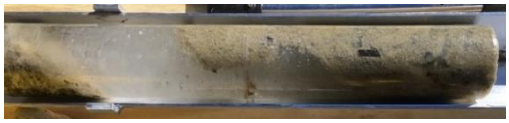
Ice Drilling Design and Operations

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) Foro 400 Drill testing at the IDDO Drill Development and Maintenance Facility; (upper right) Testing of the new RAM Drill compressors; (lower right) PI Ryan Bay with the Deep Logging Winch at Minna Bluff, Antarctica; (lower left) a mixed media core collected in Ong Valley, Antarctica using the Winkie Drill

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 2018-2028 Update:

General highlights and changes:

- Sediment Laden Lake Ice Drill fabrication, assembly and in-house testing completed; the system is now ready for issue.
- Noted completion of the conceptual design of the sanitation unit for the Scalable Hot Water Drill (ScHWD) system design.
- Delaying fabrication of the ScHWD system per NSF direction.

Additions:

- Plan to resolve electromagnetic interference issues experienced with the IDDO Deep Logging Winch.
- Plan to complete the conceptual design for a Foro 700 Drill.
- Plan to initiate fabrication of a second Winkie Drill.
- Plan to have one IDDO engineer participate in the RAID maintenance activities near McMurdo Station, Antarctica during the 2018-2019 field season.
- Plan to investigate lighter weight sources of power to replace generators for drilling operations.
- Added a description of IDDO's philosophy for the Foro class of drill systems in section 2.0.

Deletions:

- 'Conduct Antarctic field trials of the Rapid Access Ice Drill (RAID)' removed from the Recommended Technology Investments listed in the corresponding Long Range Science Plan as well as in this document.

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 2018-2028.

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.
- Complete repairs to the Intermediate Depth Drill and integration of its updated control system.
- Finish building a stand-alone Foro 3000 Drill as per the IDPO Science Requirements.
- Develop the conceptual design for a Foro 700 Drill for drilling to 700 m under conditions of limited logistics as per the IDPO Science Requirements.
- Initiate fabrication of a second ice-ready Winkie Drill.
- Develop IDPO 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.

Priority 2 (needed within the next three years):

- Finish building the Foro 400 Drill system.
- Finish fabrication of a second ice-ready Winkie Drill.
- Build duplicate components of the Intermediate Depth Drill to enable same-year use in both the Arctic and Antarctic.
- Finish building a second Blue Ice Drill for wide-diameter drilling to 200 m.
- 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 capability to be used for clean access.
- Investigate a rapid hole qualifier (temperature and caliper) for use with RAID and other borehole logging applications.
- Resolve logging winch electrical noise issues.

Priority 3 (needed within three to five years):

- Continue to evaluate options for new drilling fluids, and exploring/testing shallow drill fluid columns.
- Investigate a lighter weight source of power to replace generators for drilling systems, in order to ease demand on logistics, including renewable energy.

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.

One of the guiding principles for development of drilling technology expressed in the U.S. Ice Drilling Program Long Range Science Plan 2018-2028 prescribes that *"Major drilling systems (e.g. sondes, winches, control and other major electronics systems) should be fungible to the maximum extent possible. Major component inter-changeability and logistical agility should be essential deliverables for all new drilling technology projects."* IDDO has made recent strides in this area by envisioning and initiating fabrication of the Foro Drill series. The term 'Foro' in Latin means "to bore or to make a hole". Through the design of similar drill systems with varying depth capabilities and the implementation of interchangeable components, IDDO is committed to pursuing the efficient deployment of systems, a reduction in the level of logistics required and lower overall design and maintenance costs. Some of these systems, such as the Foro 400, will replace aging drills that are past their useful life (e.g. 4-Inch Drill), while others like the Foro 3000 will dramatically decrease the amount of logistics required to collect cores to a certain depth. Finally, others will fill a void where capability does not currently exist, but is highly desired (e.g. Foro 700).

The following sections provide a brief history of each piece of equipment in the 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 41 mm (1.6-inch) diameter cores in solid ice. It has two barrels, one 15 cm long and one 50 cm long. The drill has been used on one funded project (for which it was designed) at Pakitsoq, West Greenland, in 2003 and 2004, for exploratory work at the South Pole in 2013, and for several demonstrations of ice coring for the public in the U.S.

Current Status

The drill is functional, but improvements are needed.

Technical Issues

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

Plans

While 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 half-meter or one-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 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. Recently, an issue has been experienced with the IDDO hand augers where the aluminum drilling extensions can become fused or bonded together during field use, preventing the user from disassembling the sections.

Plans

1. Develop a plan and implement modifications to the IDDO hand auger extension couplers to prevent fusing – PY 2018.
2. Improve hand augers based on feedback from users – Ongoing.
3. Continue to phase out aging PICO equipment – 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

Five working systems are available. In PY 2018, IDDO initiated a minor redesign effort to remove the cleats from the stem, allowing for ease and safety of operations.

Technical Issues

While no known operator safety issues have occurred during use of the Sidewinder, an assessment of the units by IDDO engineers showed that the cleat setup could pose a personnel safety hazard. The cleat components are also integrated with the braking system of the unit. In PY 2018, IDDO is implementing minor changes to the system to remove the cleats and modify the brake. Prototype parts have been fabricated and installed in one unit and will be implemented in the remaining four kits in inventory.

Plans

1. Implement cleat and braking system modifications across the Sidewinder inventory – PY 2018.
2. Maintain Sidewinder systems – Ongoing.
3. Review and update documentation – Ongoing.
4. 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, ready for issue and IDDO has seen a recent increase in requests for its use. The Prairie Dog is typically operated by one IDDO engineer/driller with assistance from the science team.

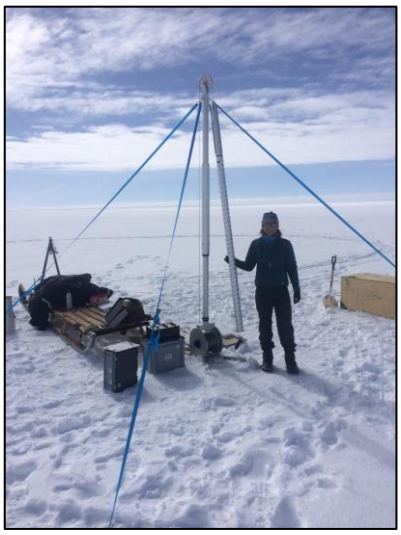
Technical Issues

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. General maintenance and modification – Ongoing as needed.

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. Two drillers were able to put the small, solar-powered system through its paces and subsequently drafted a comprehensive test report. In late 2017, IDDO completed minor maintenance and repairs, identified and procured spare parts, and procured shipping cases and bags for modularity and very lightweight deployment. IDDO also purchased a lightweight Tentipi Safir tent for use with the system. IDDO engineers also designed a new aluminum cutter head with removable steel cutters, as the original manufacturer's design employed a one piece aluminum head with cutters machined in. The removable steel cutters are expected to be more durable and will save costs on head replacement. The system was recently deployed for an NSF-funded field project in the Yukon Territory, Canada, where it was operated by the science team.

Technical Issues

None known.

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 (BID) is an agile drill capable of retrieving cores of approximately 9-1/2 inches (241 mm) in diameter. The BID system had a depth capability of 30 m in solid ice in its original design and has been used successfully in both Greenland and Antarctica for many years. In PY 2014, the system was modified to allow for deeper coring to 200 m depth at the request of the scientific community. A new cable winch and tower were implemented in the design as well as several new down-hole components. The control box was modified as well. 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. The current equipment has likely reached its operational limits and assuring depths of 200 m would require a re-design of the system. The standard BID typically utilizes a ropes setup for coring to shallow depths, and the cable winch is used for achieving greater depths. The drill has been used extensively in both the Arctic and Antarctic. 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.

Current Status

Fabrication of the second system continued in 2017, but was temporarily suspended in late 2017 due to budget constraints and decisions on the funding of field projects. In early 2018, IDDO engineers implemented modifications to the original BID footplate assemblies to make them more robust. IDDO is also working with a vendor to design and fabricate a tent enclosure that attaches to the BID tripod.

Technical Issues

Collecting good core quality at greater depths has proven to be an issue. 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, 70 m depth in a firn-free area in Taylor Valley in Antarctica. 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.

Plans

1. Maintain the BID and BID-Deep components – Ongoing.
2. Complete fabrication of the second BID-Deep as funding allows and based on user need – PY 2022 and PY 2023.
3. Work with IDPO and the science community to explore fabrication of a BID 300 m Drill – PY 2022 and PY 2023.

Badger-Eclipse Drill

The Badger-Eclipse Drills are modified Eclipse Drills originally manufactured by Icefield Instruments, Inc. The drill is an electromechanical system capable of collecting 81 mm diameter cores 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 at the University of Wisconsin in 2010.

In 2013, IDDO designed and fabricated a solar and wind power system for use in operation of the drill, which 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. IDDO also owns two Mountain Hardwear Space Station tents for use with the Badger-Eclipse Drill systems. The tents have allowed drilling operations to continue safely and reliably during inclement weather on recent projects in Alaska, Greenland and Antarctica, where drilling progress would have been halted had the tents not been available. In 2017, IDDO completed a full redesign of the aging control boxes and readout boxes to provide for simplified operation, weight reduction and new sealed cases. In 2018, new cover panels were implemented for the traversing system. New cases were also procured for the motor section and tower frame. New load pins and load pin amplifiers were implemented and tested to make the load sense circuit more robust.

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 has since implemented numerous minor, but very beneficial modifications to the drills.

Technical Issues

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

Plans

1. General maintenance and repairs – Ongoing.
2. Complete documentation and enter into database – Ongoing.
3. Ready third Eclipse Drill system for issue – As needed.

4-Inch Drill

The 4-Inch Drill is an electromechanical ice coring drill that takes a 104 mm (4-inch) diameter core. Cores can be retrieved from depths to approximately 400 m. Winches with 100, 200, and 400 m cables are available. The drill is of a mature design and has been used successfully for several decades. It is particularly useful on projects requiring a larger diameter core than that produced by the Badger-Eclipse drills. Depending on the configuration, the drill can be transported by light aircraft or helicopter.

The 4-Inch Drill was most recently used in conjunction with field testing of the Rapid Access Ice Drill (RAID) system outside of McMurdo Station near Minna Bluff during the 2017-2018 Antarctic field season. A 131-meter core of good quality was drilled and firn-air samples were collected from nine separate depths. The drilling effort also aided in determination of the depth of the firn-ice transition at the site, providing valuable data for the nearby RAID field testing operations.

Current Status

IDDO currently has two 4-Inch Drill systems ready for issue. A new set of barrels was machined and tested during two recent Antarctic field 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. An Operator's Manual, complete with Preventive Maintenance checklists, was drafted and refined in PY 2018 using operator feedback. To meet continued demand of a drill of this type, IDDO has designed and is nearing completion of fabrication of the new Foro Drill (see below). A 4-Inch Drill system will still be maintained; however, the Foro 400 Drill will offer new capabilities and substantial weight savings.

Technical Issues

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

Plans

1. Perform general maintenance and repairs – Ongoing.
2. Maintain at least one each of the 100, 200, and 400-meter winches – Ongoing.
3. 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 76 mm (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. The sonde 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 used 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. From discussions with PIs and IDPO, IDDO anticipates that the Thermal Drill may see more use in the upcoming years. As called for in the Long Range Science Plan, IDDO began exploring upgrades to the Thermal Drill in PY 2018 to allow for coring to 300 m. Input was solicited from community scientists and IDPO. Primary upgrades will include new heat rings with current/temperature limiting features, a new 300 m water-shedding cable, a magnetic tool to aid in core removal and an ethanol delivery mechanism.

Technical Issues

IDDO currently has a small stock of older heat rings, the exact model of which is now out of production, but has identified a suitable replacement. Inasmuch as the cable winch sleds are the 4-Inch Drill sleds, they are very heavy, making the drill not optimal for transport by small aircraft if depths beyond approximately 30 m are desired. The new Foro Design (see below) will offer weight savings in this area and will eventually be compatible with the Thermal Drill sonde. With minimal design and fabrication work, the Thermal Drill could also be adapted for use with the Badger-Eclipse Drill winch and tower.

Plans

1. Upgrade the drill to increase its performance capability to 300 m depth – PY 2018.
2. Design and implement an ethanol delivery mechanism – PY 2018.
3. Test the 300 m system in conjunction with the Juneau Icefield Research Program – PY 2019.
4. Perform maintenance and repairs – As needed.

Foro 400 Drill

In PY 2015, improvements for the 4-Inch Drill, based on driller feedback and utilizing more recent and proven designs from other IDDO drill systems, were initiated through design of the Foro 400 Drill. 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 will produce 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 2015, IDDO established the name Foro Drill for the new components, so that distinguishing between the old and new equipment would be more straightforward. The name 'Foro' is Latin for "to make a hole, pierce or to bore". 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. Continued progress was made in PY 2017 with the fabrication of the winch and tower. Sonde and control box fabrication was initiated in PY 2018.

Current Status

IDDO is currently in the final stages of sonde and control box fabrication. Following completion of those components, bench testing will be completed for the entire system. IDDO expects to complete fabrication of this system by the end of PY 2018 or in early PY 2019.

Technical Issues

Not applicable; system currently being fabricated.

Plans

1. Complete fabrication and assembly of all Foro Drill components – PY 2018 or PY 2019.
2. Complete in-house testing of Foro Drill system – PY 2018 or PY 2019.
3. Complete drill system drawings and enter into database – Ongoing.

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 and are typically used to produce holes 100-200 mm in diameter down to a maximum practical depth of 60. 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 to 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 users of the system. In recent years, IDDO 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, it is envisioned that the Scalable Hot Water Drill (see section below), designed by IDDO but not yet built, would 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. The 60 m SHWD system is slated to deploy in the fall of 2018.

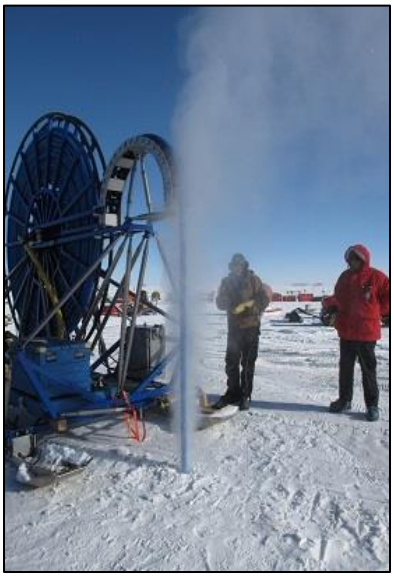
Technical Issues

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 Rapid Air Movement (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, where it routinely achieved 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 are now driving substantial modifications and upgrades to the drill system to reduce its logistical requirements. IDDO engineers completed a conceptual design for the modified/upgraded system, which will have scalable components for either shallow (~40 m) deployments or for full 100 m deployments. The modifications are serving to dramatically reduce the system weight from approximately 24,000 lbs. to about 8,000 lbs. and will 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 to characterize necessary air flow and design downhole tooling. IDDO is now in the final stages of assembly and in-house testing of the modified system. A field test is planned near Raven Camp in Greenland in July 2018, after which repairs and additional modifications will be made as needed, prior to the drill's deployment to Thwaites Glacier in Antarctica in September 2018.

Technical Issues

While the drill worked well in its previous configuration, additional modifications were deemed necessary 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).

Plans

1. Complete modifications for modularity, weight reduction and ease of logistics – PY 2018.
2. Complete field test of system in Greenland – July 2018.
3. Make post-field test modifications and repairs – August/September 2018.
4. Ship system to Antarctica for Thwaites Glacier project – September 2018.
5. Complete drill system drawings and enter into database – PY 2018 and PY 2019.
6. Develop operating procedures and other procedural documents – PY 2018 and 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. IDDO engineers developed a list of necessary modifications and upgrades and are currently completing those tasks as time allows.

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 RAID system 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. Modify and repair components – PY 2018 and PY 2019.
2. Enter completed documentation for the drill system into the documentation database – PY 2018 and ongoing.
3. Purchase remaining drill rod to enable drilling to 700 m depth – PY 2022.

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 during that initial season, drilling 8 holes between 12-54 m depth. Rock cores between 28-67 cm in length were collected in five of the holes and a semi-consolidated sediment core was retrieved from one hole. Modifications were made following that season to accommodate a request for larger core diameter as well as the replacement of the gas engine for an electric motor, for improved reliability and to allow for operation within an enclosed space such as a tent. Following those upgrades, the drill was again used successfully during the 2017-2018 season in Ong Valley, Antarctica, where two continuous mixed-media cores were collected to a depth of 9.45 m and 12.36 m. The system is expected to ship to Antarctica in September 2018 in advance of a planned project at Thwaites Glacier during the 2019-2020 field season.

Current Status

IDDO received the drill back from Antarctica in May 2018 following the recent deployment to Ong Valley. IDDO engineers are making repairs and have initiated modifications to allow the system to be utilized in areas where surface firn covers the ice and bedrock below. Casing components are being implemented as well as a packer device to seal off the porous firn layer and allow for continuous circulation of drilling fluid during operations. The drill has largely replaced the ‘dirty ice’ drilling functionality of the Koci Drill system, which will likely be decommissioned.

Technical Issues

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

Plans

1. Enter completed documentation into the documentation database – PY 2018 and ongoing.
2. Make repairs to the system following the 2017-2018 field season – PY 2018.
3. Modify the Winkie Drill for drilling in areas of firn – PY 2019.
4. Fabricate a second Winkie Drill system – PY 2019 and PY 2020.
5. Repair and maintain the Winkie Drill system(s) – 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 a drilling speed of less than 30 minutes for a 5-inch hole through a 6 m ice cover. Drill components are small, lightweight and are able to be lifted by a maximum of two people. The drill has stand-alone capability for operation at small field camps at remote sites with no heavy equipment and is intended to be PI/science team operable. Components that allow for clean access drilling were also incorporated in the design.

Current Status

Fabrication, final assembly and in-house testing of the drill were completed at IDDO in fall 2017. The system is now ready for issue.

Technical Issues

None known; system has not yet deployed.

Plans

1. General maintenance and repairs – As needed.
2. Develop operating procedures and other procedural documents – PY 2019.

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. The drill is currently able to recover cores up to 3.5 m long per run. 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 (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 would 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).

Current Status

Disassembly and packing of the remaining equipment was completed at WAIS Divide in 2015-2016. A majority of the DISC Drill components have been returned to Madison, however a few components, including the MECC machine shop remain at McMurdo Station. These components are expected to return to Madison in spring 2019. Per discussions between IDPO, IDDO and community scientists, the next deep U.S. drilling project is likely planned for Hercules Dome. In 2017, IDDO worked with IDPO and science community representatives to complete a DISC Drill vs. Foro 3000 (see description below) analysis, to help determine which system should be used for drilling at Hercules Dome. The community consensus is that IDDO should instead pursue development of the Foro 3000 Drill, which entails upgrades to the less logistically intensive Intermediate Depth Drill.

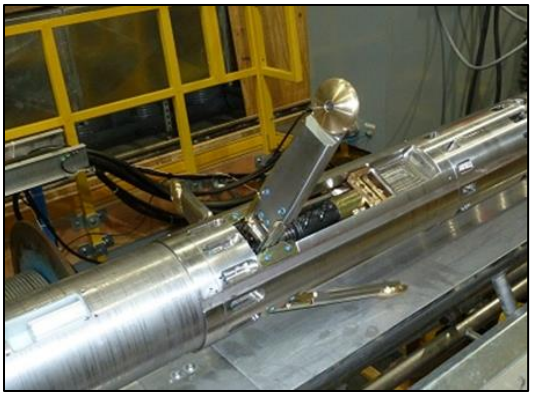
Technical Issues

The obsolescence and the resulting inability to source replacement components, particularly electronics, was an ongoing challenge throughout operation of the drill at WAIS Divide. This challenge will persist throughout the useable lifetime of the drill. A new drill fluid would 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 a future deployment of the system – Ongoing.
2. Determine components that need to be replaced to make the drill ready for a future deployment – 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 will continue to be unevenly distributed versus depth. The inventory of cores is being 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 samples at selected intervals, termed replicate coring, addresses these concerns and adds value to the scientific return from ice coring. In many applications, 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 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.

At the urging of the science community, IDDO engineers undertook evaluation of a less complex replicate coring method that might be applied with the Intermediate Depth Drill and, in turn, the Foro 3000 Drill. A *Replicate Coring System for 98mm Electromechanical Drill – Whipstock Conceptual Documentation* report was completed, describing a more passive replicate coring approach through implementation of a whipstock device, similar to those used in the oil and gas industry. IDDO believes this concept shows promise for successful implementation at Hercules Dome with the Foro 3000 Drill.

Current Status

The replicate coring-specific equipment of the DISC Drill system (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 its next deployment call; however, it is expected that the Foro 3000 Drill, once built, will largely replace the need for maintaining the DISC Drill.

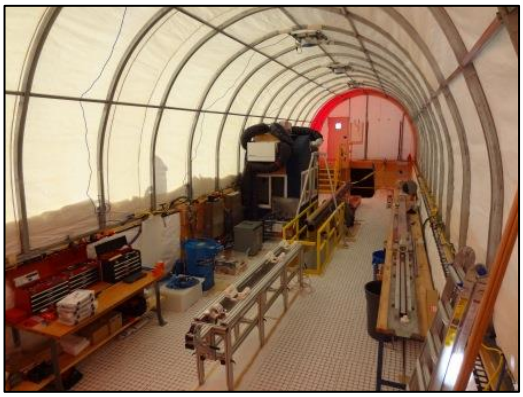
Technical Issues

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 a future 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 are achievable using an intermediate-depth drill, meaning one that can collect core from a fluid-filled hole down to a depth of approximately 1,500 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 Drill and built a new system. The system was field-tested outside of Summit Station, Greenland in spring 2014 and was recently used in the successful completion of the SPICEcore project near 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 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 working with Mage Controls Ltd., on the drill's control system and on implementing beneficial sensors (e.g. temperature, pressure, inclination). Following the purchase of new drill cables, the estimated attainable depth for the IDD is now 1,650 m.

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 SPICEcore project. Substantial delays in fabrication, acceptance testing and troubleshooting of the new control system components from Mage Controls Ltd. have delayed completion of the system's maintenance. ESTISOL 140 was used as a drilling fluid for both the drill test in Greenland as well as for the SPICEcore project. IDDO drillers, however, experienced irritating side effects during use of the fluid. See section on Drilling Fluid. Issues were also experienced with shorting of the drill cables. It is believed the shorting could be caused by flat spots in the cable, which 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 2018 and PY 2019.
2. Enter completed documentation into the documentation database – PY 2018 and ongoing.
3. Initiate fabrication of a second Intermediate Depth Drill system – This is being completed as part of the Foro 3000 Drill development, which will essentially contain its own IDD.

Foro 700 Drill

Per the Long Range Science Plan, a system similar to the existing Intermediate Depth Drill (1,650 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. In 2017 and early 2018, IDDO iterated with IDPO and community scientists on requirements for such a drill. The resulting requirements were finalized in March 2018.

Current Status

Following the recent finalization of the science requirements, IDDO plans to initiate the Conceptual Overview of a 700 m drill system. This overview would then be reviewed both internally at IDDO and externally with IDPO and community representatives prior to completion of the Detailed Design and subsequent fabrication.

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. Complete Conceptual Overview of Foro 700 system – PY 2019.
2. Complete Detailed Design of Foro 700 system – PY 2019.
3. Complete fabrication of Foro 700 system – PY 2019-2021.

Foro 3000 Drill

Beginning in PY 2016, IDDO began working with IDPO, science community representatives and Antarctic Support Contract (ASC) personnel 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 (IDD), now referred to as the Foro 3000 Drill. In May 2017, IDDO completed a Conceptual Overview document outlining necessary changes to the IDD to enable drilling to 3,000 m. The document identified 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. During the remainder of PY 2017, IDDO researched 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. IDDO subsequently completed a DISC Drill vs. Foro 3000 Drill Analysis report in October 2017, which outlines the size and weight of each system, transport options for moving each system to the next proposed deep drill site, quantity of fuel and drilling fluid needed for each system, the number of IDDO personnel required for operations, the number of ASC camp staff required, and other logistical concerns. The report ultimately helped inform IDPO, NSF, and the science community's decision to move forward with fabrication of the Foro 3000 Drill in advance of the next deep drilling project.

Current Status

Based on community consensus and support, the NSF has encouraged IDDO to proceed with modification and upgrade of the IDD to result in availability of the Foro 3000 Drill for the next deep drilling project, tentatively anticipated to occur at Hercules Dome. IDDO engineers have initiated the design of the new, longer sonde and larger winch drum to accommodate 3000 m of cable. Fabrication is expected to continue in PY 2019 through PY 2021.

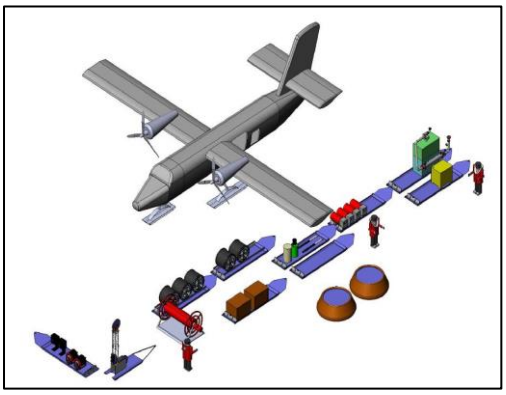
Technical Issues

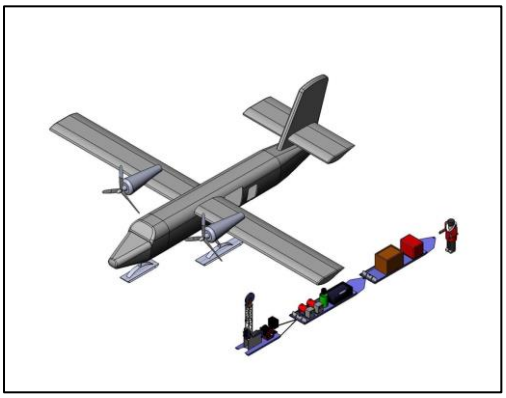
The Foro 3000 Drill is expected to be a relatively simple and straightforward expansion of the Intermediate Depth Drill currently in IDDO inventory. The Foro 3000 Drill would make use of a majority of the IDD components, and implementation of Foro 3000 components would be reverse compatible, enabling the IDD to revert to a more agile 1,650 m system as needed.

Plans

1. Complete detailed design of the Foro 3000 Drill – PY 2018 and PY 2019.
2. Complete fabrication of the Foro 3000 Drill – PY 2019 through PY 2021.
3. Deploy the drill to Antarctica – Future field project needs and funding will determine availability; currently anticipated in fall 2021.

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. This design is known as the Scalable Hot Water Drill (ScHWD).

Current Status

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

IDDO expects that components of the Kamb-Engelhardt Drill, 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. In September 2017, IDDO engineers drafted a *Preliminary Evaluation of Hot Water Sanitation Unit for Application to Scalable Hot Water Drill (ScHWD)* report.

Technical Issues

Not applicable; system is not yet built.

Plans

1. Initiate fabrication of the ScHWD – Contingent upon available budget and NSF approval; will be completed as community priorities dictate.

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 former 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, with each organization providing troubleshooting support to the other via phone throughout the fieldwork. The RAID system completed its first Antarctic Field Trial (AFT-1) at Minna Bluff during the 2016-2017 field season. The 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. During the following field season, or the AFT-2, an IDDO engineer was onsite for related coring and logging projects nearby, and was invited to view the RAID operations and testing. The RAID team was ultimately unable to complete their objective to drill through 700 m of firn at the site and to collect bedrock core below, stemming from the creation of a larger amount of chips than planned and lack of a technique to remove those cuttings. Additional issues with fluid and pressure loses due to hydrofracture events, un-optimized downhole tooling, and issues with the Fluid Recovery System (FRS) were also experienced.

Current Status

Following the recent AFT-2 and disengagement of DES from the RAID project, the University of Minnesota-Duluth and University of California-San Diego PIs are working with the NSF to determine the next steps forward. The PIs are currently planning for a short field season in January-February 2019 to complete inspection and maintenance on the drill, the FRS, the generators and the hydraulic system and

implementation of modifications and upgrades to the drill modules. Some functional testing is also anticipated for the hydraulic system, the re-designed auger tools, the FRS, pumps, tank levels, and gauges. Following discussion with the RAID PIs and the NSF, IDDO anticipates one of its engineers will play a lead role in this maintenance season. Following completion of these tasks, the NSF will determine if a third test season (AFT-3) is necessary at Minna Bluff.

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 2017-2018 field season for logging the SPICEcore 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 and more recently to Minna Bluff during the 2017-2018 field season. IDDO engineers implemented several user-recommended upgrades for the IDLW in PY 2017, including the addition of a cable grip and means of shifting gears under load, as well as re-design of the encoder scraper to allow it to function in both directions (i.e. descent and ascent). Repairs and upgrades for the DLW were also implemented and include the addition of LabVIEW program instructions, adjustment of the tension reading (calibration, noise, and oscillation), addition of a cable grip, troubleshooting of a knocking sound witnessed in the field, 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.

In PY 2014, the United States Geological Survey (USGS) gifted its 4,000 m logging winch to the University of Wisconsin-Madison for continued use by the polar logging community. The winch has been used extensively for logging boreholes in both Greenland and Antarctica and was most recently used during the 2014-2015 Antarctic season for logging at WAIS Divide. Following arrival of the winch in Madison, 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 May 2018, IDDO engineers are now executing a plan of careful inspection, repair and upgrades of the two winches. IDDO also periodically works with PIs to test communications and compatibility of their logging tools with the logging winches at IDDO's off-campus warehouse facility. Depending on the availability of funds and labor, IDDO also plans to investigate the design or purchase a rapid hole qualifier unit for use in borehole logging applications.

Technical Issues

The current IDLW cable, owned by the IceCube project, sustained some damage during the 2017-2018 field season. IDDO engineers have unspooled the cable and have performed an initial assessment. Electrical conductivity through the cable has also been tested. IDDO is working with the IceCube team to determine next steps. The system is expected to be shipped back to Antarctica this summer for operation by the science team again in 2018-2019. Despite the fact that the DLW was not actually utilized during the 2017-2018 season, due to the RAID system's inability to create a borehole to depth, an IDDO engineer was able to work with a PI onsite in the field to determine that electrical noise issues, similar to those experienced at WAIS Divide, require additional mitigation. IDDO engineers are currently evaluating options to address the electromagnetic interference (EMI) issues that persist when logging tools are attached to the DLW. 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 and 2017-2018 field seasons. IDDO has not deployed the USGS winch since it was transferred to IDDO. It will require maintenance prior to any future deployments.

Plans

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

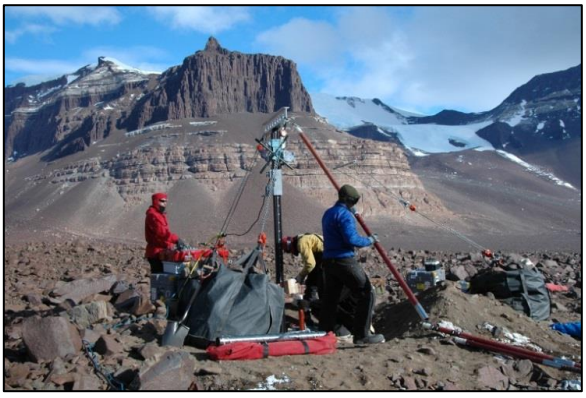
3.0 SYSTEMS SLATED FOR DECOMMISSIONING

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 systems 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 has now been replaced by the recent purchase of a 2-inch Stampfli Drill system (see Stampfli Drill section).

Koci Drill



The Koci Drill, named after the late drill engineer Bruce Koci, 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. Community 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 Ispopar K and HCFC 141b drilling fluid used at WAIS Divide and on several European drilling projects is a necessity for the continuation of intermediate and deep coring projects. A few possible substitutes have been identified: n-butyl acetate, dimethyl siloxane (silicone) oil, and an ESTISOL-COASOL mixture. Butyl acetate has been used by both the U.S. and the Japanese programs in the past, and is currently being used by the Chinese program, but because of the health risks associated with the chemical, 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. 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 SPICEcore drilling project recently completed 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 and new gloves and aprons to be worn over the drilling suits. These efforts primarily focused on decreasing the amount of fluid that ends up on the drillers' work suits and identifying a glove that is more chemically resistant to the ESTISOL 140. Following the Greenland field test in 2014, IDDO also made substantial modifications

to the IDD ventilation system, including the addition of active ventilation components for the driller control room to ensure continuous air flow and to induce an air flow pattern that pulls room air down and away from the occupants' breathing area and workspace. The system uses an energy recovery ventilator (ERV) and two inline duct heaters to circulate enough air to replace the volume of air inside the control room every 67 seconds (53 times/hour). 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 SPICEcore 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 international colleagues. The Danes have reverted back to use of a two-part ESTISOL 240 and COASOL mixture for deep drilling in Greenland. It is anticipated that ESTISOL 140 will be used with the RAID system.

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 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 deployment of the ASIG Drill in 2016-2017 and with the recent deployments of the Winkie Drill in 2016-2017 and 2017-2018, 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 its international colleagues and CSM on cold temperature drilling fluids.

Current Status

While there are currently available drilling fluids, none are ideal for drilling at very cold sites. Several papers have been published about potential fluids, including a summary issued in 2011 by the Chinese Polar Research Center (Pavel G. Talalay, *Drilling Fluids for Deep Coring in Central Antarctica*, Technical Report PRC 02-23011, Jilin University, China, December 2011) and several articles published in the Annals of Glaciology, Vol 55, No. 68, 2014. While use of ESTISOL 140 is advantageous for maintaining the borehole, the fluid's strong odor and tendency to readily vaporize in warmer areas, such as the drilling control room and facilities used to dry driller clothing, will lead IDDO to look to alternative fluids for future projects. IDDO remains in discussion with its international colleagues on this matter, as well as with Dr. Eustes at the Colorado School of Mines. In April 2018, IDDO shipped samples of three fluids to CSM for further testing, including Isopar K, Crystal 205ST and Crystal 200. CSM also plans to test a number of new Calsia drilling fluids manufactured by Calumet Specialty Products Partners, L.P. Dr. Eustes and his team are exploring use of new micronized weighting products that can remain suspended in fluids and can serve as a densifier. They intend to perform tests on how well the product mixes with each fluid sample, the density and temperature relationships, and the rheological properties versus temperature. They also plan to evaluate settling rates of the micronized product in each sample.

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 and the Colorado School of Mines 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 2018-2028

IDDO notes the following guiding principles for development of drilling technology expressed in the U.S. Ice Drilling Program Long Range Science Plan 2018-2028:

- 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 and maintenance/upgrade projects – most recently in the fabrication of the new Sediment Laden Lake Ice Drill, the substantial redesign of the RAM Drill, modification and upgrade of the Winkie Drill system, upgrades to the Thermal Drill equipment, development of the Foro 3000 concept 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 2018-2028

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 2018-2028, 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. IDDO is working with Mage Control Systems Ltd. in Scotland to troubleshoot and test the new control system boards and to tune the system to operate the new drill motors. Some sub-system maintenance remains for the core pull-out table, the core processing components and the fluid handling system.

3. *Finish building a stand-alone Foro 3000 drill as per the IDPO Science Requirements.*

   IDDO action: IDDO engineers have completed the sonde design for collection of 3-meter cores per run. The winch design is currently in progress. Remaining detailed design work is expected to be completed in late PY 2018 or early PY 2019. Fabrication of Foro 3000 components is expected to begin in late 2018 and is expected to be completed in early PY 2020, as funding and resources allow.

4. *Develop the conceptual design for a Foro 700 Drill for drilling to 700 m under conditions of limited logistics as per the IDPO Science Requirements.*

   IDDO action: Science requirements for the Foro 700 m Drill were recently finalized in April 2018. In PY 2019, IDDO plans to initiate and complete a conceptual design and cost estimate for this system. As the system will be required to drill deeper than approximately 400 m, drilling fluid and chip handling equipment will be included in the design. The system is expected to be largely based on the sonde design of the Foro 400 m Drill and the Intermediate Depth Drill, which is essentially the Foro 1650 m drill. While weight savings can be had in a reduction of the amount of cable deployed over that of the IDD, it is difficult to quantify how much lighter the

surrounding infrastructure (i.e. winch, tower) can be made until the conceptual design is complete.

5. *Initiate fabrication of a second ice-ready Winkie Drill.*

   IDDO action: The IDDO Winkie Drill system builds upon a commercially-available drill rig. In PY 2019, IDDO will pursue the purchase of a second unit and will initiate procurement of IDD0 sub-assembly equipment for adapting the drill to polar ice coring applications. The system will largely be constructed as a copy of the current Winkie Drill in IDDO inventory, incorporating the latest modifications and upgrades made to the original system.

6. *Develop IDPO 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 2019, IDDO will iterate with IDPO and community scientists on the Science Requirements for this hot water coring drill.

Priority 2 (needed in the next 3 years):

7. *Finish building the Foro 400 Drill system.*

   IDDO action: Excellent progress is being made in PY 2018 on the fabrication of this new system. All components have now been procured, including necessary spare parts, and assembly is largely complete. Load testing has been performed on the winch and tower. Shipping cases have been procured and received. Sonde assembly and testing remains, as well as integrated system functionality testing. IDDO expects the system will be ready for issue in fall 2018, though documentation tasks may remain for completion in PY 2019.

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

   IDDO action: A number of projects requiring use of an IDDO Winkie Drill have been proposed for the Antarctic, and interest in use in Greenland has also been expressed. Pending availability of resources and budget, IDDO tentatively plans to complete fabrication of a second system by PY 2021. Also see number 5 above.

9. *Build duplicate components of the Intermediate Depth Drill to enable same-year use in both the Arctic and Antarctic.*

   IDDO action: This is essentially being pursued through design and fabrication of the Foro 3000 Drill, which will combine a stand-alone Intermediate Depth Drill system and components that allow drilling to 3000 m depth. IDDO will also maintain the original IDD, which will allow for simultaneous operation of the systems in the Arctic and Antarctic if desired.

10. *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 and made continued progress throughout PY 2017. While the second BID is largely a replica of the original and very successful BID design, minor beneficial modifications and upgrades 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. A few additional equipment purchases were made in early PY 2018, but the project was subsequently put on hold to redirect personnel and funds to other higher priority systems required for approaching field work. IDDO expects to complete fabrication of the second BID-Deep system by the end of PY 2020 as funds allow and as community field work priorities dictate.

11. *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 capability 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, completed a conceptual design and conducted both internal and external reviews of the concept in PY 2014. In May 2016, a proposal was submitted to the NSF for construction of the ScHWD system. In late 2017, IDDO engineers drafted a report outlining a preliminary evaluation of how a hot water sanitation unit could be adapted to the ScHWD design. The ScHWD proposal was declined by the NSF in Mach 2018, however future development of the drill is still anticipated, due to community interest.

12. *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 has funds budgeted in PY 2018 to investigate the design or purchase of a hole qualifying tool for use with the RAID and other drill systems. This work is being pursued in conjunction with IDDO's maintenance and upgrade of the logging winches in inventory.

13. *Resolve logging winch electrical noise issues.*

    IDDO action: In response to recommendations noted by IDDO equipment operators in the 2016-2017 WAIS Divide End-of-Season Report and the 2017-2018 Minna Bluff End-of-Season Report, IDDO has initiated an investigation into the electrical noise issues experienced when borehole logging tools are attached to the IDDO Deep Logging Winch. IDDO engineers have drafted a Deep Logging Winch EMI Mitigation Report, outlining the background of the situation, previously implemented mitigation efforts, further testing required and initial estimates for

additional modifications. IDDO will continue to pursue this investigation and will plan to implement equipment changes as early as PY 2019 and prior to the system's next deployment.

Priority 3 (needed in 3 to 5 years):

14. *Continue to evaluate options for new drilling fluids, and exploring/testing shallow drill fluid columns.*

    IDDO action: Discussion on drilling fluid research is regularly included at the IDDO Technical Advisory Board (TAB) Meetings and at other drilling community meetings. Consideration of fluid cost, availability, conductivity, viscosity, etc. remains part of the ongoing conversation. In April 2018, IDDO worked with Dr. Eustes at the Colorado School of Mines to provide him with a number of fluid samples for further testing. IDDO will await the results of such tests and will continue to correspond with and provide feedback to CSM as requested.

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

    IDDO action: Two of the drills in IDDO inventory currently have solar operation capability, including the Badger-Eclipse Drills and the Stampfli Drill. It is possible that this technology could be adapted to run other equipment in the IDDO inventory. IDDO will initiate discussion on this topic with its Technical Advisory Board and with others in the drilling community and will pursue the design or purchase of power sources with low logistical demand as resources and funding permit.

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. In spring 2018, the NSF encouraged IDPO to submit a proposal for another 5-year Cooperative Agreement. The proposal is non-competitive, but will undergo a full review by NSF and community representatives. IDPO-IDDO are optimistic that the NSF will award the next CA to allow IDPO-IDDO to continue operation of the current enterprise beyond 2018 and allow IDDO to continue providing excellent equipment development and maintenance and upgrade services as well as field support for years to come. Out-year budgets beyond 2018 have been estimated based on budget projections discussed with the NSF. 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 2018-2028. 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 SPICEcore project generally require IDDO expenditures of $400,000-500,000 per field season. Beginning with the PY 2017 budget, IDDO now absorbs all labor for deploying in-house staff and for drillers under its base subaward funding. In a flat overall funding environment, absorption of these field costs under the Cooperative Agreement will affect funds available for development projects and for maintenance and upgrade work. With the additional budget cuts projected for IDPO-IDDO in the next CA, should it be awarded, it is anticipated that less development work will be conducted by IDDO.

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

AFT	Antarctic Field Trial
ARA	Askaryan Radio Array
ASC	Antarctic Support Contract (Antarctic logistics provider)
ASIG	Agile Sub-Ice Geological (Drill)
BID	Blue Ice Drill
CFM	Cubic Feet per Minute (of airflow)
CHO	Chemical Hygiene Officer
CSM	Colorado School of Mines
DES	DOSECC Exploration Services, LLC
DISC	Deep Ice Sheet Coring (Drill)
DLW	Deep Logging Winch
EFC	Environmental Fracking Compound
EMI	Electromagnetic Interference
ERV	Energy Recovery Ventilator
ETFE	Ethylene Tetrafluoroethylene
FEP	Fluorinated Ethylene Propylene
HCFC	Hydrochlorofluorocarbon
ICDS	Ice Coring & Drilling Services
IDD	Intermediate Depth Drill
IDDO	Ice Drilling Design and Operations
IDLW	Intermediate Depth Logging Winch
IDPO	Ice Drilling Program Office
IH	Industrial Hygienist
ITASE	International Trans-Antarctic Scientific Expedition
MECC	Mobile Expandable Container Configuration
NSF	National Science Foundation
OPP	Office of Polar Programs
PFS	Polar Field Services (Arctic logistics provider)
PI	Principal Investigator
PICO	Polar Ice Coring Office
PPE	Personal Protective Equipment
PY	Program Year (formerly ‘FFY’ for Federal Fiscal Year; term used after Nov. 1, 2014 to signify that the 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 initial testing)
RAM	Rapid Air Movement (Drill)
SAB	Science Advisory Board
SALSA	Subglacial Antarctic Lakes Scientific Access
ScHWD	Scalable Hot Water Drill
SDS	Safety Data Sheet

SHWD	Small Hot Water Drill
SIPRE	Snow, Ice and Permafrost Research Establishment
SLLID	Sediment Laden Lake Ice Drill
SPICEcore	South Pole Ice Coring Project
SSEC	Space Science and Engineering Center
TAB	Technical Advisory Board
USGS	United States Geological Survey
WAIS	West Antarctic Ice Sheet
WISSARD	Whillans Ice Stream Subglacial Access Research Drilling

Appendix 1 – Long Range Project Schedule

Legend:

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

	PY 2018	PY 2019		PY 2020		PY 2021		PY 2022		PY 2023
Equipment	**2018 Arctic**	**2018-19 Antarctic**	**2019 Arctic**	**2019-20 Antarctic**	**2020 Arctic**	**2020-21 Antarctic**	**2021 Arctic**	**2021-2022 Antarctic**	**2022 Arctic**	**2022-2023 Antarctic**
2-Inch Drill [1]										
4-Inch Drill 1										
4-Inch Drill 2				3 proposed						
Agile Sub-Ice Geologic Drill										
Badger-Eclipse 1 [2]										
Badger-Eclipse 2 [2]				2 proposed						
Badger-Eclipse 3										
Blue Ice Drill/Blue Ice Drill-Deep 1		2 proposed								
Blue Ice Drill/Blue Ice Drill-Deep 2				2 proposed						
Chipmunk Drill										
DISC Drill										
DISC – Replicate Coring System										
Drill Fluid Development										
Foro Drill - 400 m										
Foro Drill - 700 m [3]										
Foro Drill - 3000 m										
Hot Water Corer for Warm Sites [4]				TBD						
Intermediate Depth Drill										
Koci Drill [1]										
Logging Tower										
Logging Winch - IDDO Intermediate Depth										
Logging Winch - IDDO Deep										
Logging Winch - USGS [5]										
Logging Winch - IceCube [6]										
Power Sources (Lighter Weight)										
Prairie Dog										
Rapid Hole Qualifier [7]										
RAM (Rapid Air Movement) Drill										
Scalable Hot Water Drill										
Sediment Laden Lake Ice Drill										
Small Hot Water Drill 1										
Small Hot Water Drill 2										
Stampfli 2-Inch Drill [2]						1funded, 1 proposed				
Thermal Drill										
Winch Simulator Circuit										
Winkie Drill 1										
Winkie Drill 2				2 proposed		2 proposed				
Sidewinder (5 available)	3 funded		1funded, 1 proposed	3 proposed						
Hand Auger, 3" PICO (7 available)		Phasing out								
Hand Auger, 4" PICO (2 available)		Phasing out								
Hand Auger, 3" IDDO (8 available)	3 funded, 1 proposed		1funded, 1 proposed		2 proposed					
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 sonde is expected to be of very similar design to the Foro 400 and Intermediate Depth Drill systems.

[4] Science Requirements to be established in PY 2019. 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.

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

PY 2018 - PY 2023

Development or Maintenance & Upgrade Project	PY 2018 (Current)	PY 2019	PY 2020	PY 2021	PY 2022	PY 2023	Total (PY 2018-2023)
4-Inch Drill	30,000	22,000		22,000	44,000	22,000	**140,000**
ASIG Drill	137,000	25,000			80,000		**242,000**
Badger-Eclipse Drill	70,000	20,000		20,000	70,000	40,000	**220,000**
Blue Ice Drill [1]	205,000	51,000	18,000	29,000	310,000	70,000	**683,000**
Blue Ice Drill 300 [2]					300,000	600,000	**900,000**
Drill Fluid Evaluation					25,000	10,000	**35,000**
Foro 400 Drill	276,320	20,000			30,000		**326,320**
Foro 700 Drill [3]		350,000	650,000	400,000			**1,400,000**
Foro 3000 Drill [4]	90,000	440,000	440,000	730,000	60,000	60,000	**1,820,000**
Hand Augers [5]	35,000	35,000	10,000	10,000	10,000	10,000	**110,000**
Hole Qualifier				5,000	5,000	5,000	**15,000**
Hot Water Corer 200 m [6]		10,000					**10,000**
Intermediate Depth Drill	104,050	25,000					**129,050**
Logging Winches [7]	58,000	30,000	10,000	10,000	10,000	10,000	**128,000**
Power Sources [8]					70,000	210,000	**280,000**
RAM Drill Upgrades	486,030	75,000	100,000	50,000			**711,030**
Sediment Laden Lake Ice Drill		5,000		5,000	5,000		**15,000**
Small Hot Water Drill			15,000	15,000	15,000	15,000	**60,000**
Stampfli Drill		5,000	3,000	3,000	3,000	3,000	**17,000**
Thermal Drill [9]	83,800	20,000	5,000	5,000	5,000	5,000	**123,800**
Winkie Drill [10]	84,200	195,000	95,000	20,000	20,000	20,000	**434,200**
TOTAL COSTS	**1,659,400**	**1,328,000**	**1,346,000**	**1,324,000**	**1,062,000**	**1,080,000**	**7,799,400**

[1] Fabrication of a second BID was temporarily suspended in PY 2018; costs are included in PY 2022 and PY 2023 to finish building that system.
[2] Community interest expressed; would require iteration on Science Requirements and completion of a Conceptual Design.
[3] Tentatively planning for completion of Conceptual Design and Detailed Design, as well as initiation of fabrication, in PY 2019.
[4] Costs include Foro 3000 components and a stand-alone Intermediate Depth Drill system.
[5] PY 2019 costs include funds to remedy the galling/fusing issue with the IDDO hand auger extensions.
[6] PY 2019 costs include development of science requirements with IDPO and community scientists.
[7] PY 2019 costs include final mitigation of electromagnetic interference issues with the IDDO Deep Logging Winch.
[8] Per the 2018-2028 Science Plan, "Investigate a lighter weight source of power to replace generators for drilling systems…".
[9] A field test in Alaska is anticipated in PY 2019; costs are included here for post-test modifications.
[10] PY 2019 and PY 2020 costs include fabrication of a second Winkie Drill per the Science Plan.
NOTE: PY 2019 - PY 2023 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