of the drills with the compilation of data from field projects and the improvement of equipment documentation. IDDO also follows rigorous documentation procedures throughout the design, fabrication, testing and deployment of equipment. This allows IDDO to better maintain the equipment, and also allows IDDO to undertake modifications that improve the equipment's performance and, hence, its usefulness to the scientific investigators.

The following sections provide a brief history of each piece of equipment in IDDO 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 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 spring 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 IDDO 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 a field project.

Hand Augers

The hand auger is the most basic of mechanical drills and is driven from the surface by a series of extensions that are added as drilling proceeds into the ice. IDDO has in inventory several types of hand augers: SIPRE (3-inch core), PICO (3 and 4-inch cores), and a more recently developed IDDO system, now available in both 3 and 4-inch models. The SIPRE system takes half-meter cores, while the PICO and IDDO systems can be configured to take either one-meter or half-meter cores. 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 IDDO drillers.

Current Status

Hand augers are individually packed and assigned to specific investigators, depending on project needs. Augers for Antarctic users traveling through McMurdo Station are individually packed by IDDO and are then 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. In recent years, IDDO developed a new replacement model and fabricated eight copies of the new 3-inch IDDO hand auger. Based on the success of that new design, IDDO designed and built three 4-inch units. The new designs have now been used by several investigators in both Greenland and Antarctica and have replaced the PICO auger as the most-requested model.

Technical Issues

Some quality problems with the old augers, such as misalignment of mounting holes and parts not fitting properly. A carbide cutter option is not currently available for the new IDDO hand augers.

Plans

1. Correct quality problems of existing hand augers "one hand auger at a time" as they are prepared for issue – Ongoing as necessary.
2. Continue to phase out aging PICO equipment – Ongoing.
3. Improve hand augers based on feedback from users – Ongoing.
4. Increase distribution of a post-field season questionnaire to hand auger users to get information from investigators on hand auger performance – Ongoing.

Sidewinder

The Sidewinder is not a drill, but is a drive/lifting system used in conjunction with the hand augers. It is driven by an electric motor (power hand drill) and a winching system to help in both lowering and retrieving the drill string. The power hand drill 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 IDDO drillers.

Current Status

Due to increasing requests for this system, IDDO fabricated an additional unit in 2015. Five working systems are available.

Technical Issues

None known.

Plans

1. Maintain Sidewinder systems – Ongoing.
2. Review and update documentation – Ongoing.
3. Fabricate additional units – As needed.

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 in Wyoming in August 2016.

Current Status

The drill system is complete and is ready for issue. The Prairie Dog is typically operated by one IDDO engineer/driller with assistance from investigators.

Technical Issues

The PICO hand auger models employ carbide cutters or carbide inserts to enable drilling through very small pebbles or dirty, silty or sandy ice. Since the Prairie Dog system uses a 4-Inch PICO core barrel, narrow kerf carbide cutters are available for use with this system, but are not currently available with the IDDO hand auger barrels.

Plans

1. Update documentation as needed and enter into database – Ongoing.
2. General maintenance and modification – Ongoing as needed.

Blue Ice Drill (BID)

The Blue Ice Drill is an agile drill capable of retrieving cores of approximately 9-1/2 inches (241mm) 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. The control box was modified as well.

Current Status

Modifications to theoretically extend the depth capability of the system to 200 m (BID-Deep) were completed in 2015. In 2015, IDDO further implemented and tested new step cutters during a Greenland deployment, though depth capability is still largely influenced by site/ice characteristics. Per IDDO's discussions with the IDPO SAB, the current equipment has likely reached its operational limits. 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. The drill has been extensively used in both the Arctic and Antarctic. The equipment has sustained some wear, particularly from traversing and set-up/take-down at multiple sites per season. Repair and replacement of worn out parts is in progress. In 2016, IDDO 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. IDDO engineers are making minor design modifications, though the BID-Deep 2 will largely be a copy of the highly successful original design.

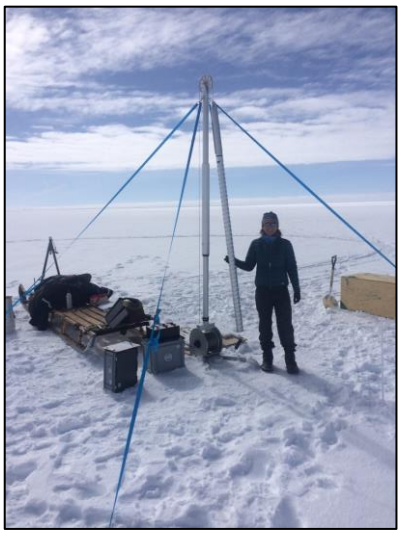
Technical Issues

Collecting good core quality at greater depths has proven to be an issue in both Greenland and Antarctica. 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 during the 2014 Arctic field season. The BID-Deep capabilities were further tested in Taylor Valley in Antarctica during the 2014-2015 season down to a depth of 70 m in a firn-free area and again in Greenland at a site with approximately 80 m of firn, down to 155 m during summer 2015. 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 be impacting the core quality. Deep drilling depths cannot be guaranteed.

Plans

1. Maintain the BID and BID-Deep components – Ongoing.
2. Build a second BID to meet user demand – PY 2017 and PY 2018.

Stampfli Drill



In 2015, IDPO initiated formulation of science requirements for a lightweight coring drill, able to be transported by backpack, named the Portable Firn Coring Drill. IDDO participated in this iterative requirements drafting process with IDPO and community scientists. Following that discussion, IDDO 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. IDDO will retain the name Stampfli Drill for this unit.

Current Status

IDDO ordered the largely off-the-shelf 2-inch Stampfli Drill in 2016, customizing the order to include a winch for depth capability to 100 m. The unit was received at IDDO in mid-April 2017, at which point IDDO engineers/drillers completed an initial assembly and inspection. IDDO shipped the very lightweight system to Greenland in early May for some preliminary in-field testing in conjunction with another funded NSF field project being supported by IDDO near Summit Station. Following completion of the testing, IDDO will assess any necessary modifications needed for the system and will work to identify and procure spare parts. As the system comes shipped from the manufacturer in one wood crate, IDDO also plans to research and procure smaller shipping bags and cases for the system, to allow for backpack transport of the drill in remote locations.

Technical Issues

None known.

Plans

1. Complete in-field testing of the drill and test report – PY 2017.
2. Identify and procure spare parts – PY 2017.
3. Research and procure lightweight shipping bags and cases – PY 2017.
4. Update documentation as needed and enter into database – Ongoing.

Badger-Eclipse Drill

The Badger-Eclipse Drills are modified Eclipse Drills manufactured by Icefield Instruments, Inc. The drill is an electromechanical system capable of collecting 81 mm diameter core to depths of approximately 300 m. The drill system is transportable by small aircraft or helicopter. IDDO 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 IDDO in 2010.

In 2013, IDDO increased the capabilities of the Badger-Eclipse Drills by designing and fabricating a solar and wind power system for use in operation of the drill. This capability has proven particularly useful at field sites where environmental impact is of special concern and where use of a generator for drill operation is not desirable or permitted. Late in 2014, IDDO purchased a new Mountain Hardwear Space Station tent for use with the Badger-Eclipse Drill systems. A second identical tent was purchased in June 2016. The tents have allowed drilling operations to continue safely and reliably during inclement weather on recent projects in both Greenland and Antarctica, where drilling progress would have been halted had the tents not been available. In 2015, IDDO initiated redesign of the aging control boxes and readout boxes to provide for simplified operation, weight reduction and new sealed cases. Fabrication of the new boxes was completed in spring 2017.

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, IDDO performed a thorough assessment of the Eclipse Drills and implemented numerous minor, but very beneficial modifications to the drills. New load pin keepers and pivot pins for the load sense systems were fabricated for both systems. Spacers were fabricated for the load sense system pivot pins to remove play and improve load reading repeatability, and new one-piece slide hammer retainers were fabricated for both systems.

Technical Issues

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

Plans

1. Ready third Eclipse drill system for issue – As needed.
2. Develop procedure, including bill-of-materials checklist, for preparing drill for issue – PY 2017.
3. General maintenance and repairs – Ongoing.
4. Complete documentation and enter into database – Ongoing.

4-Inch Drill

The 4-Inch Drill is an electromechanical ice coring drill that takes a 104 mm 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 for the RAID Auger & Packer test conducted outside of McMurdo Station near Castle Rock during the 2015-2016 Antarctic field season, and outside of South Pole Station for the placement of anchors, strain gauges and thermistor strings between 25-125 m depth during the 2016-2017 field season.

Current Status

IDDO currently has two 4-Inch Drill systems ready for issue. A new set of barrels was recently machined and tested during the 2015-2016 and 2016-2017 Antarctic seasons. Winch and cable inventory for the current 4-Inch Drills includes one system at 400 m, two at 200 m and one at 100 m. These winches received a full inspection and minor maintenance in PY 2015. To meet continued demand of a drill of this type, IDDO has designed and is fabricating the new Foro Drill (see below). A 4-Inch Drill system will still be maintained, however, the Foro Drill will offer new capabilities and substantial weight savings.

Technical Issues

The current 4-Inch Drills are repaired as needed, with the replacement of failing/aging components, however, the entire system is aging. In some cases, replacement parts may no longer be available. The cable winch sleds are very heavy, making the drill not optimal for transport by small aircraft. Improvements to the instrumentation and control system for the drill have also been noted as desirable to improve reliability and to reduce weight. All of these considerations have been taken into account with regard to the new Foro 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.
3. Complete development of operating and maintenance procedures and documentation – PY 2017 and ongoing.
4. Update drill system drawings and enter into database – 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 systems, for use in ice warmer than about minus 10 °C. The drill collects a 3-inch core and has been used to drill to approximately 200 m. For depths shallower than 30 m, a simpler tripod assembly for operation of the drill has been used with good success. It is particularly useful in ice close to the pressure melting point, where electromechanical drills are at risk 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 deployed and used successfully to drill through firn aquifer layers in SE Greenland during spring 2013 and spring 2015.

Current Status

IDDO has one Thermal Drill ready for issue. A new 65 meter water-shedding cable was procured in 2015 to prevent the fibrous cable typically used with the Thermal and 4-Inch Drills from soaking with water in aquifer layers, refreezing and causing issues with travel over the upper sheave on the drill tower. Numerous firn aquifer layers have recently been located in Greenland. From discussions with PIs, IDPO, and from the Long Range Science Plan, IDDO anticipates that the Thermal Drill may see considerably more use in the upcoming years. As per the Long Range Science Plan, IDDO plans to upgrade the Thermal Drill to allow for coring to 300 m beginning in PY 2018. This will primarily involve the specification and purchase of new heat rings and a new cable.

Technical Issues

IDDO currently has a small stock of older heat rings, the exact model of which is now out of production. The availability of replacement parts is unknown. 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 (see 4-Inch Drill above) if depths beyond approximately 30 m are desired. The new Foro Design (see below) will offer weight savings in this area and will be compatible with the Thermal Drill sonde. With minimal design and fabrication work, the Thermal Drill could also be adapted for use with the Eclipse Drill base/tower.

Plans

1. Complete/update drawings to the extent practicable and enter into database – Ongoing.
2. Perform maintenance and repairs – As needed.
3. Upgrade the drill to increase its performance capability to 300 m depth – PY 2018.

Foro Drill

In PY 2015, improvements for the 4-Inch Drill, based on driller feedback and utilizing more recent and proven designs from other IDDO drill systems, were initiated. It is envisioned that 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 diameter core, the same as IDDO's Intermediate Depth Drill. In addition, the new sonde design will also be submersible and watertight. In March 2015, IDDO circulated a 'Name That Drill' Doodle poll to encourage IDPO and IDDO team members to vote on a name for the new components, so that distinguishing between the old and new equipment would be more straightforward. The name 'Foro' was selected, and is Latin for "to make a hole, pierce or to bore". In April 2015, IDDO held a Preliminary Design Review showcasing the new and upgraded components of the 'Foro Drill'. A new drill sonde, based on the Intermediate Depth Drill (IDD) design, has been designed, as well as a new tower, winch and control system, largely based on the current 4-Inch Drill equipment, but offering generous weight savings wherever possible. 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). IDDO initiated fabrication of the new Foro Drill components during PY 2016. In PY 2017, good progress has been made on prototyping of the winch control loop and in fabrication and assembly of the Foro Drill control boxes.

Current Status

IDDO expects to complete fabrication of this system in PY 2018, pending available funding.

Technical Issues

Not applicable; system currently being designed/fabricated.

Plans

Continue fabrication and assembly of new Foro Drill components including winch, tower, sonde and control box – PY 2017 to PY 2019.

Small Hot Water Drill

The IDDO Small Hot Water Drills (SHWD) use hot water to create shallow holes in the ice. They are non-coring. 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. These systems are typically operated by investigators without assistance from IDDO drillers, though IDDO encourages science teams visit Madison for drill system training prior to deployment. The system was most recently used in west Antarctica during the 2015-2016 field season.

Current Status

IDDO has two small hot water drills in inventory. Feedback on system performance is continuously collected from primary users of the system. In recent years, IDDO has implemented substantial modifications to the drills, with assistance from UW-Madison Physical Sciences Lab (PSL) personnel. IDDO 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 IDDO built up a fully-operational second unit. One of the two systems maintains 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. Related to IDDO's SHWD capability, the Scalable Hot Water Drill (see section below), once developed and built, will serve as IDDO's scalable and deep hot water drilling system, with a proposed depth range of 50-1,000 m. See also the Sediment Laden Lake Ice Drill section, which outlines another portable hot water drilling system recently designed by IDDO for drilling larger diameter holes through shallow lake ice.

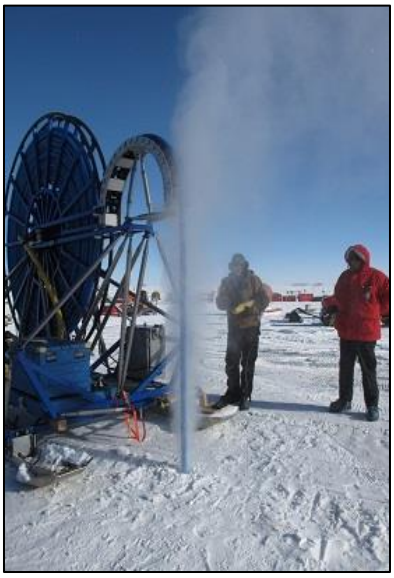
Technical Issues

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

Plans

1. Provide drill operator training – PY 2018 and as needed.
2. Update completed operating procedures as needed – Ongoing.

Rapid Air Movement (RAM) Drill



The RAM Drill was developed for use in 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 has been used three times in West Antarctica, most recently during the 2009-2010 field season, when it routinely attained depths of 90 m. The Askaryan Radio Array (ARA) project, funded by NSF-OPP, 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.

Current Status

In early 2017, IDPO, IDDO and community scientists finalized science requirements which will be used to drive substantial modifications and upgrades to the drill system to reduce its logistical requirements. IDDO engineers are currently working on the conceptual overview for the modified/upgraded system, envisioned to have scalable components for either shallow (~40 m) deployments or for full 100 m deployments. Planned modifications should also serve to dramatically reduce the system weight and allow for easier assembly and operations in remote areas. IDDO also supported a student Capstone Design project at the Colorado School of Mines, where a student team worked through both the fall and spring semesters to characterize necessary air flow and design downhole tooling.

Technical Issues

While the drill worked well during the 2009-2010 season, additional modifications are needed to make the drill less cumbersome to transport and set up. Drill performance is sensitive to the local permeability of the firn being drilled, as shown by Whelsky & Albert (Cold Regions Science and Technology 123, p. 149-154, 2016). Techniques and equipment are currently being explored to minimize compressed air demand in order to reduce required fuel and the weight of compressor equipment. The current hose reel also presents logistical problems, necessitating the use of heavy equipment for assembly at the field sites, and will be redesigned.

Plans

1. Complete analysis of potential downhole equipment solutions – PY 2017.
2. Develop System-Level Conceptual Design – PY 2017.
3. Design and Build Downhole Equipment – PY 2017.
4. Complete modifications for modularity, weight reduction and ease of logistics – PY 2018.
5. Test RAM Drill modifications – PY 2019.

Agile Sub-Ice Geological (ASIG) Drill

The Agile Sub-Ice Geological (ASIG) Drill is the first sub-glacial access rock coring drill of its kind for IDDO. The drill system design is based on a commercially-available minerals exploration rig, which IDDO has 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, IDDO began designing auxiliary systems and then received the base minerals exploration rig purchased from Multi-Power Products Ltd. In early 2016, IDDO 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 was shipped to Antarctica in September 2016 for the 2016-2017 field season. The ASIG Drill system was successfully used in remote west Antarctica near the Pirrit Hills during the 2016-2017 field season, where it drilled through approximately 150 m of ice and collected 8 m of 39 mm diameter rock core of excellent quality. 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 recently developed at IDDO, see the Winkie Drill section for more information.

Current Status

The ASIG Drill system returned to Madison in April 2017 and has been inspected. IDDO engineers have developed a list of necessary modifications and upgrades and have initiated work on those tasks.

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. Some level of technical risk is to be expected in implementing an exploration drill rig in a new application such as polar ice coring and drilling. Throughout the development of the ASIG Drill, IDDO worked closely with industry experts as well as with the team developing the Rapid Access Ice Drill (RAID) to share knowledge that is 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. Complete first field deployment of system (completed) – PY 2017.
2. Modify and repair components – PY 2017 and PY 2018.
3. Enter completed documentation for the drill system into the documentation database – PY 2017 and ongoing.

Winkie Drill

In 2015, IDDO purchased a commercially-available Winkie Drill system from Minex that is capable of coring rock. IDDO subsequently worked to modify and upgrade the system to add ice augering and ice coring capabilities. The system has a depth capability of 120 m. The ice augering capability of the system was initially tested outside of McMurdo Station, Antarctica in February 2016. The system then underwent more comprehensive testing in Madison prior to its shipment back to Antarctica in September 2016 for a funded field project in 2016-2017. The drill performed well in Antarctica, 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-cosolidated sediment core was retrieved from one hole.

Current Status

IDDO received the drill back from Antarctica in April 2017 and is making necessary repairs. Modifications are being made to accommodate larger-diameter core requirements for an upcoming Antarctic field project. An electric motor is being implemented and will to provide the power required for the upcoming field project as well as provide other operational advantages going forward (e.g. ability to operate inside a tent in inclement weather). In addition to coring ice and rock, the drill is expected to replace the ‘dirty ice’ drilling functionality of the Koci Drill system, which will likely be decommissioned.

Technical Issues

A comprehensive account of the drill's performance during its first deployment is contained in the drillers' End-of-Season report for the 2016-2017 season. During the Antarctic test of the system’s ice augering capability in early 2016, issues with ice chip transport were observed. IDDO used this information to develop an air drilling option for creating access holes to the bed. During the 2016-2017 Antarctic season, however, augering was found to be effective at creating access holes and removing chips. This suggests the chips removal rate may be dependent on ice/site characteristics. The air drilling option did not work well at that field site, prompting IDDO to re-examine the air drilling bit geometry.

Plans

1. Enter completed documentation into the documentation database – PY 2017 and ongoing.
2. Make repairs to the system following the 2016-2017 field season – PY 2017.
3. Modify the Winkie Drill for larger-diameter dirty ice coring – PY 2017.
4. Prepare and ship the drill system to Antarctica – PY 2017.
5. Make repairs to the system following the 2017-2018 field season – PY 2018.
6. Repair and maintain the Winkie Drill system – Ongoing.

Sediment Laden Lake Ice Drill (SLLID)

Per the recommended technology investments in the Long Range Science Plan, IDDO worked with IDPO and 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, IDDO initiated the conceptual design of the system. In early 2017, the detailed design was completed and reviewed by community scientists as well as non-IDDO technical personnel from the polar ice drilling community. Following a successful review in April 2017, IDDO made minor adjustments to the design and iniated fabrication of the system. Basic requirements include drilling speed of less than 30 minutes for a 5-inch hole through a 6 m ice cover. Drill components will be small, lightweight and able to be lifted by a maximum of two people. The drill will also have stand-alone capability for operation at small field camps at remote sites with no heavy equipment and will be PI/science team operable. Design of the drill has incorporated componets that allow for clean access drilling.

Current Status

The drill system is currently in fabrication at IDDO. Components are on order and assembly was initiated in June 2017. The system is expected to be completed by late October 2017.

Technical Issues

Not applicable; system currently being designed/fabricated.

Plans

1. Complete fabrication and assembly of new Sediment Laden Lake Ice Drill – PY 2017.
2. Complete system testing following assembly – PY 2017.
3. Enter completed documentation for the drill system into the documentation database – PY 2017 and ongoing.

Deep Ice Sheet Coring (DISC) Drill

The Deep Ice Sheet Coring (DISC) Drill developed by Ice Coring and Drilling Services (ICDS) under contract with the NSF is a tilting-tower electromechanical drill designed to take 122 mm diameter ice cores to depths of 4,000 m with variable core lengths up to a design limit of 4 m. The drill is currently able to recover cores up to 3.5 m long. An essential part of the DISC Drill system to maintain field operations is the 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 and completed the deepest U.S. ice core ever drilled at 3,405 m depth. Replicate coring operations were also successfully completed onsite, resulting in the collection of 285 m of high quality replicate core from five deviation and four different depths in the main hole (See Replicate Coring section). In PY 2015, IDDO worked with IDPO and community scientists to complete revised science requirements for the DISC Drill. This iterative process included some discussion of the feasibility of reducing the drill's logistical footprint, and revised requirements were finalized in early PY 2016. In addition, a new drilling fluid will need to be identified prior to the drill's next deployment, since the densifier fluid (HCFC 141b) used in the two-component fluid at WAIS Divide has now been phased out of production by the Environmental Protection Agency (see Drill Fluid section below).

Current Status

Disassembly and packing of the remaining equipment was completed at WAIS Divide in 2015-2016. Most of the DISC Drill system returned to Madison by April 2017, however a few components, including the MECC machine shop remain at either WAIS Divide or McMurdo Station. Components remaining in Antarctica are expected to return to Madison in spring 2018. Per discussions between IDPO, IDDO and community scientists, the next deep U.S. drilling project is likely planned for Hercules Dome. IDDO is currently working with IDPO and science community representatives on a DISC Drill vs. Foro 3000 (see description below) analysis, to help determine which system should be used for drilling at Hercules Dome. Prior to this deployment, which is not anticipated before 2023-2024, the DISC Drill would need to undergo substantial repairs and modifications.

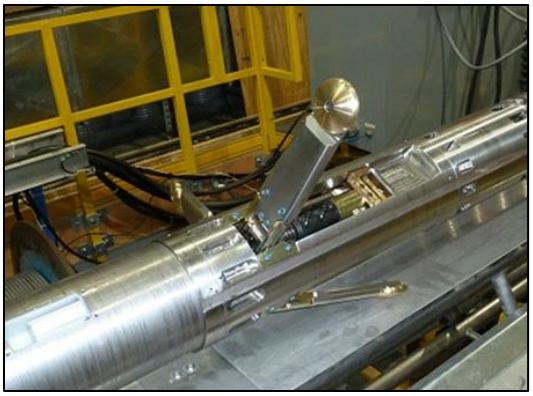
Technical Issues

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 lifetime of the drill. A new drill fluid will need to be selected prior to the next field project. In East Antarctica, the drill fluid would have to retain a low viscosity at very low temperatures.

Plans

1. Clean and store returned DISC Drill components until the next deployment of the system – Ongoing.
2. Complete DISC Drill vs. Foro 3000 analysis in collaboration with community scientists and ASC – PY 2017.
3. Determine components that need to be replaced to make the drill ready for Hercules Dome and other field sites in East Antarctica and test components as necessary – Will be completed as community priorities dictate.
4. Repair/upgrade the drill system, including the capability to operate at very low temperatures, and enhance the performance and implement logistical improvements in response to community desires – Will be completed as community priorities dictate.

Replicate Coring



Taking a single deep ice core from a given region makes replication and verification of the validity and spatial representativeness of key results difficult. Furthermore, scientific demand for ice samples has been and will continue to be unevenly distributed versus depth. The inventory of ice core is being completely depleted in depth intervals of high scientific interest, whereas at other intervals, more than 50% of the ice cores drilled remain. The ability to obtain additional volumes of ice samples at selected intervals, termed replicate coring, addresses these concerns and adds value to the scientific return from ice coring. It is important that the taking of replicate cores doesn't compromise other scientific activities, in particular borehole logging.

The design of the IDDO replicate coring system for the DISC Drill incorporates, as its essential performance requirement, tilting and forcing of the sonde against the drill hole wall by 'actuators' that push against the wall upon command from the surface. This action then 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 in the latter part of the 2011-2012 field season. No core was obtained, but using insight from that test, IDDO engineers made modifications to the sonde and carried out further testing in Madison. The benefit and result of that work was total success in replicate coring during the 2012-2013 field season at WAIS Divide, where 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 in the first coring of its kind.

Current Status

The replicate coring-specific equipment of the DISC Drill system (i.e. sondes, actuator sections, control computers) were returned to IDDO in 2013 and have been dried, re-packed and stored. The replicate coring system is an integral component of the DISC Drill and awaits the next call for deep drilling.

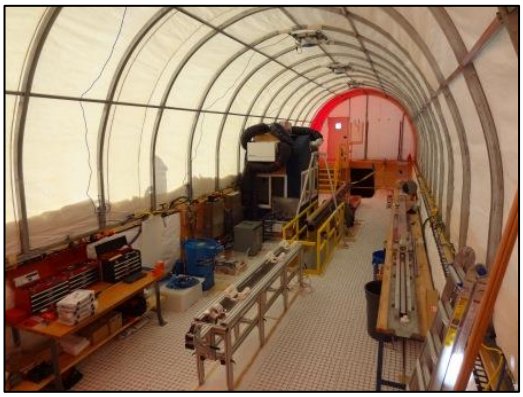
Technical Issues

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 returned DISC Drill Replicate Coring components until the next deployment of the system – Ongoing.

Intermediate Depth Drill (IDD)



Many of the coring objectives outlined in the U.S. Ice Drilling Program Long Range Science Plan, such as those in the IPICS 2k array and 40k network, are achievable using an intermediate-depth drill, meaning one that can collect core from a fluid-filled hole down to a depth of approximately 1,650 m. In PY 2014, IDDO completed the design and fabrication of a new Intermediate Depth Drill (IDD). With assistance from international colleagues, IDDO modified the existing design of the Hans Tausen intermediate depth drill and built a new system. The system was field-tested outside of Summit Station, Greenland in spring 2014 and was recently used in successful completion of the SPICE Core project just outside of South Pole Station, where a total of 1,751 m of core was collected using a longer cable option.

Current Status

A subset of components including the sondes and the control box were returned to Madison in spring 2016 and subsequently underwent inspection and limited repairs. Disassembly and packing of the IDD and drill tent was completed at South Pole during the 2016-2017 field season. Remaining IDD equipment returned to Madison in April 2017 and is currently being processed. IDDO engineers are currently working with Mage Controls Ltd., who is redesigning the control system of the drill, on implementing additional beneficial sensors (e.g. temperature, pressure, inclination).

Technical Issues

The drill was designed with limited sensors onboard to keep the system simple and easily repairable in the field, however, the original control system proved unreliable during the SPICE Core project. ESTISOL 140 was used as a drilling fluid for both the drill test in Greenland as well as for the SPICE Core project. IDDO drillers, however, experienced irritating side effects during use of the fluid. See section on Drilling Fluid for additional information. Issues were also experienced with shorting of the drill cables. It is believed the shorting could be caused by flat spots in the cable, that may be a result of the cable tensioning process at IDDO or more likely due to the type of insulation (FEP) in the original cables. IDDO has purchased two new cables with a new type of insulation (ETFE). This is a harder/tougher material that is less prone to extrusion failure.

Plans

1. Modify and repair components – PY 2017 and PY 2018.
2. Enter completed documentation for the drill system into the documentation database – PY 2017 and ongoing.
3. Initiate fabrication of a second Intermediate Depth Drill system – PY 2019 or later.

Foro 3000 Drill

Beginning in PY 2016, IDDO began working with IDPO and science community representatives to conduct an analysis on using the DISC Drill for the next U.S. deep ice coring project versus using an adaptation of the Intermediate Depth Drill, now referred to as the Foro 3000. Currently, IDDO is looking for input from the Antarctic Support Contract (ASC) personnel to help determine the logistics burden of each drill system. Such considerations include the method of transport to the next identified drill site, likely Herc Dome, the number of ASC camp staff required, and other logistical concerns. IDDO is refining numbers for each drill system's cargo footprint, including fuel and drilling fluids. Upon completion of information gathering, IDDO expects to complete an analysis report in PY 2017 that will ultimately help to inform IDPO, NSF, and the science community's decision on whether or not the DISC Drill will be repaired or if the IDD will be expanded and adapted into the Foro 3000 Drill.

Current Status

In May 2017, IDDO completed a Conceptual Overview document outlining necessary changes to the IDD to enable drilling to 3,000 m. The document also identifies potential maintenance shop options for deployment with the drill at remote locations. In early June 2017, a Concept Review was held with IDPO, IDDO and several community scientists. IDPO also plans to solicit feedback on the conceptual design from polar drilling engineers from other nations. IDDO will respond to reviewer comments when received and will make modifications to the concept as necessary. During the remainder of PY 2017, IDDO also plans to research the adaptation of whipstock technology to allow for replicate coring on the downhill side of the borehole with the IDD and potentially other systems. This directive was identified in the 2016-2026 version of the Long Range Science Plan. Ultimately, the IDD system may or may not be modified pending results of the conceptual design review and availability of NSF funding.

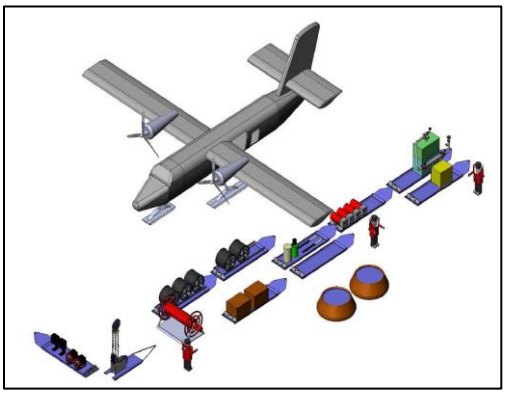
Technical Issues

The Foro 3000 Drill is expected to be a relatively simple and straightforward expansion of the Intermediate Depth Drill currently in IDDO inventory. The Foro 3000 Drill would make use of a majority of the IDD components, and implementation of Foro 3000 components would be reverse compatible, enabling the IDD to revert to a more agile 1,600 m system as needed.

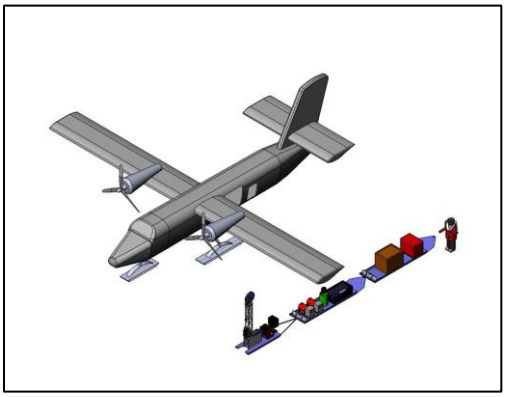
Plans

1. Complete conceptual overview – PY 2017.
2. Respond to reviewer comments – PY 2017.
3. Modify conceptual design based on reviewer comments – PY 2017.
4. Complete detailed design of the Foro 3000 Drill – PY 2018.
5. Deploy the drill to Antarctica – Future field project needs and available funding will determine availability.

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 where it is relatively thin. 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 as well as for seismic studies. IDDO does not at present have a field-ready deep hot water access drill. Based on science requirements established in 2014, IDDO 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.



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. The proposal remains under consideration.

IDDO expects that components of the Kamb-Engelhardt, currently on loan to the University of Nebraska-Lincoln will be returned to Madison at the completion of the SALSA Project, though much of the drill may be unsalvageable for use in building a new hot water rapid access drill. In May 2017, IDPO requested that IDDO initiate a conceptual design for a sanitation unit for use with the ScHWD, in accordance with the IDPO 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.

Technical Issues

Not applicable; system is not yet built.

Plans

1. Initiate and complete conceptual design for ScHWD sanitation unit – PY 2017 and PY 2018.
2. Contingent on available budget, initiate fabrication of the ScHWD – PY 2018 and beyond.
3. Conduct full-scale system testing in North America, Greenland or Antarctica – Will be based on drill development timeline.

Agile 700 m Ice Coring Drill or 'Foro 700'

Per the Long Range Science Plan, a system similar to the existing Intermediate Depth Drill (1,600 m) and the Foro Drill (400 m) that is currently in development, a mid-range drill (700 m) is desired for use in remote areas such as mountain glaciers in the Arctic. IDDO is currently iterating with IDPO and community scientists on requirements for such a drill.

Current Status

Following finalization of the science requirements, anticipated in PY 2017, IDDO will develop a Conceptual Overview of a 700 m drill system.

Technical Issues

Not applicable; system is not yet built. While a system of these specifications does not yet exist, the design is expected to heavily utilize proven concepts from the IDD and Foro Drills, which share the same sonde design.

Plans

1. Finalize IDPO science requirements – PY 2017.
2. Complete Conceptual Overview of Foro 700 system – PY 2018.

Rapid Access Ice Drill (RAID)

The Rapid Access Ice Drill (RAID) is a University of Minnesota-Duluth and University of California-San Diego project funded by the National Science Foundation. Design, fabrication, and test activities were performed by DOSECC Exploration Services, LLC (DES). IDDO did not directly participate in the design, fabrication or testing of the RAID, however, throughout the process of designing, building and fielding the RAID, ASIG Drills and Winkie Drills, the RAID PIs, the DES engineering and management team, and the IDDO 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 IDDO engineers were able to participate in and view the RAID North American Test (NAT) outside of Salt Lake City, UT, by invitation of the RAID PIs. In May 2015, a review was held for each system. Another IDDO engineer was invited to attend a post-NAT RAID review in Salt Lake City while IDDO invited DOSECC's Director of Operations and primary engineer on the RAID project to attend the ASIG Drill review via web and teleconference. Additionally, IDDO and DES personnel jointly supported the RAID Auger & Packer Test field project conducted outside of McMurdo station in February 2016. During the brief test, IDDO 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. Each organization provided troubleshooting support to the other via phone throughout the fieldwork.

Current Status

The RAID system completed its first Antarctic Field Trial (AFT-1) at Minna Bluff during the 2016-2017 field season. The RAID system was successfully towed 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. A second test season (AFT-2) is planned for the 2017-2018 field season at Minna Bluff to complete testing, which will include drilling with fluid and testing the filtration system. Upon successful completion of the AFT-2, a third test (AFT-3) is planned up on the Antarctic Plateau.

Logging Winches

Following an IDPO-SAB recommendation articulated in the U.S. Ice Drilling Program Long Range Science Plan, IDDO 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 was most recently used during the 2016-2017 field season for logging the SPICE Core borehole at South Pole. The second logging winch, the IDDO 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 at WAIS Divide. IDDO engineers are now working to complete maintenance and beneficial upgrades to the system based on that first deployment.

In PY 2014, the United States Geological Survey (USGS) gifted its 4,000 m logging winch to IDPO-IDDO 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, IDDO invited Gary Clow, a USGS employee and the former predominant operator of the winch, to Madison in summer 2015 to help train the IDDO staff on the setup, operations, crating, maintenance and troubleshooting of the winch.

Through consultation with IDPO and the borehole logging community, IDDO generally plans to require at least one IDDO logging winch operator be sent with the systems each time they deploy. Exceptions to this may be made on a case by case basis, particularly for deployment of the IDLW. When slow speed, multi-shift logging is required, IDDO will work to train a member of the science team to assist with winch operation, as was done during the 2016-2017 season at WAIS Divide.

IDPO-IDDO have also arranged for the transfer of the IceCube logging winch to IDDO, which has the capability of logging to depths of more than 2,500 m. The IceCube logging winch was used for logging operations at NEEM in Greenland during summer 2012 and will be transferred to IDDO when it is no longer in use with the WISSARD system for the planned SALSA project.

Current Status

Upon return of the IDLW and DLW from Antarctica in April 2017, IDDO engineers are now executing a plan of careful inspection, repair and upgrades of the two winches. Planned user-recommended

upgrades for the IDLW include 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). Planned repairs and upgrades for the DLW 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, an oil change, addition of adjustable leveling screws between the winch and sled frame, 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. IDDO also periodically works with PIs to test communications and compatibility of their logging tools with the logging winches in IDDO's off-campus warehouse facility.

Technical Issues

A comprehensive list of technical issues and general recommendations for the IDLW and the DLW is contained in the End of Season Reports for the 2016-2017 season. IDDO has not deployed the USGS winch since it was transferred to IDDO. It will require maintenance prior to a future deployment.

Plans

1. Maintain and upgrade the IDLW, the DLW and the USGS logging winch systems – Ongoing.
2. Procure spare parts for the IDLW and the DLW – PY 2017.
3. Investigate and design or purchase a rapid hole qualifier unit for use in RAID and other borehole logging applications – PY 2018 and PY 2019.
4. Receive IceCube logging winch following use with the WISSARD system on the SALSA project – PY 2020.
5. Refurbish and modify, if necessary, the IceCube logging winch – PY 2020, depending on its use with WISSARD, community needs, and available budget.

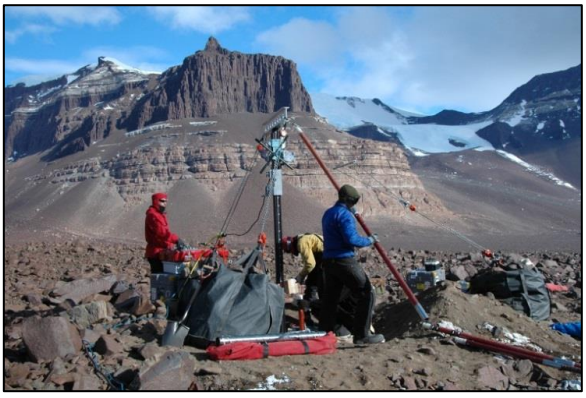
3.0 SYSTEMS SLATED FOR DECOMMISSIONING

IDDO plans to retire the following drill systems in light of operational/technical issues, components having aged beyond use or the systems' function having been replaced by newer technology in the IDDO inventory. Equipment will either be cannibalized and useful components kept for future testing and development efforts, or the system will be disposed of per the proper channels and with NSF approval.

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 has cored is 42 m. A number of performance issues were noted with the drill. The system has not been used since 2003. IDDO engineers assembled and inspected the drill in late 2015 and prepared a status report of the equipment in inventory. The system would require extensive repair and/or redesign to be made into a useful tool. IDDO is pursuing decommissioning of this system, as its function will now be replaced by the recent purchase of the 2-inch Stampfli Drill system (see Stampfli Drill section).

Koci Drill



The Koci Drill, named after the late drill engineer Bruce Koci, is an electromechanical, single-barrel coring drill that was designed to operate in ice containing limited amounts of sand, silt and very small sedimentary rocks. It is not a rock drill. The system includes cutters with replaceable carbide inserts for drilling in mixed media ice. A non-coring rock bit and auger is used for penetrating through larger segments of rock and gravel. The drill bit is rotated via a rigid drill string by a surface-mounted electric motor mounted to a tower. Drill penetration is controlled by a feed system on the drill tower to account for varying ice conditions. The drill produces 76-mm (3-inch) diameter cores a few tenths of a meter long. It was tested and used to collect scientific samples in Beacon Valley during the 2006-2007 Antarctic field season and again, after repair and modification, in the 2008-2009 and 2009-2010 field seasons. It has not been used since. The drill sustained significant damage during its last deployment in 2009-2010. Periodic interest remains in collecting 'dirty ice', however, many investigators have voiced a desire for a rock coring drill. To that end, IDDO purchased an off-the-shelf rock coring drill (see Winkie Drill section) and has modified it to drill through ice and to collect rock cores below, instead of making extensive repairs to the Koci Drill and attempting to modify it to drill rock. The Koci Drill system will likely be retired in the near future.

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 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, IDDO 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. With that said, members of IDDO's Technical Advisory Board (TAB) have indicated that silicone oils are now available that evaporate cleanly from ice surfaces. 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 candidate for 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 IDDO's drilling colleagues in Denmark, ESTISOL 140 was chosen as the drilling fluid for the Greenland test of IDDO's Intermediate Depth Drill (IDD) as well as for the SPICE Core drilling project at the South Pole Station.

After IDDO drillers working with the fluid experienced mild headaches, minor lung and throat irritation, chapped skin and other side effects when working with the ESTISOL 140, IDDO and SSEC Quality Assurance & Safety personnel initiated an investigation into the fluid's composition. IDDO/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, 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 drillers' work suits and identifying a glove that is more chemically resistant to the

ESTISOL 140. Following the Greenland field test, IDDO also made substantial modifications to the IDD ventilation system, including an active ventilation system for the driller control room to ensure continuous air flow and to induce an air flow pattern that pulls room air down and away from the occupants' breathing area and workspace. The system uses an energy recovery ventilator (ERV) and two inline duct heaters to circulate enough air to replace the volume of air inside the control room every 67 seconds (53 times/hour). Ventilation upgrades were also made in the following areas: added two new roof vent fans, added a slot ventilator and added a centrifuge ventilator. Total added ventilation capacity following the Greenland test exceeds 5,000 cfm. The volume of the drill tent is approximately 13,760 ft3, so the exchange rate of the air is 163 sec/exchange or 22 exchanges per hour. An air monitoring sensor that has 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. IDDO completes safety assessments for all of its drill systems. For large field drilling projects such as the WAIS Divide Ice Core Project and the SPICE Core Project, IDDO 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. IDDO continued its discussions with UW Health & Safety personnel, the fluid manufacturer and the drillers, 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, IDDO would like to identify an alternative fluid to use in place of Estisol 140. A good replacement has not yet been identified, however IDDO continues to discuss this issue with its colleagues in China, who are conducting ongoing testing of potential candidate fluids. The Danes have reverted back to use of a two-part Estisol 240 and Coasol mixture for deep drilling in Greenland. DOSECC has continued to use Estisol 140 with good success with the RAID testing operations.

In 2014, under the Direction of IDPO 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 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. In addition to the study conducted at the CSM, the international ice drilling community continues to very 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 IDDO 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 IDDO group. Isopar K is a naphtha and

was used with HCFC 141b by IDDO for the DISC Drill project at WAIS Divide. The three chemicals were evaluated to assess the impact to the health and safety of the drillers 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 IDDO. IDDO used Isopar K, without the addition of a densifier, for the first deployments of both the ASIG Drill and the Winkie Drill in 2016-2017, 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, IDPO-IDDO will continue to work with international colleagues on cold temperature drilling fluids.

Current Status

While there are currently available drilling fluids, none are ideal for drilling at very cold sites. Several papers have been published about potential new 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 IDDO to look to alternative fluids for future projects. IDDO remains in discussion with its international colleagues on this matter, particularly with Dr. Talalay at the Polar Research Center at Jilin University in China.

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 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 DIRECTIVES FROM THE LONG RANGE SCIENCE PLAN 2017-2027

IDDO notes the following guiding principles for development of drilling technology expressed in the U.S. Ice Drilling Program Long Range Science Plan 2017-2027:

- 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 IDPO 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 IDDO's development projects – most recently in the fabrication of the new Sediment Laden Lake Ice Drill, the Agile Sub-Ice Geological Drill, the modification and upgrade of the new Winkie Drill system, and in iterations between IDPO, IDDO and community scientists in establishing new or updated Science Requirements for a variety of systems. IDDO also works closely with both the Arctic and Antarctic logistics providers to ensure that ease in transport of IDDO equipment and logistical support of IDDO projects is achievable. Through IDPO and IDDO's collaboration with the science community and IDPO's Science Advisory Board (SAB), IDDO ensures that the drilling systems and technologies it develops will directly support the priorities in the Long Range Science Plan. IDDO 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 2017-2027

The IDPO 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 page 5). IDPO-IDDO works to plan its investments in technology within the time frames listed in the Long Range Science Plan, however its annual schedule is influenced by a number of factors:

- 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 2017-2027, together with the corresponding IDDO 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 Shot Hole Drills, the Blue Ice Drill, the Prairie Dog, the ASIG Drill and the Winkie drill.*

   IDDO action: This is a major focus of this Plan – see related sections for each drill system.

2. *Maintain and upgrade the Intermediate Depth Drill.*

   IDDO action: This work is in progress. Remaining components arrived back in Madison in April 2017 and are being unpacked, inspected, repaired and modified as needed.

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

   IDDO action: Due to increased interest in use of the Blue Ice Drill (BID), IDDO initiated fabrication of a second BID-Deep system in late PY 2016. While the second BID is largely a replica of the original and very successful BID design, minor beneficial modifications and upgrades are being 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. IDDO expects to complete fabrication of the second BID-Deep system in PY 2018.

4. *Finish building the Sediment Laden Lake Ice Drill.*

   IDDO action: In early 2017, IDDO completed the detailed design, which was then reviewed by community scientists as well as non-IDDO technical personnel from the polar ice drilling community. Following a successful review in April 2017, IDDO made minor adjustments to the design and initiated fabrication of the system. IDDO expects to complete fabrication and testing of the system in PY 2017.

5. *Finish cost estimate, construction schedule and detailed design for upgrading the Intermediate Depth Drill to 3,000 m ('Foro 3000').*

IDDO action: In May 2017, IDDO completed a Conceptual Overview document outlining necessary changes to the IDD to enable drilling to 3,000 m. The document also identifies potential maintenance shop options for deployment with the drill at remote locations. In early June 2017, a Concept Review was held with IDPO, IDDO and several community scientists. IDPO also plans to solicit feedback on the conceptual design from polar drilling engineers from other nations. IDDO will respond to reviewer comments when received and will make modifications to the concept as necessary. During the remainder of PY 2017, IDDO also plans to research the adaptation of whipstock technology to allow for replicate coring on the downhill side of the borehole with the IDD and potentially other systems. This directive was identified in the 2016-2026 version of the Long Range Science Plan. Ultimately, the IDD system may or may not be modified pending results of the conceptual design review and availability of NSF funding.

6. *Finish the RAM Drill modifications for modularity, weight reduction and ease of logistics based on existing IDPO Science Requirements for rapidly creating shot holes.*

   IDDO action: In late PY 2016 and into PY 2017, IDDO worked with IDPO and science community representatives to finalize updated science requirements for modifications to the RAM Drill. The updated requirements call for a substantial weight reduction of the system. In PY 2017, IDDO is conducting an analysis of potential downhole equipment solutions and plans to complete the entire system-level conceptual design. Following successful review of the modified RAM Drill concept, IDDO plans to initiate the detailed design and fabrication of downhole equipment. In PY 2018, IDDO will look to complete fabrication of all modified components.

7. *Conduct Antarctic field trials of the Rapid Access Ice Drill (RAID).*

   IDDO action: Development of the RAID system was completed by the University of Minnesota-Duluth and the University of California-San Diego, with design, fabrication, and test activities being performed by DOSECC Exploration Services, LLC (DES). IDPO-IDDO helped design the initial requirements and concept for the drill. IDDO and the University of Nebraska-Lincoln have also provided reviewer capacity and field testing support when requested. The RAID team tested the system at Minna Bluff near McMurdo Station during the 2016-2017 field season. At the request of NSF and the RAID PIs, IDDO plans to send an engineer for the upcoming second test season near Minna Bluff in 2017-2018. The IDDO engineer will support auxiliary work, such as 4-Inch Drill operations at the site and operation of the DLW following drilling by the RAID. The engineer will also participate in RAID drilling activities for familiarization with that system.

Priority 2 (needed in the next 3 years):

8. *Finish building the Foro Drill system.*

   IDDO action: Good progress has been made in PY 2017 on the fabrication of this new system. Control box components have been procured and wiring is in progress. IDDO also plans to

complete the detailed design of the tower and initiate fabrication of that system. Pending availability of funds in PY 2018, IDDO hopes to largely complete fabrication of this system, due to a large number of requests for agile electromechanical drills (e.g. Eclipse, 4-Inch, Foro) in upcoming seasons.

9. *Modify the Badger-Eclipse (or Foro) drill for drilling to 700 m under conditions of limited logistics based on established science requirements.*

   IDDO action: Following finalization of the Science Requirements for the 700 m ice coring drill (final name TBD), which are expected to be completed in PY 2017, IDDO will complete a conceptual design and cost estimate for this system. Preliminary weight and cubic feet estimates for the lighter system are being provided, as they become available, to IDPO and science community representatives, to help inform future directives. Based on discussions to date, it is likely that this drill will be a modification of the Badger-Eclipse Drill, since the smaller diameter core enables a significant reduction in logistics compared to the Foro Drill core. The possibility of using less than a full hole of drilling fluid will also be assessed. Any system required to drill deeper than approximately 400 m will need drilling fluid and chip handling equipment, which increases its logistics burden. While weight savings can be had in a reduction of the amount of cable deployed, it is difficult to quantify how much lighter the surrounding infrastructure (i.e. winch, tower) could be made until the conceptual design is complete. Consideration for logistics of such a system would also be discussed with Polar Field Services (PFS; Arctic) or with Antarctic Support Contract (ASC; Antarctic) personnel.

10. *Upgrade the Electrothermal Drill to allow for coring to 300 m through temperate and poly-thermal firn and ice. The drill needs to be agile and light weight (transportable by helicopter).*

    IDDO action: IDDO will evaluate the existing electrothermal drill for its capability of reaching 300 m depth and will implement minor upgrades, as needed. Depth range may simply be a function of winch size and available cable length, of which IDDO has several options to choose from. The thermal heat rings for the electrothermal drill were purchased some time ago and are believed to now be out of production. IDDO has a small inventory of remaining heat rings but will look to identify an alternate source and supplier of the heat rings as needed.

11. *Build Foro 3000 components (i.e. IDD add-on components).*

    IDDO action: Detailed design of the Foro 3000 system is planned for completion in PY 2018. Following successful review of that design, IDDO will initiate fabrication of Foro 3000 components, as funds allow.

12. *Build a Scalable Hot Water Access drill for creating access holes in ice from 50 m up to approximately 1,000 m depth with modular potential to be used for clean access.*

IDDO action: In PY 2014, science requirements for a Scalable Hot Water Drill (ScHWD) were formalized. IDDO subsequently completed engineering requirements for the system and completed a conceptual design as well as both internal and external conceptual reviews of the concept in PY 2014. In May 2016, a proposal was submitted to the NSF for construction of the ScHWD system. Pending successful review and funding of that proposal, IDDO will initiate fabrication of the drill. This is anticipated in PY 2018. Along with fabrication of the main drill system, IDDO also plans to complete the detailed design of a sanitation unit for use with the drill.

13. *Develop science requirements for a hot water drilling system that can be used to recover ice core samples from warm sites (e.g., Chile, NZ, Asia) to 200 m depth.*

    IDDO action: Beginning in PY 2018, IDDO will work with IDPO and community scientists to draft, revise and finalize Science Requirements for this hot water coring drill.

14. *Investigate a rapid hole qualifier (temperature and caliper) for use with RAID and other borehole logging applications.*

    IDDO action: IDDO does not currently maintain any borehole logging tools within its inventory. IDDO will investigate the design or purchase of a hole qualifying tool for use with the RAID and other drill systems. This work will likely be completed in conjunction with IDDO's maintenance and upgrade of logging winches in inventory.

Priority 3 (needed in 3 to 5 years):

15. *Build replicate components of the IDD drill to enable same-year use in both the Arctic and Antarctic.*

    IDDO action: As funds allow and as requests for use of the IDD are received via science proposal submissions, IDDO will initiate fabrication of a second IDD. The second system is expected to largely be a replica of the original IDD.

16. *Continue to evaluate options for new drilling fluids.*

    IDDO action: A discussion on drilling fluid research is included at each year's IDDO Technical Advisory Board (TAB) Meeting. The Polar Research Center at Jilin University in China, headed by Dr. Pavel Talalay, a member of the TAB, is conducting ongoing research of a wide variety of candidate fluids at this time. Consideration of fluid cost, availability, conductivity, viscosity, etc. remains part of the ongoing conversation.

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, IDDO 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, IDDO 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 and current field projects supported by IDDO can be found in the Expeditions section of the IDPO-IDDO website, located at:
http://icedrill.org/expeditions/index.shtml

7.0 EXPENDITURES

IDPO-Dartmouth's Cooperative Agreement with NSF, as well as IDDO's related subaward from Dartmouth, currently runs through October 31, 2018. IDPO-IDDO are optimistic that the NSF will continue this arrangement beyond 2018 and allow IDDO to continue providing excellent equipment development and maintenance and upgrade work as well as field support for years to come. Out-year budgets beyond 2018 have been estimated with an assumption of flat funding following PY 2018. Final determination of the IDDO annual budgets for PY 2019 and beyond will determine how much funding will be available for equipment development and maintenance and upgrade of ice drilling and related equipment associated with the science projects outlined in the U.S. Ice Drilling Program Long Range Science Plan 2017-2027. Appendix 2 outlines potential development and maintenance and upgrade expenditures by program year for the next five years.

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. Expenditures needed for maintenance and upgrades are largely a function of the maturity of the equipment (fewer upgrades can be expected for proven designs than for newly developed technology) and its use. Annual expenditures for this maintenance and upgrade function have increased each year, as the number of drills in the IDDO inventory increases. IDPO-IDDO is cognizant of this issue and is considering a variety of strategies, including 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 may only require IDDO expenditures of $3,000-$5,000. Large, multi-year projects such as the SPICE Core project generally require IDDO expenditures of $400,000-500,000 per field season. Beginning with the PY 2017 budget,

IDDO has now absorbed all labor for deploying in-house staff and for drillers under its base subaward funding. As such, field support costs for labor are expected to be $500,000-$800,000 per year, depending on the number projects funded and the number of people deployed. In a flat overall funding environment, absorption of these field costs under the Cooperative Agreement will in turn affect funds available for development projects and for maintenance and upgrade work.

8.0 REFERENCES

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

Whelsky AN and Albert MR. 2016. Firn Permeability Impacts on Pressure Loss Associated with Rapid Air Movement Drilling, Cold Regions Science and Technology, doi: 10.1016/j.coldregions.2015.11.018

9.0 ACRONYMS

ARA	Askaryan Radio Array
ASC	Antarctic Support Contract (Antarctic logistics provider)
ASIG	Agile Sub-Ice Geological (Drill)
BID	Blue Ice Drill
BLWG	Borehole Logging Working Group
CSM	Colorado School of Mines
DES	DOSECC Exploration Services, LLC
DISC	Deep Ice Sheet Coring
ICDS	Ice Coring & Drilling Services
ICWG	Ice Core Working Group
IDD	Intermediate Depth Drill
IDDO	Ice Drilling Design and Operations
IDPO	Ice Drilling Program Office
ITASE	International Trans-Antarctic Scientific Expedition
NSF	National Science Foundation
OPP	Office of Polar Programs
PFS	Polar Field Services (Arctic logistics provider)
PI	Principal Investigator
PICO	Polar Ice Coring Office
PY	Program Year (formerly 'FFY' for Federal Fiscal Year; term used after Nov. 1, 2014 to signify that the IDPO-IDDO 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, utilizing DOSECC Exploration Services for fabrication and testing)
RAM	Rapid Air Movement (Drill)
SAB	Science Advisory Board
SAWG	Subglacial Access Working Group
TAB	Technical Advisory Board
SALSA	Subglacial Antarctic Lakes Scientific Access
ScHWD	Scalable Hot Water Drill
SHWD	Small Hot Water Drill
SIPRE	Snow, Ice and Permafrost Research Establishment
SLLID	Sediment Laden Lake Ice Drill
SPICE	South Pole Ice Coring Project
SSEC	Space Science and Engineering Center
UNH	University of New Hampshire
LW	Logging Winch
WAIS	West Antarctic Ice Sheet
WISSARD	Whillans Ice Stream Subglacial Access Research Drilling

Appendix 1 – Long Range Project Schedule

Legend:

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

	PY 2017	PY 2018		PY 2019		PY 2020		PY 2021		PY 2022
Equipment	**2017 Arctic**	**2017-18 Antarctic**	**2018 Arctic**	**2018-19 Antarctic**	**2019 Arctic**	**2019-20 Antarctic**	**2020 Arctic**	**2020-21 Antarctic**	**2021 Arctic**	**2021-2022 Antarctic**
2-Inch Drill [1]	System slated for decommissioning									
4-Inch Drill 1										
4-Inch Drill 2				2 proposed						
Agile Sub-Ice Geologic Drill								2 proposed		
Badger-Eclipse 1 [2]				2 proposed		2 proposed				
Badger-Eclipse 2 [2]	2 funded			2 proposed						
Badger-Eclipse 3										
Blue Ice Drill/Blue Ice Drill-Deep 1			2 proposed			2 proposed				
Blue Ice Drill/Blue Ice Drill-Deep 2										
Chipmunk Drill										
DISC Drill	Will be repaired/upgraded as community priorities dictate									
DISC – Replicate Coring System	Will be repaired/upgraded as community priorities dictate									
Drill Fluid Development										
Foro Drill - 400 m										
Foro Drill - 700 m [3]										
Foro Drill - 3000 m										
Hot Water Corer for Warm Sites [4]										
Intermediate-Depth Drill 1										
Intermediate-Depth Drill 2										
Koci Drill [1]	System slated for decommissioning									
Logging Tower										
Logging Winch - IDDO Intermediate Depth										
Logging Winch - IDDO Deep										
Logging Winch - USGS [5]										
Logging Winch - IceCube [6]										
Prairie Dog										
Rapid Hole Qualifier [7]										
RAM (Rapid Air Movement) Drill						2 proposed		2 proposed		
Scalable Hot Water Drill		Development TBD								
Sediment Laden Lake Ice Drill										
Shaw Backpack Drill [8]										
Small Hot Water Drill 1										
Small Hot Water Drill 2										
Stampfli 2-Inch Drill										
Thermal Drill				3 proposed						
Winch Simulator Circuit										
Winkie Drill						2 proposed				
Sidewinder (5 available)	2 funded	1proposed	1funded	7 proposed		1proposed				
Hand Auger, 3" PICO (7 available)				Phasing out						
Hand Auger, 4" PICO (2 available)				Phasing out						
Hand Auger, 3" IDDO (8 available)	2 funded	1funded, 1 proposed	1funded	6 proposed		1proposed				
Hand Auger, 4" IDDO (3 available)										
Hand Auger, SIPRE (6 available)	1funded									

[1] IDDO exploring decommissioning of this system; function largely replaced by newer systems in inventory.

[2] Solar/wind power capabilities available.

[3] Conceptual study to be conducted. Drill may be similar to Foro/IDD or Eclipse. Results of study will help inform if system will be built.

[4] Science Requirements to be established by PY 2020 or earlier. Conceptual design/fabrication will be completed as community priorities dictate.

[5] Winch transferred from USGS to IDDO inventory in 2014.

[6] Winch will be added to IDDO inventory after use by the University of Nebraska with the WISSARD system.

[7] Planned purchase or development in conjunction with Logging Winches maintenance and upgrade.

[8] Off the shelf unit identified for proposed project in 2018-2019; will be purchased if project is funded.

Appendix 2 – Estimated Costs for Equipment Development and Maintenance & Upgrade Projects

PY 2017 - PY 2022

Development or Maintenance & Upgrade Project	PY 2017 (Current)	PY 2018	PY 2019	PY 2020	PY 2021	PY 2022	Total (PY 2017-2022)
4-Inch Drill	18,776	30,000	30,000	30,000	30,000	30,000	**168,776**
ASIG Drill	151,049	150,000	50,000	50,000	50,000	50,000	**501,049**
Badger-Eclipse Drill	69,621	70,000	30,000	20,000	15,000	15,000	**219,621**
Blue Ice Drill [1]	149,993	95,000	25,000	25,000	25,000	25,000	**344,993**
DISC Drill [2]	19,955						**19,955**
Drill Fluid Evaluation					10,000	10,000	**20,000**
Foro Drill	141,271	230,000	15,000	35,000	20,000	15,000	**456,271**
Foro 700 Drill				40,000	900,000	460,000	**1,400,000**
Foro 3000 Drill		65,000	475,000	505,000	85,000	60,000	**1,190,000**
Hand Augers [3]	58,316	30,000	15,000	15,000	15,000	15,000	**148,316**
Hot Water Corer 200 m [4]				10,000			**10,000**
Intermediate Depth Drill [5]	180,271	90,000	80,000	130,000	250,000	750,000	**1,480,271**
Logging Winches [6]	51,366	40,000	15,000	15,000	15,000	15,000	**151,366**
RAM Drill Upgrades	167,468	300,000	100,000	15,000	15,000	15,000	**612,468**
Scalable Hot Water Access Drill [7]		520,000	730,000	660,000	150,000	115,000	**2,175,000**
Sediment Laden Lake Ice Drill	85,123	15,000	10,000	10,000	10,000	10,000	**140,123**
Small Hot Water Drill			15,000	15,000	15,000	15,000	**60,000**
Stampfli Drill	83,850	5,000	5,000	5,000	5,000	5,000	**108,850**
Thermal Drill [8]		105,000	5,000	5,000	5,000	5,000	**125,000**
Winkie Drill	88,638	75,000	15,000	15,000	15,000	15,000	**223,638**
TOTAL COSTS	**1,265,697**	**1,820,000**	**1,615,000**	**1,600,000**	**1,630,000**	**1,625,000**	**9,555,697**

[1] PY 2017 and PY 2018 costs include building a second BID per the 2016-2026 Science Plan.
[2] Funds will be reallocated for DISC Drill maintenance and upgrade if the drill is selected for use at Herc Dome; if this occurs, Foro 3000 will likely not be built.
[3] PY 2018 costs include funds to modify the Sidewinder units to remove the cleats on the stem.
[4] PY 2020 costs include development of science requirements with IDPO and community scientists.
[5] PY 2021 and PY 2022 costs include fabrication of a second (replica) Intermediate Depth Drill, per the 2017-2027 Science Plan.
[6] PY 2018 costs include development of science requirements for a Rapid Hole Qualifier and potential design/fabrication or procurement of an OTS unit.
[7] Proposal under consideration for fabrication; PY 2018 costs include detailed design of ScHWD Sanitation Unit as well as initiation of general component purchases.
[8] PY 2018 funds include upgrading the Thermal Drill to allow coring to 300m, per the Long Range Science Plan.

NOTE: PY 2019 - PY 2022 estimates are subject to change based on levels of NSF funding, the number of deployments/associated required maintenance for each system and annually updated technology investment priorities in the Long Range Science Plan.

	Equipment Development
	Maintenance & Upgrade