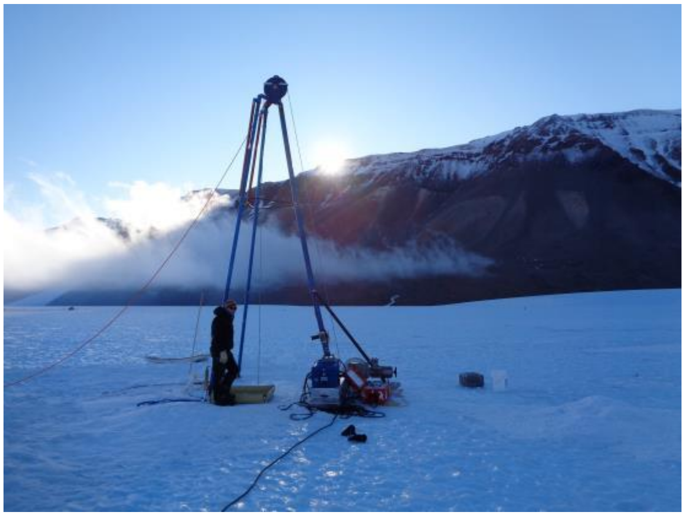
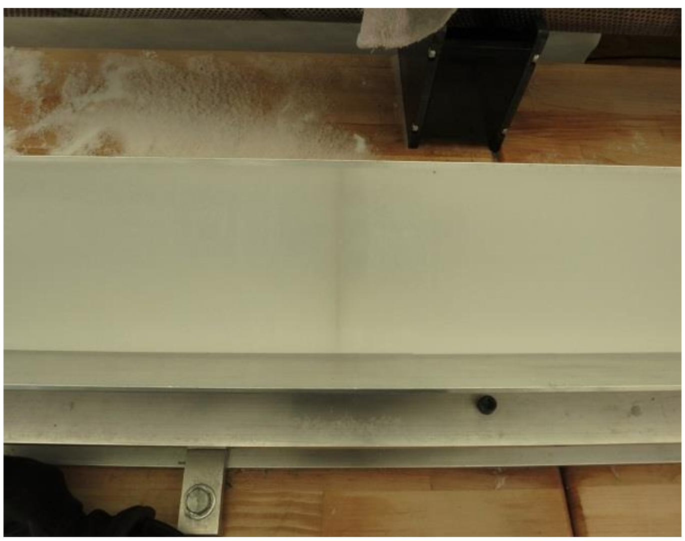
Ice Drilling Design and Operations

Long Range Drilling Technology Plan





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

June 30, 2016

IDPO NSF UNIVERSITY OF WISCONSIN-MADISON IDDO ICE DRILLING DESIGN AND OPERATIONS

Sponsor: National Science Foundation

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Cover photos: (upper left) Blue Ice Drilling in Taylor Valley, Antarctica; (upper right) ASIG Drill packer device testing near McMurdo Station, Antarctica; (lower right) Granite core collected during ASIG Drill testing in Stoughton, WI; (lower left) Ash layer seen in the South Pole Ice Core (SPIce Core project).

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 as well as field projects that would make use of the drills. Finally, this plan briefly addresses the funding allocated for its implementation.

The high priority tasks and investments identified by the IDPO Science Advisory Board (SAB) as needed to achieve identified science goals are shown below as listed in the U.S. Ice Drilling Program Long Range Science Plan 2016-2026.

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 the following existing agile equipment: hand augers, 2” and 4” electromechanical drills, 3” electrothermal drill, 3.25” Badger-Eclipse drills, logging winches, 30 m hot water shot hole drill, the Blue Ice drill, and the Winkie drill.
- Return the DISC Drill to Madison.
- Prepare a comparison of total cost estimates for drilling at Herc Dome with DISC versus IDD-Deep, by adding a 3-m or 4-m sonde to the IDD and for extending the IDD capability to 2,800 m.
- Develop a Conceptual Design for adapting the IDD for drilling to 2,800 m and for replicate coring with IDD using a whipstock.
- Construct a very lightweight highly-portable drill that can be transported by backpack for shallow ice coring to 100 m.
- Build a second Blue Ice Drill for wide-diameter drilling.
- Develop and build the Lake Ice Drill, a small highly portable hot-water drill for creating 5” holes through up to 6-m of sediment-laden lake ice.
- Adapt or construct an agile shot-hole drill capable of drilling fifteen 10 cm diameter holes per day up to 100 m deep in both East and West Antarctica. This may include consideration of a RAM drill upgrade, or other means.
- Develop IDPO Science Requirements for, and design and build, winch simulators.
- Evaluate practicality of acquiring WISSARD Drill system and operating it under IDDO.
- Develop IDPO Science Requirements for modular clean access capability for the Scalable Hot Water Drill for depths less than 1,000 m.
- Develop IDPO Science Requirements and a conceptual plan for a hot water drill, with modular clean access add-on, capable of creating access holes in ice depths of 2,500 m or greater for deeper targets (i.e. sites around Thwaites, interior sedimentary basins).
- Conduct Antarctic field trials of the Rapid Access Ice Drill (RAID)[1].

Priority 2 (needed within the next three years):

- Using science requirements provided by IDPO, provide a cost estimate and conceptual design for adapting the existing Intermediate Depth Drill and infrastructure to minimize logistical requirements for the drill, shelter and fluid plan for ice coring to approximately 600-800 m, if weight and cube estimates indicate this should go forward. The system must have significantly smaller logistical requirements than the current IDDO Intermediate Depth Drill and its associated infrastructure. Published lessons learned (e.g. Sheldon et al, 2014 and Triest et al, 2014) and performance of the Danish drilling at Renland should be considered.
- Evaluate if the agile shot-hole drill design could be used, and is desired, for 15 cm diameter boreholes (up to 220m, xx per day) for radio neutrino detectors as well.
- Build a Scalable Hot Water Drill for creating access holes in ice from 50 m up to approximately 1,000 m depth with modular potential to be used for clean access[2].
- Upgrade the electrothermal drill to allow for coring to 300 m through temperate and poly-thermal firn and ice. The drill needs to be agile and lightweight (transportable by helicopter).
- Continue to evaluate options for new drilling fluids.
- Conduct Antarctic field trials of the Rapid Access Ice Drill (RAID)[1].

Priority 3 (needed within three to five years):

- Investigate rapid hole qualifier (temperature and caliper) for RAID boreholes
- Investigate potential of in situ probes for englacial and subglacial observations and sampling.
- Investigate potential for improved and more efficient site selection for ice core drilling projects.

[1] RAID has been developed by the University of Minnesota Duluth and the University of California, San Diego. Fabrication and testing is being provided by DOSECC Exploration Services (DES), LLC.
[2] The IDDO Conceptual Study for the ScHWD found that scalable capability deeper than 1,000 m would require different components that are not practical for use between 50-1,000 m.

IDPO-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 DRILLING SYSTEMS AND TECHNOLOGIES

Important technical aspects of the 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. In addition, drill development of major drilling systems should be fungible to the maximum extent possible. 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. These programs will not only allow IDDO to better maintain the equipment, but will also allow it to undertake modifications that improve the equipment's performance and, hence, its usefulness to the scientific investigators.

2.1 AGILE DRILLS

Agile coring and drilling capability continues to be seen by the IDPO Science Advisory Board as one of the top priority investments in drilling technology needed in the next decade (2016-2026). These drills, which include hand augers, are the smallest of the IDDO systems and can drill holes to maximum depths of approximately 350-400 m. Most of the agile drill systems are capable of recovering either ice or rock cores. They are relatively lightweight and generally do not require a drilling fluid. IDDO has a number of such systems in inventory and is continuing the development of these agile, lightweight systems through the recent design and fabrication of the Winkie Drill.

2.1.1 Chipmunk Drill – The smallest drill in the IDDO inventory, it is a hand-held, motor driven coring drill that collects 2-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, including 1) fix wobble due to the looseness of the bayonet mount, 2) strengthen springs that hold the barrel in place on the mount and 3) fix attachment method of bayonet pins, as one of the three pins tends to pop out.
Technical Issues:	Performance Data – None. The system has only been deployed a few times and requires testing to characterize its performance. Documentation – Exists, but requires a review for accuracy, which will be done when the drill is needed. Other – None known.
Plans:	1. 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 – As needed.

2.1.2 Hand Augers – The next larger type of drill is the hand auger. 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. The drill, like all other coring drills, has to be retrieved each time a core section is recovered. IDDO has in inventory several types of hand augers: SIPRE (3-inch core), PICO (3 and 4-inch cores), and a more recently developed IDDO system, now available in both 3 and 4-inch models. The SIPRE system takes half-meter cores, while the PICO and IDDO systems can be configured to take either one-meter or half-meter cores. The maximum depth to which hand augers can be used without power assistance (see section 2.1.4 on the Sidewinder) is approximately 20 m.

Hand augers are typically operated by investigators without assistance from IDDO drillers.

Current Status:	Hand augers to be sent to the field are inspected and repaired as needed and are individually assigned to specific investigators. 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. Drawings, operating instructions, and maintenance procedures have been written and are updated regularly. Existing PICO hand augers in inventory are aging and worn parts that have reached the end of their useful life are being removed from inventory over time. In recent years, IDDO developed a new replacement model and fabricated eight copies of the new 3-inch IDDO hand auger. Based on the success of that new design, IDDO designed and built a prototype 4-inch unit in 2015. 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. Several sizes of coring hand augers are also available commercially.
Technical Issues:	Performance Data – Data has been collected for the new IDDO 3-inch auger in Antarctica beginning in the 2011-2012 Antarctic field season and in each Arctic and Antarctic season since that time. IDDO continues to gather user feedback in order to continuously improve and refine the hand auger design. IDDO engineers tested the prototype IDDO 4-inch unit in several locations in Antarctica during the 2015-2016 field season. Documentation – Most drawings have been completed; operator's manuals have been updated and a maintenance procedure has been written and is updated annually. Other – Some quality problems with the old augers, e.g. misalignment of mounting holes, parts not fitting properly. Some issues with proper fit of new IDDO auger extension connections; threaded or ridged

	sections become stuck together when liquid water refreezes at the connection. Parts have been re-machined in house, when necessary, and tolerances have been updated on design drawings. Several of the hand auger models employ carbide cutters or carbide inserts to enable drilling through very small pebbles or dirty, silty or sandy ice. A carbide cutter option is not currently available for the new IDDO hand augers.
Plans:	1. Correct quality problems of existing hand augers "one hand auger at a time" as they are prepared for issue – Ongoing as necessary. 2. Design and implement minor changes for the IDDO 4-inch prototype unit – PY 2016. 3. Fabricate two additional copies of the IDDO 4-inch hand auger – PY 2017. 4. Continue to phase out aging PICO equipment – Ongoing. 5. Maintain SIPRE hand auger kits – Ongoing. 6. Improve hand augers based on feedback from users – Ongoing. 7. Increase distribution of a post-field season questionnaire to hand auger users to get information from investigators on hand auger performance – Ongoing. 8. Continue to work with IDPO to expand questionnaire distribution to include Antarctic science teams – Ongoing.

2.1.3 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 drill has been used almost exclusively by Jay Kyne, its designer, who is a part-time driller/engineer with IDDO. 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 is planned for use in Wyoming again in August 2016.

Current Status:	A portion of the equipment was lost during the 2010-2011 Antarctic field season, where it was stuck in the ice at Lake Vida and abandoned rather than risk environmental damage to the site, which is in the Dry Valleys Antarctic Specially Protected Area (ASPA). Additional components were lost in transit, between Lake Vida and McMurdo Station in 2010-2011 and were replaced by IDDO. The missing components were subsequently located in McMurdo during the 2014-2015 field season and were returned to Madison in spring 2015. The drill system is complete and is ready for issue.
Technical Issues:	Performance Data – Little data exists due to infrequency of use. Documentation – System drawings and an operator's manual exist. Other – 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.
Plans:	1. Update documentation as needed and enter into database – Ongoing. 2. General maintenance and modification – Ongoing as needed.

2.1.4 Sidewinder – The Sidewinder is not a drill, but is a drive/lifting system used in conjunction with the hand augers. It is driven by an electric motor (power hand drill) and a winching system to help in both lowering and retrieving the drill string. The power hand drill component can also be used to help spin the hand auger barrel itself during drilling. The Sidewinder extends the maximum practical depth of coring with a hand auger to about 40 m.

Like the hand augers, the Sidewinders are typically operated by investigators without assistance from IDDO drillers.

Current Status:	Due to increasing requests for this system, IDDO fabricated an additional unit in 2015. Five working systems are available.
Technical Issues:	Performance Data – IDDO continues to collect performance data from users. Documentation – System drawings are complete; operating procedures for the Sidewinder are continually updated. Other – Several potential safety hazards (ladder use, loosening chuck) have been noted in the operation of the Sidewinder; modifications have been made to correct the problems; their effectiveness; however, has not been evaluated.
Plans:	1. Maintain Sidewinder systems – Ongoing. 2. Review documentation, update and enter into database – Ongoing. 3. Fabricate additional units – As needed.

2.1.5 Blue Ice Drill (BID) – The Blue Ice Drill is an agile drill capable of retrieving cores of approximately 9-1/2 inches (241mm) in diameter. The BID system had a depth capability of 30 m in solid ice in its original design. The drill, originally developed for the University of California, San Diego, has been repeatedly used with great success to collect samples of 'Blue Ice' on Taylor Glacier each year since its initial deployment during the 2010-2011 field season. Modifications made to the drill for use in firn were tested successfully in Greenland in 2013. In PY 2014, the system was modified to allow for deep coring 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. This new BID-Deep system, to which it is referred can easily drill through at least 80 m of firn, and deeper through another 70 m of solid ice. The drill has only reached 187 m in practice in Greenland during the 2014 Arctic field season. The BID-Deep capabilities were further tested in Taylor Valley in Antarctica during the 2014-2015 field season down to a depth of 70 m and in Greenland again down to 155 m during summer 2015.

Current Status:	Modifications to theoretically extend the depth capability of the system to 200 m (BID-Deep) were completed in 2015. In 2015, IDDO further implemented and tested new step cutters during a Greenland deployment, though depth capability is still largely influenced by site/ice characteristics. Per IDDO's discussions with the IDPO SAB, the current equipment has likely reached its operational limits. Assuring depths of 200 m would require a re-design of the system. The standard BID typically utilizes a ropes setup for coring to shallow depths, and the cable winch is used for achieving greater depths. At this point, the drill has been extensively used in both the Arctic and Antarctic for 6 years. The equipment has sustained some wear, particularly from traversing and set-up/take-down at multiple holes per season. Repair and replacement of worn out parts is in progress.
Technical Issues:	Performance Data – Comprehensive accounts of the drill's performance are contained in the drillers' End-of-Season reports and in the PI seasonal feedback reports. Collecting good core quality at greater depths has proven to be an issue in both Greenland and Antarctica. Poor core quality was experienced below 70 m depth in Antarctica in the blue ice region of Taylor Valley and below approximately 140 m depth outside of Summit Station in Greenland. Site-specific ice properties such as temperature and structure as well as the large core diameter and/or mechanical aspects of the drill are all potential factors that may be impacting the core quality, thus deep drilling depths cannot be guaranteed. Documentation – Design documentation for the drill has been completed and entered in the SSEC document control database. An operator's manual has also been completed and is updated periodically.
Plans:	1. Maintain the BID and BID-Deep components – Ongoing. 2. Build a second BID to meet user demand – PY 2017 and PY 2018.

2.1.6 2-Inch Drill – The 2-Inch Drill is a highly portable electromechanical coring drill that can be powered by conventional batteries, solar power cells, or a generator. A cable is wound up and paid out using a hand-powered winch. The 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.

Current Status:	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. The drill is being retired and its function is largely being replaced by new IDDO drill designs (see Portable Firn Coring Drill).
Technical Issues:	Performance Data – Very little exists due to lack of use. Documentation – Some from the manufacturer. Other – IDDO engineers/drillers believe that the drill requires extensive modification to be a truly useful tool.
Plans:	1. Pursue decommissioning of this system and re-purposing of components, as this drill is no longer considered a useful tool – PY 2017. 2. IDDO is continuing work with IDPO and community scientists on development of Science Requirements for a 'Portable Firn Coring Drill' (see below), which will replace the 2-Inch Drill capability in the IDDO inventory – PY 2017.

2.1.7 Portable Firn Coring 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, and expects the science requirements will be finalized in 2016.

Current Status:	Development of Science Requirements for this system is currently in progress with IDPO, IDDO and community scientists.
Technical Issues:	Not applicable; system not yet built.
Plans:	1. Work with IDPO to establish science requirements for the drill – PY 2016. 2. Initiate purchase or design of the drill – PY 2016. 3. Complete fabrication, assembly and testing of the drill – PY 2017. 4. Investigate clean technologies for such lightweight drills for shallow coring to study microbes in the ice – As needed.

2.1.8 Badger-Eclipse Drills – The Badger-Eclipse Drills are modified Eclipse Drills manufactured by Icefield Instruments, Inc. The drill is an electromechanical system capable of collecting 81 mm diameter core to depths of approximately 400 m. The drill system is transportable by small aircraft or helicopter. IDDO has two Badger-Eclipse Drill systems that it regularly deploys and a third Eclipse Drill that was transferred from the University of New Hampshire to IDDO in 2010.

In 2013, IDDO increased the capabilities of the Badger-Eclipse Drills by designing and fabricating a solar and wind power system for use in operation of the drill. This new power set up was subsequently used with great success to drill two 200 m ice cores near Denali National Park in Alaska. This capability can be 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. In 2014, IDDO, with input from Badger-Eclipse Drill operators, carefully inventoried all Badger-Eclipse Drill equipment, removed aging and out-of-spec parts from circulation, purchased a new cutter head and cutters and engraved components for easy identification, since the two systems, while similar, are not identical. Late in 2014, IDDO purchased a new Mountain Hardwear Space Station tent for use with the Badger-Eclipse Drill systems. The tent has allowed drilling operations to continue safely and reliably during inclement weather on recent projects in both Greenland and Antarctica, where drilling progress would have been halted had the tent not been available. In 2015, IDDO initiated redesign of the aging control boxes and readout boxes to provide for simplified operation, weight reduction and new sealed cases. Fabrication of the new boxes began in early 2016.

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. A third Eclipse drill, which arrived from UNH in June 2010, needs to be refurbished before it is operable and is being stored for possible future repair or modification. IDDO does not plan to refurbish this drill in the near-term, but will repair it as necessary to support funded field projects.
Technical Issues:	Performance Data – Data from several projects have been collected; these data sets need to be analyzed both to determine their usefulness and to develop some preliminary performance specifications. Procedures for more consistent recording of data during projects need to be defined by IDDO and used. Documentation – Since the basic drills were purchased, IDDO lacks detailed engineering documentation for the drill. During drill modification, some 'reverse engineering' has been completed and a few drawings have been produced; many drawings are currently in draft form or are contained in the database; new drawings are being created and released as system upgrades are made. Preventive Maintenance checklists, both seasonal and weekly, have now been developed. An operator's manual was completed in late 2015. IDDO

	plans to draft a Failure Modes and Effects Analysis (FMEA) document, which identifies potential system hazards and mitigations implemented to eliminate reduce the effects of such hazards. Other – Improvements to instrumentation and the control system are being implemented to improve operational flexibility and reliability. Components of the drills, as modified, are not entirely interchangeable. Some variation between the drills may be desirable to accommodate differing project requirements. Some components are aging and are being replaced as necessary.
Plans:	1. Complete fabrication of new control boxes and readout boxes – PY 2016 and PY 2017. 2. If needed, ready third Eclipse drill system for issue. 3. Develop procedure, including bill-of-materials checklist, for preparing drill for issue – PY 2017. 4. Analyze project performance data, develop (if possible) preliminary performance baseline and institute guides for data collection. Continue to collect and analyze data – PY 2016 and thereafter. 5. Standardize components of the drills to the extent desirable and practicable* – PY 2016 and ongoing. 6. General maintenance and repairs – Ongoing. 7. Complete documentation and enter into database – Ongoing. * Participants at the IDDO 2010 Drillers' Workshop suggested making downhole equipment interchangeable and surface equipment distinct, with distinct names and transportability options.

2.1.9 4-Inch Drill – The 4-Inch Drill is an electromechanical ice coring drill that takes a 104 mm diameter core. Cores can be retrieved from depths to approximately 400 m. Winches with 100, 200, and 400 m cables are available. The drill is of a mature design and has been used successfully for several decades. It is particularly useful on projects requiring a larger diameter core than that produced by the Badger-Eclipse drills. Depending on the configuration, the drill can be transported by light aircraft or helicopter.

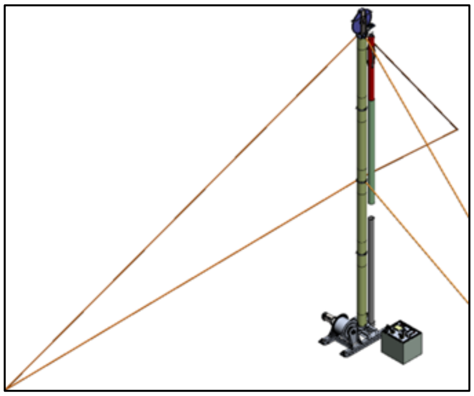
General maintenance and minor modifications were implemented between PY 2011 and PY 2013 and are ongoing. All budget requests since PY 2012 have included, and will continue to include, maintenance and upgrade costs. The 4-Inch drill was most recently used for the RAID Auger & Packer test field project conducted outside of McMurdo Station near Castle Rock during the 2015-2106 Antarctic field season.

Current Status:	IDDO currently has two 4-Inch Drill systems ready for issue and plans to maintain at least one of those systems into the future. The current 4-Inch Drills are repaired as needed, with the replacement of some

	failing/aging components, however the entire system is aging. In some cases, replacement parts may no longer be available. A new set of barrels were recently machined and were tested during the 2015-2016 Antarctic season. Winch and cable inventory for the current 4-Inch Drills includes one system at 400 m, two at 200 m and one at 100 m. These winches received a full inspection and minor maintenance in PY 2015. To meet continued demand of a drill of this type, IDDO has designed and is fabricating the new Foro Drill (see below). A 4-Inch Drill system will still be maintained, however the Foro Drill will offer new capabilities and substantial weight savings.
Technical Issues:	Performance Data – Comprehensive accounts of the drill's performance are contained in the drillers' End-of-Season reports. Data from several projects have been collected; these data sets have been analyzed, to a certain extent, throughout the design of the new Foro Drill. Procedures for more consistent recording of data during projects should be defined and used. Documentation – The 4-Inch Drills were designed and built by PICO and AutoCAD drawings exist, but are not up-to-date. Drawings for more recent modifications of the 4-Inch Drill have been made; approximately 50 drawings exist in the database. An operator's manual is currently being drafted. Other – The 4-Inch Drills are aging and replacement parts are becoming harder to find. The cable winch sleds are very heavy, making the drill not optimal for transport by small aircraft. Improvements to the instrumentation and control system for the drill have also been noted as desirable to improve reliability and to reduce weight. All of these considerations have been taken into account with regard to the new Foro Drill design.
Plans:	1. Perform general maintenance and repairs – Ongoing. 2. Maintain at least one each of the 100, 200, and 400-meter winches – Ongoing. 3. Define data collection procedures – PY 2016 and thereafter. 4. Complete development of operating and maintenance procedures and documentation – PY 2016 and ongoing. 5. Update drill system drawings and enter into database – Ongoing.

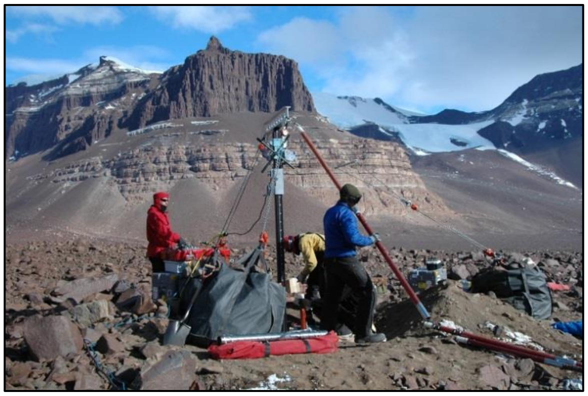
2.1.10 Electrothermal Drill – The Electrothermal Drill melts an annulus around the ice cores it collects. It supplements the 4-Inch Drills and can be substituted for the 4-Inch Drill sonde, using the same winch systems, for use in ice warmer than about minus 10 °C. The drill collects a 3-inch core. It is particularly useful in ice close to the pressure melting point, where electromechanical drills are at risk from melting and refreezing of the surrounding ice. Much simpler than the electromechanical drills, the electrothermal drill has performed well in British Columbia, Alaska and in southeastern Greenland. Using a scaled-down, lightweight setup, the drill was tested by an investigator on McCall Glacier, Alaska, in spring 2012. The drill was most recently deployed and used successfully to drill through firn aquifer layers in SE Greenland during spring 2013 and spring 2015.

Current Status:	IDDO has one electrothermal drill that is available for use. A new 65 meter water-shedding cable was procured in 2015 to prevent the fibrous cable typically used with the Thermal and 4-Inch Drills from soaking with water in aquifer layers, refreezing and causing issues with travel over the upper sheave on the drill tower. Numerous firn aquifer layers have recently been located in Greenland. From discussions with PIs, IDDO anticipates that the Thermal Drill may see considerably more use in the upcoming years, possibly necessitating the building of a second sonde and the procurement of additional heat rings. IDDO currently has a small stock of older heat rings, the exact model of which is now out of production.
Technical Issues:	Performance Data – Some data from previous and more recent projects have been collected and are available in the drillers' End-of-Season reports. Procedures for more consistent recording of data during projects should to be defined and implemented. Documentation – Drawings and models for the barrels, newly designed by IDDO several years ago, are completed, but otherwise no drawings are currently in the document control database. The electrothermal drill was designed and built by PICO, and AutoCAD drawings likely exist but are out-of-date; they need to be updated and entered into the database. An operator's manual was drafted and completed in 2015. Other – The availability of replacement parts is unknown. Inasmuch as the cable winch sleds are the 4-Inch Drill sleds, they are very heavy, making the drill not optimal for transport by small aircraft (see 4-Inch Drill above) if depths beyond approximately 30 m are desired. The new Foro Design (see below) will offer weight savings in this area and will be compatible with the Thermal Drill sonde. For depths shallower than 30 m, a simpler tripod assembly for operation of the drill is available and has been used with good success.
Plans:	1. Complete/update drawings to the extent practicable and enter into database – PY 2017. 2. Perform maintenance and repairs – Ongoing and as needed. 3. Upgrade the drill to improve its performance capability to 300 m depth – PY 2017 to PY 2018.



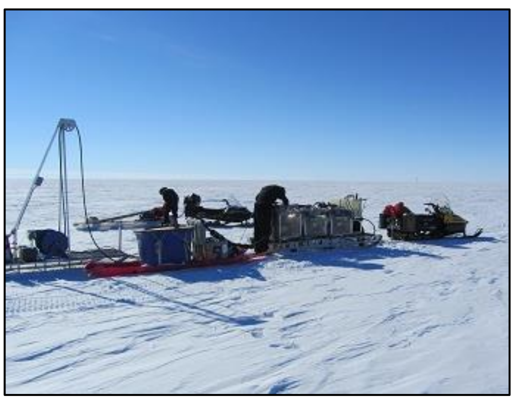
2.1.11 Foro Drill – In PY 2015, IDDO initiated design of upgraded components for the 4-Inch Drill, based on driller feedback and utilizing more recent and proven designs from other IDDO drill systems. It is envisioned that the new design will eventually replace the aging 4-Inch Drill equipment. In addition, the new sonde design will also be submersible and watertight. In March 2015, IDDO circulated a 'Name That Drill' Doodle poll to encourage IDPO and IDDO team members to vote on a name for the new components, so that distinguishing between the old and new equipment would be more straightforward. The name 'Foro' was selected, and is Latin for "to make a hole, pierce or to bore". In April 2015, IDDO held a Preliminary Design Review showcasing the new and upgraded components of the 'Foro Drill'. A new drill sonde, based on the Intermediate Depth Drill (IDD) design, has been designed, as well as a new tower, winch and control system, largely based on the current 4-Inch Drill equipment, but offering generous weight savings wherever possible. Using the IDD sonde design spreads design costs over multiple projects, strengthens component availability, and promises to reduce future operations and maintenance costs (by reducing the number of different parts). IDDO initiated fabrication of the new Foro Drill components during PY 2016.

Current Status:	Drill fabrication is currently in progress and will continue in the coming years as funds allow.
Technical Issues:	Performance Data – Not applicable; system not yet built. Documentation – Design documentation for the new Foro Drill is being added to the document database as the design progresses.
Plans:	1. Continue fabrication and assembly of new Foro Drill components including winch, tower, sonde and control box – PY 2017 to PY 2020.



2.1.12 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.

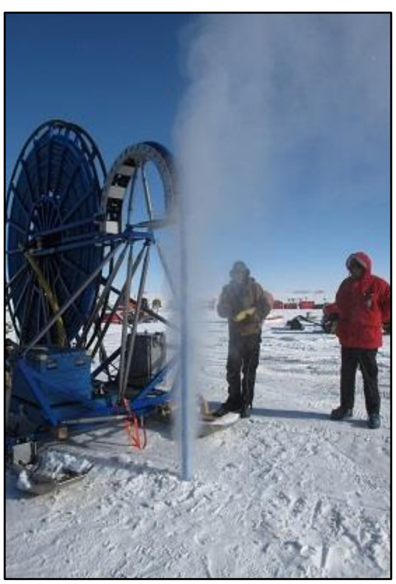
Current Status:	The Koci Drill, originally designed for drilling 'dirty ice' (i.e. ice containing silt, sand or small sedimentary rocks) sustained significant damage during its last deployment in 2009-2010. Periodic interest remains in collecting 'dirty ice', however many investigators have voiced a desire for a rock coring drill. To that end, IDDO has purchased an off-the-shelf rock coring drill (see Winkie Drill below) and is modifying it to drill through ice and to collect rock cores below, versus 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.
Technical Issues:	Performance Data – Because of the nature of the ice being drilled and the fact that conditions can vary drastically from hole-to-hole in a matter of a few meters, it would be difficult to collect anything but general performance data for this drill. Documentation – Nearly 60 system drawings for the drill have been produced and are entered into the database, as are the results of the testing of the drill; operating and maintenance procedures have not been written. Other – The drill relies on flights to move ice chips and a downhole vacuum cleaner to remove rock chips and loose silt. Rock cutting is difficult and would be better accomplished with a lightweight rock drill.
Plans:	1. Pursue decommissioning of this system and re-purposing of components – PY 2017.



2.1.13 Small Hot Water Drills – The IDDO Small Hot Water Drills (SHWD) use hot water to create shallow holes in the ice. They are non-coring. Primary use is for shot holes for seismic work, but they have also been used for access holes through a thin ice shelf. These drills are transportable by light aircraft and helicopter. These systems are typically operated by investigators without assistance from IDDO drillers. The system was most recently used in Antarctica during the 2015-2016 field season.

Current Status:	IDDO has two small hot water drills in inventory. During PY 2013 and PY 2014, IDDO enlisted the assistance of the UW Physical Sciences Laboratory (PSL) and its engineers, who have expertise in hot water drilling, to design beneficial modifications and upgrades to the small hot water drills. Feedback on system performance was also collected from primary users of the system. IDDO envisions that this system will remain its primary shallow hot water drilling system. In mid-March 2015, IDDO participated in a design review and web/teleconference arranged by IDPO and with scientist participation, and outlined the

	planned upgrades for the system. One of the systems was moved to PSL in summer 2015, where it underwent inspection and testing prior to modification and upgrade. 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 Antarctic in fall 2015. Additional planned modifications and upgrades are being made to this unit in PY 2016, and IDDO is also working to fully build up and upgrade the second unit. Ultimately, it is envisioned that one of the two systems will maintain a 30 m depth capability and the second system will have a 60 m depth capability. Related to IDDO's SHWD capability, the Scalable Hot Water Drill (see section 2.6), once developed and built, will serve as IDDO's scalable and deep hot water drilling system, with a depth range of 50-1,000 m.
Technical Issues:	Performance – Reliable and efficient to a depth of 25-30 m; much of the aging equipment is being replaced/upgraded. Documentation – Approximately 75 drawings exist in the document control database, but documentation for the drills is incomplete. An operator's manual for the systems was updated in PY 2014 and officially released in PY 2015. The operator's manual is being updated as additional modifications are made to the drills. Design drawings are also being added to the database as system modifications are made. Other – Hot water drills are expandable to create larger and/or deeper holes. They can also, to some degree, be modularized so components can be added and subtracted to create a system to meet a particular project's needs.
Plans:	1. Update completed operating procedures as needed – Ongoing. 2. Complete planned modifications to both drill systems – PY 2016. 3. Develop procedure for preparing the drills for issue – PY 2016. 4. Develop preventive maintenance (PM) checklists for the drill system – PY 2016 and ongoing. 5. Complete other documentation and add to database – PY 2016 and ongoing.



2.1.14 Rapid Air Movement (RAM) Drill – The RAM Drill was developed for a particular seismic program. 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. In typical firn/ice conditions in West Antarctica, two compressors in parallel are needed to provide enough airflow to overcome air losses in the firn. It has been used three times in West Antarctica, most recently during the 2009-2010 field season, when it routinely attained depths of 90 m. The Askaryan Radio Array (ARA) project, funded by NSF-OPP, borrowed the drill for the 2010-2011 Antarctic field season to

test methods of producing holes for radio antennae at South Pole, but could not get deeper than 63 m at that location.
The RAM drill is limited to a maximum depth of 95 m by the amount of hose that can be carried on the current configuration of its hose reel (one hose-width wide, no level wind), but in principle it could drill much deeper; once the penetration is below the firn/ice boundary, there is little additional loss of return air and greater depths should come relatively easily. Factors affecting the drilling through the firn to the firn/ice boundary, however, are not well understood and methods of drilling consistently to below the firn/ice boundary remain to be found.

Current Status:	While the drill worked well during the 2009-2010 season, additional modifications are needed to make the drill less cumbersome to transport and set up, and more reliable on longer traverses. IDDO has not repaired the drill since the 2010-2011 test at the South Pole. In PY 2014, a graduate student of Mary Albert at IDPO initiated a study to better understand return air losses in firn. Past operators of the RAM Drill also provided input to this study which was carried out at Dartmouth College. The study showed that anomalously high permeability firn layers at depth can cause sufficient air loss to limit drill performance. Early in 2016, IDDO initiated research into the design for a new hose reel. IDDO is also researching the potential for use of double-walled hose or lightweight rigid aluminum pipe, which should serve to mitigate the issues of air loss into the firn while drilling. Ultimately, as a new hose reel or rig/mast system is designed and built, an emphasis will be placed on a stand-alone unit that does not require heavy equipment for assembly in the field, which is a drawback of the current hose reel design.
Technical Issues:	Performance Data – The performance of the RAM drill is well documented for the three seasons for which it was used for seismic projects. However, drill performance appears to be very sensitive to the local characteristics of the firn being drilled. A paper published by Amber Whelsky and Mary Albert in the Cold Regions Science and Technology Journal (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 describes modeling to explain the issue. Documentation – Documentation for the drill is partially complete. Drawings for the hose reel, its sled and the drill sondes have been completed. These need to be added to the document control database. Material lists and several drawings exist for the compressor packages, but 'as-built' drawings should be completed. Drawings for new components will be added to the document database as the design and modifications progress. Operating instructions are in rough draft form and will be completed prior to any future deployment of the system. Other –Techniques and equipment are currently being explored to minimize air losses at depths in high-permeability firn. The

	number/size of compressors required for firn conditions needs to be studied and determined. The hose reel presents logistical problems, necessitating the use of heavy equipment for assembly at the field sites, and will likely be redesigned before use on any more seismic traverses.
Plans:	The following plans for the RAM drill will require considerable time, effort and funds, and work is planned for future program years. 1. Design a new hose reel or rig/mast system that does not necessitate heavy equipment for assembly in the field – PY 2016. 2. Investigate means of sealing off the firn to prevent air loss – PY 2016. 3. Make desired modifications, including fabrication of new hose reel or rig/mast and modifications to compressors, to improve traversing – PY 2017 to PY 2019.

2.1.15 Winkie Drill – The Winkie Drill is IDDO's newest drill system in inventory. In 2015, IDDO purchased a commercially-available Winkie Drill system from Minex that is capable of coring rock. In late 2015 and early 2016, IDDO has been working to modify and upgrade the system to add ice augering and ice coring capabilities. The ice augering capability of the system was initially tested during the RAID Auger and Packer Test field project, conducted outside of McMurdo Station, Antarctica in February 2016. The system is now undergoing more comprehensive testing in Madison prior to its shipment to Antarctica in September 2016 for a funded field project in 2016-2017. In addition to coring ice and rock, this new drill is expected to replace the 'dirty ice' drilling functionality of the Koci Drill system, which will likely be decommissioned.

Current Status:	IDDO purchased an off-the-shelf rock coring drill from Minex in 2015. IDDO is now nearing completion of modifications to the unit to allow for drilling access holes through ice, in order to access and drill the bedrock below. Comprehensive system and subsystem testing is currently in progress at IDDO.
Technical Issues:	Performance Data – Little data exists, as this system is being modified for an entirely new application. Data collected during a test of the system near McMurdo Station in February 2016 is being used to inform modification decisions. Documentation – Design documentation for the new Winkie Drill is being added to the document database as the design progresses. Other – During the Antarctic test of the system's ice augering capability in early 2016, issues with ice chip transport were observed. Nearly half of the ice chips drilled were left in the borehole following drilling. IDDO has used this information to develop an air drilling option for creating access holes to the bed, which helps with ice chip

	ejection from the hole.
Plans:	1. Complete fabrication, assembly and testing of the drill – PY 2016. 2. Complete documentation for the drill system and enter it into the documentation database – PY 2016 and ongoing. 3. Prepare and ship the drill system to Antarctica – PY 2016. 4. Modify the Winkie Drill for larger-diameter dirty ice coring – PY 2017. 5. Repair and maintain the Winkie Drill system – Ongoing.

2.1.16 Sediment Laden Lake Ice Drill (SLLID) – Per the Long Range Science Plan and IDDO discussions with IDPO and community scientists, most notably Peter Doran, IDDO plans to design and build a small, portable hot water drill system in 2017. Science Requirements for the system are in the final stages. Basic requirements include drilling speed of less than 30 minutes for a 5-inch hole through a 6 m ice ice cover. Drill components should be small, lightweight and able to be lifted by a maximum of two people. The drill should also have stand-alone capability for operation at small field camps at remote sites with no heavy equipment and should be PI/science team operble. Drill design will incorporate componets that allow for clean access drilling.

Current Status:	Development of Science Requirements for this system is nearing completion with IDPO, IDDO and community scientists.
Technical Issues:	Not applicable; system not yet built.
Plans:	1. Work with IDPO to finalize science requirements for the drill – PY 2016. 2. Initiate purchase or design of the drill – PY 2017. 3. Complete fabrication, assembly and testing of the drill – PY 2017.

2.2 DISC DRILL

DISC Drill – The Deep Ice Sheet Coring (DISC) Drill developed by Ice Coring and Drilling Services (ICDS) under contract with the NSF is a tilting-tower electromechanical drill designed to take 122 mm diameter ice cores to depths of 4,000 m with variable core lengths up to a design limit of 4 m. (The drill is currently able to recover cores up to 3.5 m long.) The DISC Drill consists of four major mechanical drilling subsystems, surface and down-hole control systems, and several supporting on-surface auxiliary systems. The mechanical drilling subsystems are the drill sonde, drill cable, tower, and winch. Critical on-surface activities are core handling, screen cleaning, and ice chips and drill-fluid handling. 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. Portions of this drill system are still at WAIS Divide in

Antarctica, where it finished its main-hole and replicate coring in January 2013 after six production seasons. The final drilled depth is 3,405 m. IDDO sent a small team to WAIS Divide during the 2014-2015 Antarctic season to complete disassembly and packing of the DISC Drill. Due to prolonged weather delays impacting the completion of all objectives, IDDO sent one person back to WAIS Divide during the 2015-2016 season. Again, prolonged weather delays and unavailability of aircraft to WAIS Divide impacted operations, however the drill was fully disassembled and the borehole casing extended to Arch floor level with help from ASC. The equipment is being flown out of WAIS Divide on flights of opportunity, some of which arrived back in Madison in March 2016. Return of all equipment to IDDO is planned for inspection, storage and rework.

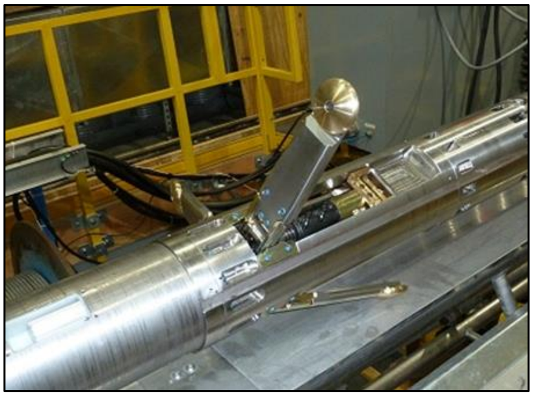
Per discussions between IDPO, IDDO and community scientists, the next deep U.S. drilling project is planned for Hercules Dome. IDDO is currently working with community representatives on a DISC Drill vs. Intermediate Depth Drill-Deep (IDD-Deep) analysis, to help determine which system should be used for drilling at Hercules Dome. Prior to this deployment, which is not anticipated before 2019-2020, the DISC Drill would need to undergo some level of modifications and repairs. The list of DISC Drill sub-systems that require repairs and maintenance includes, but is not limited to, the gantry cranes, centrifuge, screen cleaning and fluid handling systems, winch, tower, sonde and numerous surface control system electrical and software redesigns and upgrades. Should the next drilling assignment be in East Antarctica, several key components of the drill will require additional modification/redesign in order to operate at down-hole temperatures at least as cold as -50 °C and perhaps as cold as -58 °C. If the IDD-Deep is chosen, IDDO will need to design, fabricate and test modifications to extend that system's capability from the current depth of approximately 1900 m to depths expected at Hercules Dome (2,800 m).

In early PY 2015, IDPO initiated the drafting of revised science requirements for the DISC Drill, in collaboration with IDDO and with community scientists interested in using the DISC Drill. This iterative process included some discussion of the feasibility of reducing the drill's logistical footprint, and revised requirements were finalized in early PY 2016. In addition, a new drilling fluid will need to be identified prior to the drill's next deployment, since the densifier fluid (HCFC 141b) used in the two-component fluid at WAIS Divide has now been phased out of production by the Environmental Protection Agency. See section 2.9 on Drill Fluid below. Discussion and evaluation of the updated requirements for the drill will also determine how much time IDDO will need to make the system field ready for any future field projects.

Current Status:	Disassembly and packing of the remaining equipment was completed in 2015-2016. Portions of the DISC Drill have been returned to Madison, but much of the system remains at WAIS Divide. The equipment will subsequently be returned to McMurdo Station as aircraft availability allows and all components are expected back in Madison by spring 2017.
Technical Issues:	Performance Data – Extensive data were collected throughout the drilling at WAIS Divide. These data provide information useful in making modifications to the drill that will improve its performance in the future. Data gathered on subsequent DISC Drill projects will be used in a similar way.

	Documentation – The DISC Drill was documented as it was developed and over 1200 system drawings exist in the document database. IDDO makes use of an Engineering Change Notification process to ensure that documentation is updated to reflect changes to the equipment. Other – The obsolescence and the resulting inability to get replacement components, particularly electronics, has been an ongoing challenge and will continue to be during the usable lifetime of the drill. A new drill fluid will need to be selected prior to the next field project. In East Antarctica, the drill fluid would have to retain a low viscosity at very low temperatures.
Plans:	1. Clean and store returned DISC Drill components until the next deployment of the system – Ongoing. 2. Determine components that need to be replaced to make the drill ready for Hercules Dome and other field sites in East Antarctica and test components as necessary – PY 2016 and ongoing. 3. Complete DISC Drill vs. IDD-Deep analysis in collaboration with community scientists and ASC – PY 2016 and PY 2017. 4. Repair/upgrade the drill system, including the capability to operate at very low temperatures, and enhance the performance and implement logistical improvements in response community desires – PY 2018 or later.

2.3 REPLICATE CORING



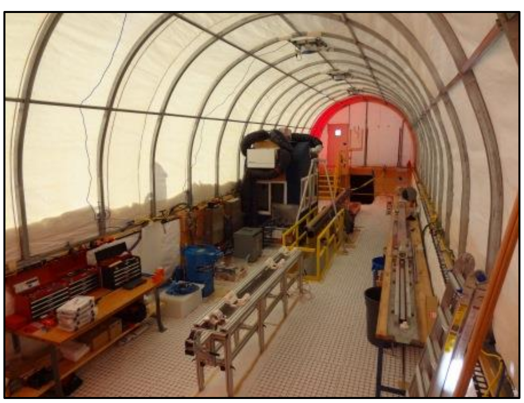
Replicate Coring – Taking a single deep ice core from a given region makes replication and verification of the validity and spatial representativeness of key results difficult. Furthermore, scientific demand for ice samples has been and will continue to be unevenly distributed versus depth. The inventory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

The design of the IDDO replicate coring system for the DISC Drill incorporates, as its essential performance requirement, tilting and forcing of the sonde against the drill hole wall by ‘actuators’ that push against the wall upon command from the surface. This action then gradually deviates the drilling out of the main borehole into the side wall and eventually into the new replicate hole.

The replicate coring system was constructed in 2011. The first field testing of the replicate coring system occurred at WAIS Divide in the latter part of the 2011-2012 field season. No core was obtained, but IDDO engineers were able to gain valuable insight into what was occurring deep within the borehole. Using that insight, they made extensive modifications to the sonde and carried out many tests in a mock-up of the borehole back in Madison. The benefit and result of that work was total success in replicate coring during the 2012-2013 field season at WAIS Divide, where the system produced five azimuth and depth-controlled deviations at four target depths. A total of 285 m of excellent quality replicate ice core was recovered in the first coring of its kind.

Current Status:	The replicate coring-specific equipment of the DISC Drill system (i.e. sondes, actuator sections, control computers) were returned to IDDO in spring 2013 and have been dried, re-packed and stored. The replicate coring system is an integral component of the DISC Drill and awaits the next call for deep drilling.
Technical Issues:	Performance Data – Extensive data were collected during production replicate coring at WAIS Divide and operational techniques were honed through the review of the data. Documentation – All work on the replicate coring system has been documented according to SSEC standards and archived in the controlled document database. Over 300 replicate coring system drawings have been created and archived. Other – While the Russians have successfully deviated their boreholes around stuck drills and the Danes have successfully tested replicating core from the low side of a borehole at the bottom, until the success at WAIS Divide no one had previously developed or deployed a system specifically to replicate ice cores at any chosen depth and at any chosen azimuth within an existing borehole.
Plans:	1. Store returned DISC Drill Replicate Coring components until the next deployment of the system – Ongoing. 2. Conduct a feasibility study on compatibility of the existing Replicate Coring System with the upgraded DISC Drill system – PY 2018 or later.

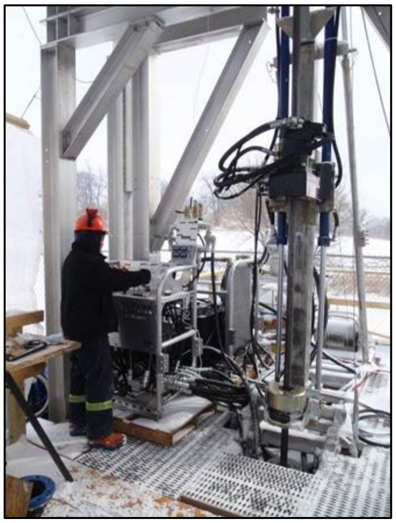
2.4 INTERMEDIATE DEPTH DRILL



Intermediate Depth Drill (IDD) – Many of the coring objectives outlined in the U.S. Ice Drilling Program Long Range Science Plan, such as those in the IPICS 2k array and 40k network, are achievable in many locations using an intermediate-depth drill, meaning one that can collect core from a fluid-filled hole down to a depth of 1,500 m. In PY 2014, IDDO completed the design and fabrication of a new Intermediate Depth Drill (IDD). The design of the IDD was completed in cooperation with the Centre for Ice and Climate, Niels Bohr Institute, University of Copenhagen, Denmark and the Science Drilling Office, Antarctic Research Centre, Victoria University of Wellington, New Zealand. IDDO modified the existing design of the Hans Tausen intermediate depth drill and built a new system. The system was field-tested outside of Summit Station, Greenland in spring 2014 and was recently used in successful completion of the SPICE Core project just outside of South Pole Station, where a total of 1,751 m of core was collected. Much of the drilling equipment and a portion of the ice core remains onsite at South Pole for packing and retro shipment during the 2016-2017 field season. IDDO also plans to use the IDD winch, tower and cable to assist with optical borehole logging in 2016-2017.

Current Status:	Much of the drill remains onsite at the SPICE Core camp outside of the South Pole Station. A subset of components including the sondes and the control box were returned to Madison in spring 2016 and are currently undergoing inspection, repairs, upgrades and testing. Remaining drill cargo is expected back in Madison in spring 2017.
Technical Issues:	A drilling fluid is needed to keep the borehole open. ESTISOL 140 was chosen for both the drill test in Greenland as well as for the SPICE Core project after successful use by the Danes. IDDO drillers, however, have noted that the fluid causes potentially irritating side effects, including headaches, smarting of the eyes and mild lung irritation. As a result, IDDO worked extensively with the fluid manufacturer and with UW Health and Safety personnel to ensure the fluid was and is safe for use and to help mitigate its side effects through the use of Personal Protective Equipment (PPE). The primary issues occur when the ESTISOL is brought into warm environments (i.e. the control room) and is allowed to evaporate, causing a considerable odor. In response, IDDO increased ventilation within the drill tent and the control room and purchased additional PPE in an attempt to keep the fluid from entering the control room on the driller suits.
Plans:	1. Modify and repair components following the 2015-2016 SPICE Core season – PY 2016. 2. Update system documentation as necessary – Ongoing. 3. Return the drill to IDDO for inspection and repair – PY 2017.

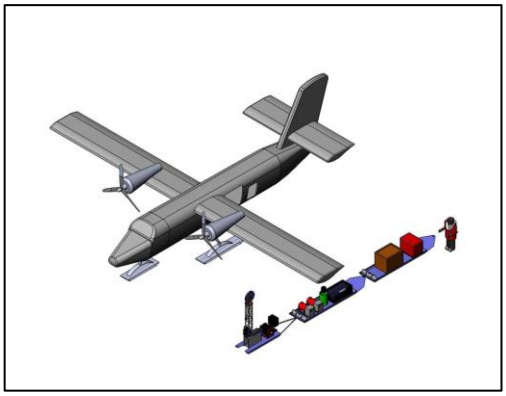
2.5 ASIG DRILL

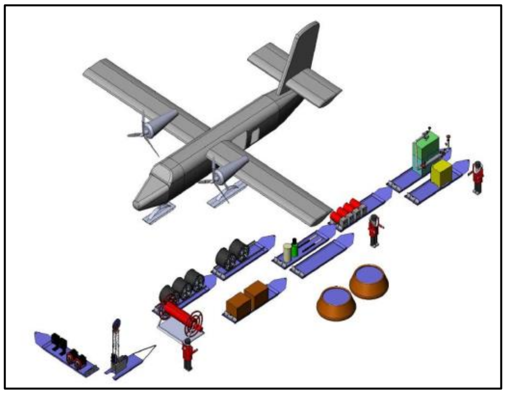


ASIG Drill – The Agile Sub-Ice Geological (ASIG) Drill is the latest system in development at IDDO. Science requirements were developed through an iterative process between IDPO, IDDO and community scientists interested in sub-glacial access and were approved in February 2014. The drill system design is based on a commercially-available minerals exploration rig, which IDDO has adapted for drilling through ice and for ice coring. The system will be able to drill access holes through ice less than 700 m thick and will subsequently collect bedrock cores from beneath glaciers. In PY 2014, IDDO began designing auxiliary systems such as ice coring attachments and fluid and ice chip handling and filtration systems to complement the base rock coring drill for use in the polar regions. In late PY 2014, IDDO awarded a build contract for a minerals exploration rig. In April 2015, IDDO received the base minerals exploration rig purchased from Multi-Power Products Ltd. in British Columbia, Canada. In late 2015, IDDO began assembly and lab testing of auxiliary components. The drill system is now in its final stages of development, in preparation for deployment to Antarctica for the 2016-2017 field season. This is the first sub-glacial access rock coring drill of its kind for IDDO and marks entry into an exciting new avenue of drilling for IDDO, whose previous work has primarily focused on drilling ice cores and creating access holes in ice. For information on another sub-glacial rock coring drill in development at IDDO, see the Winkie Drill section above.

Current Status:	IDDO received the base rig in early 2015 and completed rigorous Acceptance Testing on the unit. IDDO worked with the manufacturer on the re-machining and/or replacement of certain parts of the system that exceeded the weights specified in the contract. IDDO engineers have completed the designs for auxiliary systems including casing setting, fluid handling, filtration, ice coring, etc. In late May 2015, IDDO held an Integrated Detailed Final Design Review via the web and teleconference, inviting several rock and oil drilling industry experts to participate and to provide feedback. IDDO utilized that feedback to refine sub-system designs. In February and March 2016, the full drill system was tested at the UW Physical Sciences Lab (PSL) in Stoughton, WI, inside of a temporary ice well set up specifically for such purposes. In late April 2016, IDDO presented drill fabrication and testing progress at a virtual Verification Review for IDPO and interested community scientists. IDDO is now engaged in post-testing modifications and repairs in preparation for the system's first deployment to Antarctica in September 2016 for the 2016-2017 field season.
Technical Issues:	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. IDDO has worked closely with industry experts as well as with the team developing the Rapid Access Ice Drill (RAID) to share knowledge that is of benefit to both teams. Six issues were identified during Acceptance Testing of the base rig and were communicated to the supplier, Multi-power Products and were subsequently and successfully resolved.
Plans:	1. Complete full-scale North American system test (completed) – PY 2016. 2. Make necessary modifications and repairs to the drill system following the North American system test – PY 2016. 3. Complete documentation for the drill system and enter it into the documentation database – PY 2016 and ongoing. 4. Prepare and ship the drill system to Antarctica – PY 2016.

2.6 SCALABLE HOT WATER DRILL





Scalable Hot Water Drill – 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. ICDS (IDDO's predecessor) received the Kamb-Engelhardt hot water drill (KE drill) from Caltech in 2002. It had been used successfully to drill many holes, some as deep as 1,000 m, to the bed of the West Antarctic ice sheet in the region of the Ross Embayment ice streams, however, it has been idle since its last deployment (~1998). In May 2012, the majority of the NSF-owned Kamb-Engelhardt Drill equipment was loaned by IDDO to the University of Nebraska-Lincoln for use by the WISSARD project.

Due to increased community interest in access holes through ice shelves, IDDO has developed plans to regain this capability by designing and building a modular hot water drill with the flexibility to create holes of various sizes to depths between 50 and 1,000 m. The IDPO Science Requirements for the new Scalable Hot Water Drill (ScHWD) were completed in early 2014 and IDDO, in cooperation with hot water drill engineers from the UW Physical Sciences Lab, developed a conceptual design of the system.

Current Status:	Much of the KE hot water drill has been loaned to the University of Nebraska for use on the WISSARD Project. IDDO expects that the equipment will be returned to its inventory at the completion of the WISSARD Project, however, the drill system's condition would need to be evaluated and a determination made as to how much of the drill could be salvaged for use for a new hot water rapid access drill. Currently, there are no funded field projects for use of the new scalable drill, though there has been great interest by the science community in development of such a scalable system.
Technical Issues:	Performance History – Hot-water-drilling thermodynamics and heat transfer are well known. It is possible to predict the performance of a particular drill configuration by calculation. If a new system is developed, IDDO would institute a process for logging all relevant data while operating the drill. Documentation – With regard to IDDO's design of a Scalable Hot Water Drill, all system documentation will be collected as the system is developed in accordance with SSEC standards and archived in the

	controlled document database. Other – The degree of cleanliness of the drill water, drill components (e.g. hoses, cables) and any instruments to be deployed will need to be defined. The conceptual design of the ScHWD calls for fittings and other equipment to be adaptable for clean access requirements.
Plans:	1. Contingent on available budget, initiate fabrication of the Scalable Hot Water Drill – PY 2017. 2. Conduct full-scale system testing in North America, Greenland or Antarctica – Will be based on drill development timeline. 3. Deploy the drill to Antarctica – Future field project needs and available funding will determine availability.

2.7 RAPID ACCESS ICE DRILL

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 and building both the RAID and ASIG 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 two drill systems differ in scope, size and capability, they share many common characteristics. In March 2015, two IDDO engineers were able to participate in and view the RAID North American Test (NAT) outside of Salt Lake City, UT, by invitation of the RAID PIs. In May 2015, a review was held for each system. Another IDDO engineer was invited to attend a post-NAT RAID review in Salt Lake City while IDDO invited DOSECC's Director of Operations and primary engineer on the RAID project to attend the ASIG Drill review via web and teleconference. Additionally, IDDO and DES personnel jointly supported the RAID Auger & Packer Test field project conducted outside of McMurdo station in February 2016. During the brief test, IDDO and DES engineers worked to successfully test both the RAID and ASIG Drill packer devices. This collaborative relationship is expected to continue as both the RAID and IDDO teams deploy the two drill systems in 2016-2017.

2.8 MODIFIED AGILE ICE CORING DRILL OR IDD-LIGHT

Modified Agile Ice Coring (MAgIC) Drill or IDD-Light (name TBD) – Per the Long Range Science Plan, a system similar to the Intermediate Depth Drill, but with reduced logistics, is desired for use in remote areas such as mountain glaciers in the Arctic. IDDO is currently iterating with IDPO and community scientists on requirements for such a drill. Once requirements are finalized, the community will determine if the drill should be built. IDDO has included funds in its PY 2018 budget to complete the Detailed Design of the system, should the community wish to move forward with this development.

2.9 LOGGING WINCHES

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 sleds for these winches were designed, fabricated, and mounted to the base units. The first, the Intermediate Depth Logging Winch (IDLW), is a 1.5 km winch and is a very portable winch that is used for logging shallow and intermediate depth holes. This IDLW was first tested during the 2013-2014 Antarctic field season at Siple Dome. It will be deployed during the 2016-2017 field season as a backup winch for logging in the SPICE Core borehole at South Pole Station and for logging of the RAID test holes near Minna Bluff.

The second new logging winch, the IDDO Deep Logging Winch (DLW), is capable of logging to 4,000 m. IDDO completed all auxiliary work on this system and it is crated and ready for issue. IDDO also periodically works with PIs to test communications and compatibility of their logging tools with the logging winches in IDDO's off-campus warehouse facility. The winch is expected to deploy to WAIS Divide for borehole logging in 2016-2017.

In PY 2014, the United States Geological Survey (USGS) gifted its 4,000 m logging winch to IDPO-IDDO for continued use by the polar logging community. The winch has been used extensively for logging boreholes in both Greenland and Antarctica and was most recently used during the 2014-2015 Antarctic season for logging of the WDC06A borehole at WAIS Divide that was drilled by the DISC Drill. The USGS logging winch was shipped to IDDO in spring 2015 and was inspected by IDDO engineers. 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.

Current Status:	Several years ago, the logging community prepared a white paper that was used for guidance in procuring the logging winches. IDDO responded by purchasing two portable, off-the-shelf winches with depth capabilities of 1.5 km and 4 km. The logging winches have since been purchased, assembled and modified as needed by IDDO. They are both crated and are ready for issue. 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 2.5 km. 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 by the WISSARD project. In 2014, Gary Clow worked with IDPO-IDDO to transfer the USGS deep logging winch, which is typically operated by Clow, to IDPO-IDDO, as the USGS no longer wishes to maintain this winch.
Technical Issues:	Performance History – With only one deployment of the IDLW, minimal performance data has been collected. The new IDDO Deep Logging Winch has yet to be deployed to the field, but has been used for bench testing of logging tools at the IDDO warehouse. The USGS winch has been used extensively in both Greenland and Antarctica by Gary Clow. Documentation – Documentation for the new IDDO winches was collected throughout their development and entered into the document database. IDDO has worked with Clow to develop and update documentation for the USGS logging winch (i.e. procedures, maintenance plans) where it may not exist. IDDO is working to ensure operator's manuals and preventive maintenance checklists are available for all of the logging winches.
Plans:	1. Maintain and upgrade the IDLW, the DLW and the USGS logging winch systems – Ongoing. 2. Procure spare parts for the IDLW and the DLW – PY2016 to PY 2018. 3. Make repairs/modifications as necessary to the USGS logging winch – PY 2018. 4. Receive IceCube logging winch following use with the WISSARD Drill – PY 2018. 5. Refurbish and modify, if necessary, the IceCube logging winch – PY 2018, depending on WISSARD, community needs, and available budget.

2.10 DRILLING FLUID

Drilling Fluid – With the phase-out and banning of the production of ozone-depleting substances such as chlorofluorocarbons, a good substitute for the two-part drilling fluid used at WAIS Divide and on several European drilling projects is a necessity for the continuation of intermediate and deep coring projects. A few possible substitutes have been identified: n-butyl acetate, dimethyl siloxane (silicone) oil, and an ESTISOL-COASOL mixture. Butyl acetate has been used by both the U.S. and the Japanese programs in the past, and is currently being used by the Chinese program, but because

of the health risks associated with the chemical, ICDS/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. The mixture has a disadvantage in that ESTISOL 240, a coconut extract, could compromise biological experiments because it is a nutrient. Silicone oils have been suggested as a possible ice drilling fluid but have not been used by the U.S. community, as the oils are difficult to remove from surfaces, are expensive and may not be available in the required quantity. With that said, members of IDDO's Technical Advisory Board (TAB) have indicated that silicone oils are now available that evaporate cleanly from ice surfaces. Both the silicone oils and the ESTISOL-COASOL mixture have the major disadvantage of being significantly more viscous at low temperatures than fluids successfully used in the past. In 2013 and 2014, a new candidate for drilling fluid emerged called ESTISOL 140, made by a company in Denmark. ESTISOL 140 is dense enough to balance the borehole without a densifier and also has only a modest increase in viscosity at temperatures as low as -55 °C.
Based on positive experiences in using ESTISOL 140 by IDDO's drilling colleagues in Denmark, ESTISOL 140 was chosen as the drilling fluid for the Greenland test of IDDO's Intermediate Depth Drill (IDD) as well as for the SPICE Core drilling project at the South Pole Station.

After IDDO drillers working with the fluid experienced mild headaches, minor lung and throat irritation and chapped skin when working with the ESTISOL 140, IDDO and SSEC Quality Assurance & Safety personnel initiated an investigation into the fluid's composition. IDDO/SSEC worked with the manufacturer of the fluid, Esti Chem A/S in Denmark on acquiring the latest Safety Data Sheet (SDS). The main ingredient in ESTISOL 140 is 2-ethylhexyl acetate, and evidence based on review of the Safety Data Sheet (SDS) suggests that this fluid has low toxicity. In addition, available literature on the fluid was reviewed by a UW Safety Chemical Hygiene Officer (CHO) and a University Health Services Industrial Hygienist (UHS IH). Additional improvements to Personal Protective Equipment (PPE) were recommended and implemented through the purchase of protective eyewear, new gloves and aprons to be worn over the drilling suits. These efforts primarily focused on decreasing the amount of fluid that ends up on the drillers' work suits and identifying a glove that is more chemically resistant to the ESTISOL 140. Following the Greenland field test, IDDO also made substantial modifications to the IDD ventilation system, including an active ventilation system for the driller control room to ensure continuous air flow and to induce an air flow pattern that pulls room air down and away from the occupants' breathing area and workspace. The system uses an energy recovery ventilator (ERV) and two inline duct heaters to circulate enough air to replace the volume of air inside the control room every 67 seconds (53 times/hour). Ventilation upgrades were also made in the following areas: added two new roof vent fans, added a slot ventilator and added a centrifuge ventilator. Total added ventilation capacity following the Greenland test exceeds 5,000 cfm. The volume of the drill tent is approximately 13,760 ft3, so the exchange rate of the air is 163 sec/exchange or 22 exchanges per hour. An air monitoring sensor that has been shown to work down to -40 °C was identified through RAECO, a distributor of detection instrumentation, and after further discussion with the UW Health and Safety professionals, an Ion Science PhoCheck Tiger detection unit was procured for use with the ESTISOL 140. IDDO completes safety assessments for all of its drill systems. For large field drilling projects such as the WAIS Divide Ice Core Project and the SPICE Core Project, IDDO also institutes seasonal startup, daily and weekly safety checks of equipment and operations while in the field. This includes the measuring of fluid vapor levels and the recording of the results. Following improvements to the drill structure's ventilation system and to the available PPE, side effects from use of the fluid abated a bit, but were still present during operations at the South Pole. IDDO continued its discussions with UW Health & Safety personnel, the fluid manufacturer and the drillers, but all sources indicate that while the fluid is an irritant, it is not toxic. For future drilling projects where the borehole needs to remain open, IDDO would like to identify an alternative fluid to use in place of Estisol 140. A good replacement has not yet been identified, however IDDO continues to discuss this issue with its colleagues in China, who are conducting ongoing testing of potential candidate fluids.

In 2014, under the Direction of IDPO Industry Liaison Bill Eustes, student Benton Ellis at the Colorado School of Mines (CSM) conducted a study of potential ice core drilling fluids, analyzing temperature versus viscosity and density from minus 60 °C to 10 °C. Seven candidate fluids were tested, many of which are used in the petroleum mining industry, and Ellis presented the results at the 2014 TAB meeting. Results of the study showed that viscosity is highly dependent upon temperature, getting thicker with lower temperatures, that there is a temperature at which the viscosity rises nonlinearly and that density generally varies linearly with temperature. In addition to the study conducted at the CSM, the international ice drilling community continues to very actively pursue good candidate drilling fluids. Several papers in the recently published Annals of Glaciology Vol 55, No 68, 2014, discuss the pursuit of identifying new fluids.

In addition to the study conducted at the CSM, 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 ICDS/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.
With deep (i.e. >1,000 m) drilling in very cold regions in East Antarctica likely in the near future, IDPO-IDDO will continue to work with international colleagues on cold temperature drilling fluids.

Current Status:	While there are currently available drilling fluids, none is ideal for drilling at very cold sites. Several papers have been published about potential new fluids, including a summary issued in 2011 by the Chinese Polar Research Center (Pavel G. Talalay, *Drilling Fluids for Deep Coring in Central Antarctica*, Technical Report PRC 02-23011, Jilin University, China, December 2011) and several articles published recently 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. For upcoming use of the ASIG Drill and the Winkie Drill in Antarctica, IDDO will use Isopar K without a densifier, as the holes do not need to remain open after drilling. IDDO remains in discussion with its international colleagues on this matter, particularly with Dr. Talalay at the Polar Research Center at Jilin University in China.
Technical Issues:	Drilling fluids should, among other things, be non-hazardous, have low viscosity at very low temperatures, and not inhibit or complicate biological studies.
Plans:	1. Continue to work with international colleagues to investigate alternative drilling fluids – Ongoing. 2. Provide proper Personal Protective Equipment (PPE) for drill system deployments and operator safety – Ongoing.

3.0 POTENTIAL UPCOMING NEW TECHNOLOGY DEVELOPMENTS

The U.S. Ice Drilling Program Long Range Science Plan 2016-2026 outlines several areas of technology development for the coming years. In section 4.0, IDDO has outlined how it plans to address and pursue such investments. Some new areas of development are also included in the current plan, including:

- Rapid hole qualification devices (temperature and caliper) for RAID boreholes
- In situ probes for englacial and subglacial observations and sampling
- Modular, clean access hot water drilling technology capable of reaching 2,500 m depth

As the Long Range Science Plan and this Long Range Drilling Technology Plan are living documents, they will be revisited each year to ensure IDDO development funds are continually allocated to those areas of equipment development that are expected to provide the largest scientific payoff for the community.

4.0 RESPONSES TO DIRECTIVES FROM THE LONG RANGE SCIENCE PLAN 2016-2026

IDDO notes the following guiding principles for development of drilling technology expressed in the U.S. Ice Drilling Program Long Range Science Plan 2016-2026:

1. *Designs require that the supporting logistical needs do not impede execution of the science.*
2. *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.*
3. *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.*
4. *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.

5. *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 major development projects – the fabrication of the new Agile Sub-Ice Geological Drill, the modification and upgrade of the new Winkie Drill system, and in iterations between IDPO, IDDO and community scientists in establishing Science Requirements for upcoming drills such as the Portable Firn Coring Drill and the Sediment Laden Lake Ice Drill. 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 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 2016-2026

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 pages 3-4). 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 2016-2026, together with the corresponding IDDO action taken or to be taken.

Priority 1 (needed this year):

1. Maintain and upgrade the following existing agile equipment: hand augers, 2" and 4" electromechanical drills, 3" electrothermal drill, 3.25" Badger-Eclipse drills, logging winches, 30 m hot water shot hole drill, the Blue Ice Drill, and the Winkie Drill.

Science goals

Industrial & instrumental period
Pre-Industrial baseline
Prior to 800 ka (blue ice)
Pre-quarternary atmosphere
Tracers requiring large samples

Ancient microbial life
Nimble geologic coring under shallow ice
Internal layering
Seismic imaging
Sediments/ice sheet dynamics
Geology/ice sheet history

IDDO action: This is a major focus of this Plan – see section 2.1 on Agile Drills.

2. Return the DISC Drill to Madison.

Science goals

Large-scale global climate change
Last Interglacial
Prior to 800 ka (IPICS oldest ice)
Ancient microbial life
Borehole array
Rheological properties
Internal layering

IDDO action: This work is in progress. Remaining components are expected to arrive back in Madison in spring 2017.

3. Prepare a comparison of total cost estimates for drilling at Herc Dome with DISC versus IDD-Deep, by adding a 3-m or 4-m sonde to the IDD and for extending the IDD capability to 2,800 m.

Science goals

Pre-industrial baseline
Large-scale global climate change
Last Interglacial
Prior to 800 ka (blue ice)
Prior to 800 ka (IPICS oldest ice)
Ancient microbial life
Borehole array
Rheological properties
Internal layering

IDDO action: During PY 2016, IDDO initiated a comparison/analysis of DISC vs. IDD-Deep and is iterating on a specification worksheet with community scientists. IDDO is also in the process of estimating development and fabrication costs for extending the depth of the IDD. Logistical requirements are also being determined, after which point ASC will be brought into the discussion. This will help to provide a more comprehensive picture of entire project costs for the anticipated drilling effort at Herc Dome.

4. Develop a Conceptual Design for adapting the IDD for drilling to 2,800 m and for replicate coring with IDD using a whipstock.

Science goals

Pre-industrial baseline
Large-scale global climate change
Last Interglacial
Prior to 800 ka (blue ice)
Ancient microbial life
Borehole array
Rheological properties
Internal layering

IDDO action: In conjunction with the action outlined in number 3 above, IDDO will proceed with the conceptual design of an IDD-Deep system, which will include research into whipstock technology for replicate coring on the downhill side of the borehole. The IDD system may or may not be modified pending results of the conceptual design.

5. Construct a very lightweight highly-portable drill that can be transported by backpack for shallow ice coring to 100 m.

Science goals
Industrial & instrumental period

IDDO action: IDDO is currently iterating with IDPO and community scientists on a final draft of the Science Requirements for this lightweight drill being referred to as the Portable Firn Coring Drill. Once the Science Requirements are finalized, IDDO will complete related Engineering Requirements for the system, a Conceptual Design and a Cost Estimate. Following that work, the system, which is expected to be quite simple, will either be purchased, if an appropriate commercial unit is identified, or will be designed by IDDO. In either case, the system will be assembled and tested to the extent possible.

6. Build a second Blue Ice Drill-Deep for wide-diameter drilling.

Science goals
Tracers requiring large samples
Ancient microbial life

IDDO action: Due to increased interest in use of the Blue Ice Drill (BID), IDDO plans to include funds within the PY 2017 IDDO subaward budget to initiate fabrication and assembly of a second BID. Lessons learned through the development and use of the original BID will be reviewed and utilized. The majority of the cost in fabricating a second system will lie in the purchase of capital equipment and materials, however labor will also be needed for re-initiating contact with the component manufacturers, as the original BID was built several years ago back in 2009-2010.

7. Develop and build the Lake Ice Drill, a very portable clean hot-water drill for creating 5" holes through up to 6-m of sediment-laden lake ice.

Science goals
Sub-ice shelf/stream instrumentation

IDDO action: Systems in IDDO inventory currently do not have the capability of drilling through sediment laden ice. In addition, IDDO does not currently have established 'clean drilling' protocols, however certain equipment cleaning protocols have been implemented on a project-by-project basis.

Prior to the 2015-2016 field season, IDDO worked with PI Peter Doran to specify Hotsy Drill add-on parts that might serve as a proof of concept for this Sediment Laden Lake Ice Drill. Doran purchased the necessary components and tested the equipment during the 2015-2016 season. Doran noted the new equipment was a big stride in the right direction, but that a system that uses a small generator, that doesn't require use of a Hotsy unit, and that could make its own seed water, should still be developed.

In PY 2015, IDDO worked with IDPO and the science community to iterate on draft science requirements for the Sediment Laden Lake Ice Drill. This discussion has continued in PY 2016, and the science requirements are expected to be finalized in late PY 2016. IDDO will then plan to develop and finalize Engineering Requirements based on the Science Requirements and will begin the conceptual design, including a preliminary cost estimate for building of the drill.

8. Adapt or construct an agile shot-hole drill capable of drilling fifteen 10 cm diameter holes per day up to 100 m deep in both East and West Antarctica. This may include consideration of a RAM drill upgrade, or other means.

Science goals

Seismic imaging

IDDO action: IDDO's current hot water drill technology is limited to depths of approximately 30 m. With upgrades nearing completion for IDDO's Small Hot Water Drill (SHWD) system, one system will have a 30 m depth capability and the other will have a depth capability of 60 m. These SHWDs are most often utilized for the rapid drilling of numerous holes for seismic research, and the primary users of the system have determined that expanding this capability for drilling to 60 m depth would be ideal.
It is possible that upgrades to the IDDO RAM Drill could serve to achieve the goals outlined for a '15 holes per day up to 100 m depth' drill. It is also possible that IDDO's Scalable Hot Water Drill (ScHWD), once developed and fabricated could also serve this need, as it will be scalable from 50-1,000 m. If it is determined that upgrade of the RAM drill is the best approach for this purpose, RAM Drill upgrades will be planned for PY 2017-2019. Additionally, in PY 2016, IDDO began investigating options for purchase or design of a new hose reel, possibly using double-walled hose. This approach would help to mitigate a current problem with the RAM Drill, which is loss of air to the firn while drilling. In early 2016, the Physics community from IceCube and ARA in Madison, WI also expressed interest in use of and further modification/upgrade of the RAM Drill. IDDO also plans to build the ScHWD system, as funds allow.

9. Develop IDPO Science Requirements for, and design and build, winch simulators.

Science goals

Large-Scale Global Climate Change
Last Interglacial
Rheological Properties
Internal Layering

IDDO action: Beginning in PY 2017, IDDO will work with IDPO and community scientists to draft, revise and finalize Science Requirements for a winch simulator device. It remains to be seen if IDDO will design such a device in the future or would purchase a more off-the-shelf system.

10. Evaluate practicality of acquiring WISSARD Drill system and operating it under IDDO.

Science goals

- Ancient microbial life
- Sub-ice shelf/ice stream instrumentation
- Ice shelf ROV deployment
- Grounding zone
- Biogeochemistry
- Subglacial lake biogeochemistry

IDDO action: At the request of NSF and IDPO, IDDO will communicate with the University of Nebraska-Lincoln (Frank Rack), the current owner and caretaker of the WISSARD Drill system. IDDO will work to learn about operating specifications for the drill and to determine the current state of the equipment as well as its location. With this information, IDDO can develop a plan for what additional resources (space, staff, maintenance and upgrade funds) would be needed if the drill were to be transferred to IDDO.

11. Develop IDPO Science Requirements and a conceptual plan for a hot water drill, with modular clean access add-on, capable of creating access holes in ice to depths of 2,500 m or greater for deeper targets (i.e. sites around Thwaites, interior sedimentary basins).

Science goals

- Ancient microbial life
- Sub-ice shelf/ice stream instrumentation
- Grounding zone
- Sediments/ice sheet dynamics
- Biogeochemistry
- Subglacial lake biogeochemistry

IDDO action: Beginning in PY 2017, IDDO will work with IDPO and community scientists to draft, revise and finalize Science Requirements for this hot water drill. Due to budget constraints and per a discussion with IDPO, completion of a conceptual design will be delayed until PY 2018 or later. It is possible that existing or already-planned hot water drill systems (ScHWD, WISSARD, IceCube, international drills) may diminish the need or desire to build up a new 2500 m system.

12. Conduct Antarctic field trials of the Rapid Access Ice Drill (RAID).[1]

Science goals

- Prior to 800 ka (IPICS oldest ice)
- Site selection for IPICS oldest ice
- Borehole array
- Bed conditions
- Geothermal flux
- Geologic coring for cosmogenic samples
- Rheological properties
- Bedrock geology/Tectonics

IDDO action: Development of the RAID system was completed by the University of Minnesota-Duluth and University of California-San Diego, with design, fabrication, and test activities being performed by DOSECC Exploration Services, LLC (DES). IDDO helped design the initial concept for the drill and provides reviewer capacity and field testing support when requested. IDDO and DES personnel cooperated with PI Jeff Severinghaus on a test of the RAID packer device outside of McMurdo Station in February 2016. At the request of PI John Goodge, IDDO plans to send an IDDO engineer to participate in the RAID field trials near Minna Bluff, Antarctica for a short period in December 2016.

Priority 2 (needed within the next three years):

13. Using science requirements provided by IDPO provide a cost estimate and conceptual design for adapting the existing Intermediate Depth Drill and infrastructure to minimize logistical requirements for the drill, shelter and fluid plan for ice coring to approximately 600-800 m, if weight and cube estimates indicate this should go forward. The system must have significantly smaller logistical requirements than the current IDDO Intermediate Depth Drill and its associated infrastructure. Published lessons learned (e.g. Sheldon et al, 2014 and Triest et al, 2014), and performance of the Danish drilling at Renland should be considered.

Science goals
- Industrial & instrumental period

IDDO action: Following finalization of the Science Requirements for the MAgIC or IDD-Light drill (final name TBD), which are expected to be completed in PY 2016, IDDO will complete a conceptual design and cost estimate for this system. Preliminary weight and cubic feet estimates for the lighter system will be provided to IDPO in advance, to help inform future directives. IDDO will utilize lessons learned, particularly from its international colleagues, but cautions that a reduction in the logistical requirements of an 800 m drill may not be as dramatic as the science community envisions. IDDO, in development of the IDD, worked very hard to keep the system design as lean as possible, and notes that the Danes encountered issues with their winch when too dramatic of a weight reduction was made. Any system required to drill deeper than approximately 400 m will need drilling fluid and chip handling equipment, which increases its logistics burden. While weight savings can be had in a reduction of the amount of cable deployed, it is difficult to quantify how much lighter the surrounding infrastructure could be made (i.e. winch, tower, etc.) until the conceptual design is complete. Consideration for logistics of such a system would also be discussed with Polar Field Services (Arctic) or with Antarctic Support Contract (ASC; Antarctica) personnel.

14. Evaluate if the agile shot-hole drill design could be used, and is desired, for 15 cm diameter boreholes (up to 220m, xx per day) for radio neutrino detectors as well.

Science goals
- Astrophysics
- Seismic imaging

IDDO action: IDDO will continue a conversation with members of the UW-Madison Physics community and the IceCube and ARA drilling communities. Some interest in the RAM Drill for this application has been expressed by these groups.

15. Build a Scalable Hot Water Access drill for creating access holes in ice from 50 m up to approximately 1,000 m depth with modular potential to be used for clean access.[2]

Science goals

- Bed conditions
- Geothermal flux
- Sub-ice shelf/stream instrumentation
- Ice shelf ROV deployment
- Grounding zone
- Sediments/ice sheet dynamics
- Biogeochemistry

IDDO action: IDDO does not currently have deep hot water drilling equipment in its inventory. While some equipment exists from the former Kamb-Engelhardt Drill, much of this equipment has been loaned to the IceCube and WISSARD projects over the years, per NSF direction.

In PY 2014, science requirements for a Scalable Hot Water Drill were formalized. IDDO subsequently completed engineering requirements for the system and completed a conceptual design as well as both internal and external conceptual reviews of the concept in PY 2014. With continued interest in this expressed at the annual Science Advisory Board (SAB) meeting, IDDO plans to begin development of this system as funds allow.

16. Upgrade the electrothermal drill to allow for coring to 300 m through temperate and poly-thermal firn and ice. The drill needs to be agile and lightweight (transportable by helicopter).

Science goals

- Industrial & instrumental period

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

17. Continue to evaluate options for new drilling fluids.

Science goals

- Large-scale global climate change
- Interglacial
- Prior to 800 ka (IPICS oldest ice)
- Internal layering

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

Priority 3 (needed within three to five years):

18. Investigate rapid hole qualifiers (temperature and caliper) for RAID boreholes.

Science goals

Borehole array
Geothermal flux
Rheological properties
Internal layering

IDDO action: IDDO does not currently maintain any borehole logging tools within its inventory. IDDO will investigate the design or purchase of a hole qualifying tool for use with the RAID and other drill systems.

19. *Investigate potential of in situ probes for englacial and subglacial observations and sampling.*

Science goals

Borehole array
Bed conditions
Geothermal flux
Rheological properties
Grounding zone
Subglacial lake biogeochemistry

IDDO action: IDDO does not currently maintain any in situ probes within its inventory. IDPO will work with community scientists and with IDDO to draft and finalize science requirements for such tools. IDDO will investigate the design or purchase of such probes once requirements are better understood.

20. Investigate potential for improved and more efficient site selection for ice core drilling projects.

Science goals

Identification of ice coring sites to facilitate efficient project planning

IDDO action: This is largely a responsibility of the ice coring community, specifically the Ice Core Working group, possibly in conjunction with groups providing airborne or ground penetrating radar surveys. IDDO will offer assistance at any time if this would be of benefit for site selection.

[1] This development is happening with DOSECC Exploration Services, LLC.

[2] The IDDO Conceptual Study for the ScHWD found that scalable capability deeper than 1,000 m would require different components that are not practical for use between 50-1,000 m.

5.0 FIELD SUPPORT OF SCIENCE PROJECTS

In addition to the development of new drilling equipment and the maintenance and upgrade of existing ice 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 the drilling 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. Below, known projects for the next several years are discussed.

WAIS Divide Ice Core Project

PY 2016 – Due to the severe delays experienced in getting to WAIS Divide during the 2014-2015 season, IDDO sent one person back to the site during the 2015-2016 field season to complete the remaining DISC Drill disassembly activities. Despite additional delays due to weather and unavailability of aircraft, drill disassembly and extension of the borehole casing was successfully completed. A portion of the equipment returned to Madison in spring 2016. DISC Drill equipment is flying from WAIS Divide to McMurdo on flights of opportunity and remaining DISC Drill equipment is now planned to be returned to Madison in spring 2017. Upon its return to Madison, IDDO will clean, inspect and store all remaining DISC Drill equipment until such time as it is needed for a future drilling project.

PY 2017 – IDDO plans to send the IDDO Deep Logging Winch and one operator to WAIS Divide during the 2016-2017 field season in support of borehole logging operations. During summer 2016, IDDO will train PI Erin Pettit and her science team in Madison on operation of the IDDO Deep Logging Winch, to allow for multi-shift logging at WAIS Divide.

South Pole Ice Core Project – SPICE Core

PY 2016 – In January 2016, IDDO completed drilling operations at the South Pole Station in support of the SPICE Core project. The final borehole depth was recorded as 1,751 m. IDDO partially disassembled, packed and shipped out a portion of the equipment, but much of it remains onsite at South Pole. Cargo that returned to Madison in spring 2016 is currently being inspected and repaired.

PY 2017 – IDDO plans to send two people to the South Pole during the 2016-2017 field season to assist with borehole logging operations, to disassemble and pack any remaining drilling equipment and to disassemble and pack the drill tent, with assistance from core handling and ASC personnel. IDDO plans to return remaining IDD components to Madison where they will be cleaned, inspected and repaired as needed, to ready the drill for its next field use.

Shallow Coring and Drilling Projects

Support of NSF shallow coring and drilling (400 m or less) single-investigator or small group projects in the Arctic, Antarctic and on lower latitude ice sheets and glaciers is an important ongoing activity of IDDO. IDDO will continue to support these projects in much the same manner as done in the past. The involvement of IDDO with a project begins in the proposal phase, in which IDDO and IDPO work with the prospective PI to understand the objectives of the project and to determine how best to support it. The close collaboration of the researchers and IDPO-IDDO is the key to success, and upon funding of a project, IDPO and IDDO work closely with the principal investigators to define project requirements more fully and prepare a project plan, which will be followed in the conduct of the project. At the end of each project, the PIs and the drillers, if any, are asked to provide feedback on the successes attained and difficulties encountered over the course of the project. This feedback is used by IDPO-IDDO to continuously improve its services to the science community. After the return of the equipment from the field, IDDO typically makes the necessary repairs to ready the equipment for use on the next project.

PY 2016 – IDDO plans to support three shallow coring projects in Antarctica during the 2016-2017 field season as well as a number of projects requiring hand auger equipment.

PY 2017 - IDDO plans to deploy drillers and engineers to support funded field projects in Alaska, Antarctica and Greenland, as needed. Several projects in the Arctic are still in the proposed phase at this time. Should they be funded, IDDO will work to prepare and ship equipment and to hire and deploy drillers, as necessary.

Preserving Ice Core Boreholes for Logging Science

The Long Range Science Plan speaks to the importance of retaining access to previously-drilled boreholes for logging purposes. Such logging opportunities provide access to the interior of ice sheets and enable wide-ranging observations from glaciology, climatology and planetary science to experimental astroparticle physics. The borehole logging community has expressed interest in repairing and maintaining the GISP2 and Siple Dome boreholes, among those at other locations. The IDPO Borehole Logging Working Group (BLWG) is working to prepare a list of U.S. boreholes in the polar regions and will then work with the polar community on prioritizing which holes should be maintained and repaired for future logging endeavors. IDPO will continue discussions with the NSF to determine prioritization of borehole repair and preservation after firm science targets have been identified by the Borehole Logging Working Group. The GISP2 and Siple Dome boreholes, in particular, are in danger of collapsing. Direct visual evidence of serious damage to the casing in the GISP2 borehole at Summit, Greenland is available, and it is likely that the similarly-emplaced casings in the younger boreholes on Taylor and Siple Domes in Antarctica will become vulnerable to similar damage. Additional science remains to be carried out in these boreholes if access is preserved.

PY 2017 or thereafter – If tasked by IDPO following the research and recommendation of the SAB’s BLWG, IDDO will undertake evaluation of the situation in the GISP2, Siple Dome and other named boreholes and will develop a plan for the restoration of unimpeded access to those holes, if possible.

PY 2018 or thereafter – IDDO will work to implement any repairs identified in PY 2017, and as directed, particularly in the GISP2 and Siple Dome boreholes. IDDO will seek opportunities to evaluate the situations at Taylor Dome and other boreholes, if tasked to do so.

Subglacial Access

As mentioned in both the section on the Agile Sub-Ice Geological (ASIG) Drill and the Winkie Drill system, IDDO is nearing completion of these two systems able to provide subglacial access through relatively thin ice (1,000 m for less). Components from both systems were tested in Antarctica in 2016-2017 and were further tested at IDDO and at PSL in Madison.

PY 2016 – IDDO plans to deploy both the ASIG Drill and the Winkie Drill to Antarctica in September 2016 for funded field projects.

PY 2017 - IDDO plans to deploy four drillers and engineers to support the two funded field projects in Antarctica.

6.0 EXPENDITURES

Based on the current status of equipment in IDDO inventory and the plans for the development of new equipment, IDDO estimates between $8-9 million in funding will be available from PY 2016 through PY 2021 for the 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 2016-2026. This is a reduction from previous years, as IDDO now allocates more of its annual subaward funding toward field support labor, for which the NSF will no longer provide supplemental funds. The $8-9 million does not include IDDO management and support costs as well as general field support efforts handled within the subaward base funding (i.e. Antarctic Hand Auger projects). Appendix 3 summarizes the expected development and maintenance and upgrade expenditures by program year.

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 typically been between $300,000-$600,000, but are increasing each year. As the number of drills in the IDDO inventory increases, funds allocated to maintenance and upgrade work will correspondingly increase. IDPO-IDDO is cognizant of this issue and is considering a variety of strategies, including decommissioning equipment that is no longer desired by the science community.

Annual expenditures for operations supporting field projects vary depending upon the science projects funded by the NSF. Preparation and shipping of equipment for very simple projects may only require IDDO expenditures of $3,000-$5,000. Large, multi-year projects such as the SPICE Core project generally require IDDO expenditures of $400,000-500,000 per field season. Beginning with the PY 2017 budget, IDDO will now absorb all labor for both deploying in-house staff and for drillers under its base subaward funding. As such, field support costs for labor are expected to be $500,000-$800,000 per year, depending on the number projects funded and the number of people deployed. This will affect funds available for development projects and for maintenance and upgrade work.

7.0 ACRONYMS

ARA: Askaryan Radio Array

ASIG: Agile Sub-Ice Geological (Drill)

BID: Blue Ice Drill

BLWG: Borehole Logging Working Group

CSM: Colorado School of Mines

DES: DOSECC Exploration Services, LLC

DISC: Deep Ice Sheet Coring

ICDS: Ice Coring & Drilling Services

IDD: Intermediate Depth Drill

IDDO: Ice Drilling Design and Operations

IDPO: Ice Drilling Program Office

ITASE: International Trans-Antarctic Scientific Expedition

KE: Kamb-Engelhardt

NSF: National Science Foundation

OPP: Office of Polar Programs

PI: Principal Investigator

PICO: Polar Ice Coring Office

PY: Program Year (formerly 'FFY' for Federal Fiscal Year; term used after Nov. 1, 2014 to signify that the IDPO-IDDO fiscal year does not sync with the Federal Fiscal Year)

RAID: Rapid Access Ice Drill (currently in development by DOSECC Exploration Services and the University of Minnesota-Duluth)

RAM: Rapid Air Movement (Drill)

SAB: Science Advisory Board

SAWG: Subglacial Access Working Group

TAB: Technical Advisory Board

ScHWD: Scalable Hot Water Drill

SHWD: Small Hot Water Drill

SIPRE: Snow, Ice and Permafrost Research Establishment

SPICE: South Pole Ice Coring Project

SSEC: Space Science and Engineering Center

UNH: University of New Hampshire

LW: Logging Winch

WAIS: West Antarctic Ice Sheet

WISSARD: Whillans Ice Stream Subglacial Access Research Drilling

Appendix 1
Science – Technology Development Matrix

	SCIENCE																										
	Climate											Ice Dynamics and Glacial History										Subglacial Geology, Sediments and Ecosystems					
TECHNOLOGY	Industrial & instrumental period	Pre-industrial baseline	Large-scale global climate change	Last interglacial	Prior to 800 ka (IPICS oldest ice)	Site selection for IPICS oldest ice	Prior to 800 ka (blue ice)	Pre-Quarternary atmosphere	Tracers requiring large samples	Ancient microbial life	Borehole array	Bed conditions	Geothermal flux	Geologic coring cosmogenic samples	Nimble geologic coring shallow ice	Rheological properties	Internal layering	Sub-ice shelf/stream instrumentation	Ice shelf ROV deployment	Grounding zone	Seismic imaging	Sediments/ice sheet dynamics	Biogeochemistry	Bedrock geology/Tectonics	Geology/ice sheet history	Subglacial lake biogeochemistry	Projected Year Technology Available (PY)
Agile Drills	x	x					x	x	x	x					x		x				x	x			x		2016
Rapid Air Movement (RAM) Drill																					x						2016 [1]
Deep Ice Sheet Coring (DISC) Drill			x	x	x					x	x					x	x										2019 [2]
Intermediate Depth Drill (IDD)		x	x	x			x			x	x					x	x										2018 [3]
Rapid Access Ice Drill (RAID)					x	x					x	x	x	x		x	x						x	x	x		2017 [4]
Scalable Hot Water Drill (ScHWD)												x	x					x	x	x		x	x				2021 [5]
Agile Sub-Ice Geological (ASIG) Drill											x	x	x	x	x	x								x	x		2016
Winch Simulators			x	x												x	x										2017
Modified Agile Ice Coring Drill (MAgIC)	x	x									x					x											TBD [6]
Borehole Preservation Technology Development		x	x	x	x						x		x			x											TBD [7]
Modular 2,500 m Clean Hot Water Drill										x								x		x		x	x			x	TBD [6]
Hole Qualifiers for RAID (temperature/caliper)											x		x			x	x										2021
In Situ Probes for Observation											x	x	x			x				x						x	2021

[1] Current system is ready for issue; upgrades planned for PY 2018 and PY 2019
[2] Modifications envisioned to make logistics and operation easier; IDDO completing a DISC vs. IDD-Deep analysis
[3] Equipment is still at South Pole Station; return to IDDO expected in spring 2017
[4] Field trials to be conducted by DOSECC Exploration Services near Minna Bluff in 2016-2017 field season
[5] Technology may be available sooner; proposal pending
[6] Completion of system Science Requirements in PY 2016/PY 2017 will help inform a decision on whether or not to build this drill
[7] This is being addressed by the Borehole Logging Working Group, a sub-committee of the IDPO Science Advisory Board

Appendix 2
Long Range Project Schedule

Legend:

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

	PY 2016	PY 2017		PY 2018		PY 2019		PY 2020		PY 2021		PY 2022
Equipment	**2016 Arctic**	**2016-17 Antarctic**	**2017 Arctic**	**2017-18 Antarctic**	**2018 Arctic**	**2018-19 Antarctic**	**2019 Arctic**	**2019-20 Antarctic**	**2020 Arctic**	**2020-21 Antarctic**	**2021 Arctic**	**2021-22 Antarctic**
2-Inch Drill*												
4-Inch Drill 1												
4-Inch Drill 2												
Agile Sub-Ice Geologic Drill												
Badger-Eclipse 1^												
Badger-Eclipse 2^												
Badger-Eclipse 3*												
Blue Ice Drill/Blue Ice Drill-Deep				2 proposed								
Chipmunk Drill												
DISC Drill												
DISC – Replicate Coring System												
Drill Fluid Development	Ongoing											
Foro Drill												
In situ Probes for Observation & Sampling												
Intermediate-Depth Drill												
Koci Drill*												
Logging Tower												
Logging Winch - Deep												
Logging Winch - USGS**												
Logging Winch - IceCube***												
Logging Winch - Intermediate				2 proposed								
Modified Agile Ice Coring Drill^^		Development TBD										
Modular 2,500 m Clean Hot Water Drill^^^												
Portable Firn Coring Drill												
Prairie Dog												
RAID Rapid Hole Qualifier												
RAM (Rapid Air Movement) Drill												
Sediment Laden Lake Ice Drill												
Small Hot Water Drill 1												
Small Hot Water Drill 2												
Scalable Hot Water Drill			Development TBD									
Thermal Drill												
Winch Simulator												
Winkie Drill												
Sidewinder (4 available)	1 in use		1 proposed	2 proposed	1 proposed	1proposed		1proposed				
Hand Auger, 3" PICO (7 available)				Phasing out								
Hand Auger, 4" PICO (2 available)				Phasing out								
Hand Auger, 3" IDDO (8 available)	1 in use		2 proposed	3 proposed	2 proposed	1proposed	1proposed	1proposed				
Hand Auger, 4" IDDO												
Hand Auger, SIPRE (6 available)	1 in use	1 in use	1 in use									

* System could be repaired and refurbished if user-demand necessitates.

** Winch transferred from USGS to IDDO inventory in 2014.

*** Winch will be added to IDDO inventory after use by the University of Nebraska with the WISSARD Drill.

^ Solar/wind power capabilities available.

^^ Conceptual study to be conducted for coring to depths of 700 meters. Drill may be similar to IDD, but with reduced logistics. Results of study will help inform if system will be built.

^^^ Science Requirements to be established in PY 2017. Conceptual design and fabrication TBD at a later date.

Appendix 3

Estimated Costs for Equipment Development and Maintenance & Upgrade Projects
PY 2016 - PY 2021

Development or Maintenance & Upgrade Project	PY 2016 (Current)	PY 2017 (Estimated)	PY 2018 (Estimated)	PY 2019 (Estimated)	PY 2020 (Estimated)	PY 2021 (Estimated)	Total (PY 2016-2021)
2- Inch Drill	66,009						**66,009**
4-Inch Drill	10,268	35,000	10,000	10,000	10,000	10,000	**85,268**
Agile Sub Ice Geologic Drill	748,000	150,000	50,000	50,000	50,000	50,000	**1,098,000**
Badger-Eclipse Upgrades	98,041	60,000	10,000	10,000	10,000	10,000	**198,041**
Blue Ice Drill [1]	47,023	75,000	185,000	25,000	25,000	25,000	**382,023**
DISC Drill – Herc Dome	117,527	20,000	400,000	300,000	150,000	50,000	**1,037,527**
Foro Drill	97,116	141,000	270,000	55,000	69,000	10,000	**642,116**
Hand Augers	36,331	56,000	15,000	15,000	15,000	15,000	**152,331**
In Situ Probes for Observations					20,000	200,000	**220,000**
Intermediate Depth Drill	159,166	180,000	65,000	50,000	50,000	50,000	**554,166**
Logging Winches	69,656	37,000	64,300	15,000	15,000	15,000	**215,956**
Modified Agile Ice Coring Drill	20,352		35,000				**55,352**
Modular 2,500 m Clean Hot Water Drill		10,000	25,000				
Portable Firn Coring Drill		180,000	18,000	10,000	10,000	10,000	**228,000**
RAID Rapid Hole Qualifier					20,000	200,000	**220,000**
RAM Drill – Enhanced Capabilities	50,464	132,000	250,000	350,000	50,000	50,000	**882,464**
Scalable Hot Water Access Drill		10,000		303,000	923,500	573,500	**1,810,000**
Sediment Laden Lake Ice Drill		70,000	10,000	10,000	10,000	10,000	**110,000**
Small Hot Water Drill	106,000	25,000	15,000	15,000	15,000	15,000	**191,000**
Thermal Drill [2]			5,000	105,000	5,000	5,000	**120,000**
Winch Simulators		5,000	55,000	5,000	5,000	5,000	**75,000**
Winkie Drill	69,945	70,000	10,000	10,000	10,000	10,000	**179,945**
WISSARD Analysis [3]		13,000					
TOTAL COSTS [4]	**1,695,898**	**1,269,000**	**1,492,300**	**1,338,000**	**1,462,500**	**1,313,500**	**8,571,198**

[1] PY2017 and PY2018 costs include building a second BID per the 2016-2026 Science Plan
[2] PY 2019 funds include upgrading the Thermal Drill to allow coring to 300m (see 2016-2026 Science Plan)
[3] Per the 2016-2026 Science Plan, "Evaluate practicality of acquiring WISSARD Drill system and operating it under IDDO."
NOTE: Annual Development and Maintenance & Upgrade Costs are estimates at this time; individual annual budgets will be finalized in each annual Program Plan. The current IDPO CA runs through PY 2018. Out-year funding for PY 2019-PY 2021 assumes flat funding based on the PY 2018 IDDO subaward total.

Blue	Equipment Development
Green	Maintenance & Upgrade