Ice Drilling Design and Operations

Long Range Drilling Technology Plan

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

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Cover photo: The new minerals exploration rig, the base component of IDDO's new Agile Sub-Ice Geological (ASIG) Drill system. Photo credit: Chris Gibson, IDDO.

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 2015-2025.

Recommended technology investments (prioritized by time)

Priority 1 (needed this year):

- Maintain and upgrade the following existing agile equipment: hand augers, 2" and 4" electro-mechanical drills, 3" electrothermal drill, 3.25" Badger-Eclipse drills, logging winches, and 30 m hot water shot hole drill.
- Complete fabrication of the agile sub-ice rock coring drill (ASIG) capable of retrieving 10 m of rock core beneath ice up to 700 meters thick.
- Procure and modify a Winkie drill to also include conditions containing ice.
- Maintain the DISC Drill, and establish science requirements and cost estimates for minimal upgrades for the DISC drill for use at Hercules Dome with the goal to lessen its logistics requirements while maintaining its replicate coring capability, keeping in mind upgrades to be added later for future use for Oldest Ice.
- Develop IDPO Science Requirements and create a conceptual design and cost estimate for adapting an agile coring drill to minimize logistical requirement for the drill, shelter and fluid plan for ice coring to approximately 900m. The system must have significantly smaller logistical requirements than the IDPO Intermediate Depth Drill and associated infrastructure. Published lessons learned (e.g. Sheldon et al, 2014 and Triest et al, 2014) should be considered.
- 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.
- Establish IDPO Science Requirements and repair, modify or acquire a very lightweight highly portable drill for shallow ice coring.
- Prepare for field trials of the Rapid Access Ice Drill (RAID)[1].
- Prepare WISSARD & UNL Roving drill & recovery of hot water ice cores for projects proposed in 2015[2].

[1] This development is happening with DOSECC Exploration Services, LLC.
[2] If funded, this development would happen with an IDPO subaward to the University of Nebraska-Lincoln.

Priority 2 (needed within the next three years):

- Continue development of a scalable, modular 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.
- Conduct a conceptual design and start construction of an agile shot-hole drill capable of drilling 15 holes per day up to 100 m depth in both East and West Antarctica. This may include consideration of a RAM drill upgrade, or other means. A secondary consideration is that a 15 cm diameter borehole would make this drill of interest for radio neutrino detectors as well.
- Upgrade the electrothermal drill to allow for coring to 300m through temperate and polythermal firn and ice. The drill needs to be agile and light weight (transportable by helicopter).
- Build a replicate Blue Ice Drill for wide-diameter drilling to 200 m.

Priority 3 (needed within three to five years):

- Assess the potential of recovering cores to depths of 300-500 m without use of drilling fluid.
- Develop IDPO Science Requirements for clean access drill for depths over 3,000 m.
- Conduct a feasibility study to modify the Blue Ice drill to enable large-volume sampling of firn and ice up to 300 m depth.
- Develop IDPO Science Requirements and conduct a feasibility study for a drill capable of coring horizontally (or at low angles) several 100 m.
- Construct a jig to support a hand auger to facilitate horizontal coring up to 20 m into ice cliffs.

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 development 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 (2015-2025). 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 core. They are relatively light weight 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, light weight systems through the recent design and fabrication of new hand auger systems, incorporating many user-requested upgrades into former designs.

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 (3-inch core) system. 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 Sidewinder) is approximately 20 m.

Hand augers are typically operated by the investigator 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. IDDO recently developed a new replacement model and fabricated eight copies of the new 3-inch IDDO hand auger. The new design has now been used by several investigators in both Greenland and Antarctica and has replaced the PICO auger as the most-requested model. Based on the success of that new

	design, IDDO has now completed the design of a 4-inch hand auger to eventually replace the three aging 4-inch PICO hand augers in IDDO's inventory. Design drawings have been completed and parts have been ordered for the building of one prototype unit later this year. Several sizes of coring hand augers are also available commercially.
Technical Issues:	Performance Data – Data has been collected for the new 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. 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 fabricate a 4-inch model of the new IDDO hand auger – PY 2015. 3. Continue to phase out aging PICO equipment – Ongoing. 4. Maintain SIPRE hand auger kits, as requests for this kit have seen a resurgence in recent years – Ongoing. 5. Improve hand augers based on feedback from users – Ongoing. 6. Work with IDPO to establish science requirements for a very lightweight 'backpack drill' or other highly-portable drill for shallow coring – PY 2016. 7. Investigate and possibly purchase a 'backpack drill' or other highly-portable drill – PY 2016. 8. Construct a jig to support a hand auger to facilitate horizontal coring up to 20 m into ice cliffs – PY 2018 or as needed.

	9. Investigate clean technologies for such lightweight drills for shallow coring to study microbes in the ice – As needed. 10. Continue distribution of a post-field season questionnaire to hand auger users to get information from investigators on hand auger performance – Ongoing. 11. 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 most recently used in both Wyoming and Montana in 2013 for ice patch coring.

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 – 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 this system.
Plans:	1. Review other documentation available and determine needs; update and create documentation as needed and enter into database – Ongoing. 2. Investigate use of carbide cutters or inserts to aide in drilling of dirty, silty or sandy ice – As needed.

	3. 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.

The Sidewinders are increasingly being used by investigators without the assistance of IDDO drillers and this trend is expected to continue.

Current Status:	Four working systems are available.
Technical Issues:	Performance Data – Information regarding performance should be systematically collected from users; this task is in progress. Documentation – System drawings near completion; operating procedures for the Sidewinder are continually updated to include a greater array of pictures and diagrams, as available. 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. Evaluate design and operation of the Sidewinder, including review of safety concerns and design required modifications as necessary – Ongoing. 2. Modify Sidewinder systems per design evaluation – As needed. 3. Review documentation, update and enter into database – PY 2015 and ongoing. 4. Modifications – As recommended by users. 5. Repairs – Ongoing as needed.

2.1.5 Blue Ice Drill (BID) – 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, developed for the University of California at San Diego, has been repeatedly used with great success to collect samples of 'Blue Ice' on Taylor Glacier each season 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, is theoretically capable of reaching depths to 200 m. The BID-Deep system was first tested in Greenland during the 2014 Arctic field season, reaching a depth of 187 m. 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. The drill is again on assignment in Greenland, where new step cutters are being tested with the BID-Deep system.

Current Status:	Modifications to extend the depth capability of the system to 200 m (BID-Deep) have essentially been completed. The BID-Deep system was tested in Greenland in 2014 and in Antarctica in 2014-2015 with mostly positive results and is being used again during the 2015 Arctic season and the 2015-2016 Antarctic season. The standard BID typically utilizes a ropes setup for coring to shallow depths, and the cable winch is used for achieving greater depths.
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. IDDO will continue to evaluate this issue and make additional modifications to the BID, in an effort to improve deep core quality, as directed by IDPO and the science community. 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 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 will be updated periodically.
Plans:	1. Continued modifications to the drill to increase core quality down to 200 m – If feasible and as directed in PY 2015 and PY 2016. 2. Carry out further shallow and deep coring – As needed. 3. Build another BID for wide-diameter drilling to 200 m – PY 2018 or earlier. 4. Conduct a feasibility study to modify the BID to enable drilling to 300 m depth in firn and ice – PY 2018 to PY 2020 or later.

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.

Current Status:	Needs repairs and possible modification before being deployed for use.
Technical Issues:	Performance Data – None exist due to lack of use. Documentation – Some from manufacturer. If drill is to be used, documentation should be more fully developed. Other – IDDO engineers/drillers believe that the drill requires extensive modification to be a truly useful tool.
Plans:	1. This drill was used on the US-ITASE traverse and is in need of significant repair. Pending 2015 development of the IDPO Science Requirements for a 'highly-portable drill', repair of this drill may be needed for a science project proposed in 2015 which would be fielded in 2016-2017, if funded.

2.1.7 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 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 tested prior to the drill's deployment in May 2013 and was subsequently used with great success to drill two 200 m ice cores near Denali National Park in Alaska. This capability will 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 will allow drilling operations to continue safely and reliably in inclement weather and has already proven itself very useful in such conditions during a spring 2015 project in Greenland.

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, has not yet been refurbished, but will be repaired 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; over 60 drawings are currently in draft form or are contained in the database. Preventive Maintenance checklists, both seasonal and weekly have now been developed. An operator's manual is currently being drafted. Other – Improvements to instrumentation and the control system have been evaluated and 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 new instrumentation and control system – PY 2015 and PY 2016. 2. If needed, ready third Eclipse drill system for issue. 3. Develop procedure, including bill-of-materials checklist, for preparing drill for issue – PY 2016. 4. Analyze project performance data, develop (if possible) preliminary performance baseline and institute guides for data collection. Continue to collect and analyze data and update performance – PY 2016 and thereafter. 5. Standardize components of the drills to the extent desirable and practicable* – PY 2015 and ongoing. 6. General maintenance and repairs – Ongoing. 7. Complete documentation and enter into database – Ongoing. 8. Determine desired evolution of Badger-Eclipse drills in general – Ongoing. * Participants at the IDDO 2010 Drillers' Workshop suggested making downhole equipment interchangeable and surface equipment distinct, with distinct names and transportability options.

2.1.8 4-Inch Drill & New Foro 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 many years. It is particularly useful on projects requiring a larger diameter core than that produced

by the Badger-Eclipse drills. Depending on the configuration, the drill can be transported by light aircraft or helicopter.

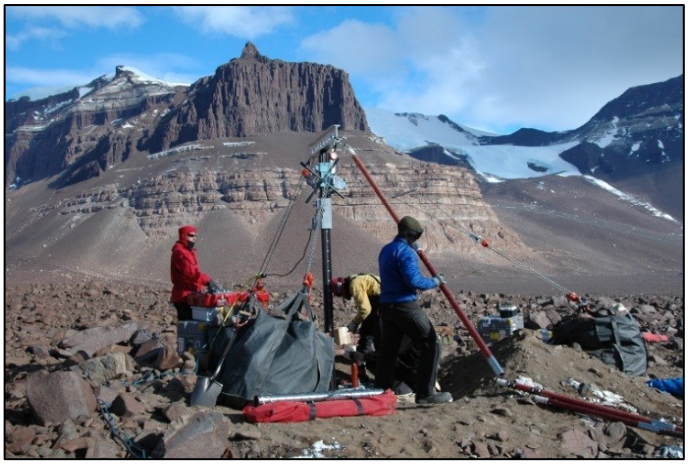
The 4-Inch drill was most recently used during the 2013 Arctic field season. General maintenance and minor modifications were implemented between PY 2011 and PY 2013 and are ongoing. All budget requests since PY 2012 have included, and will continue to include, upgrade costs. In PY 2015, IDDO initiated 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). While IDDO still maintains two 4-Inch Drills that are ready for issue, IDDO plans to begin fabrication of the new Foro Drill components during PY 2016.

Current Status:	IDDO currently has two 4-Inch Drill systems ready for issue and plans to maintain those systems along with building up one new Foro Drill system. The current 4-Inch Drills are being refurbished, as needed, including the replacement of some aging components. A new set of barrels of the existing design were recently machined and are ready for issue. 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. Much of the maintenance and many of the upgrades for the 4-Inch Drill that were postponed in recent years due to the prioritization of IDDO's projects have now been completed.
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 Foro Drill. Procedures for more consistent recording of data during projects need to 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. Design documentation for the new Foro Drill is being added to the document database as the design progresses. An operator's manual is currently being drafted for the 4-Inch Drill and one will be drafted for the Foro Drill once it is developed. 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. Fabricate new Foro Drill components including winch, tower, sonde and control box – PY 2016 to PY 2019. 4. Analyze drill performance data, establish a performance baseline if possible, and define data collection procedures – PY 2015 and thereafter. 5. Complete development of operating and maintenance procedures and documentation – PY 2015 and ongoing. 6. Update drill system drawings and enter into database – Ongoing.

2.1.9 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.

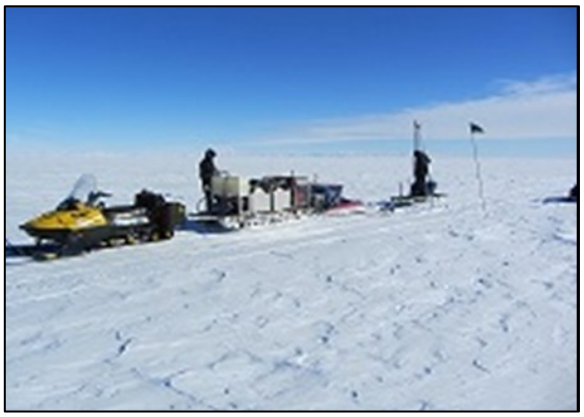
Current Status:	IDDO has one electrothermal drill that is available for use. A new 65 meter water-shedding cable was procured in 2015 to prevent the fibrous cable typically used with the Thermal and 4-Inch Drills from soaking with water in aquifer layers, refreezing and causing issues with travel over 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 need to be defined and used. 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 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. Analyze drill performance data and establish a performance baseline if possible and define data collection procedures – PY 2015 and ongoing. 2. Complete/update drawings to the extent practicable and enter into database – PY 2016. 3. Perform maintenance and repairs – Ongoing and as needed. 4. Upgrade the drill to improve its performance capability to 300 m depth – PY 2016 to PY 2018.



2.1.10 Koci Drill – The Koci Drill, named after the late great drilling engineer Bruce Koci, is an electromechanical, single-barrel, coring drill 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. Through discussions with the NSF and IDPO, IDDO determined that the science community might be better served by IDDO purchasing an off-the-shelf rock coring drill and 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. Since the Koci Drill was not designed as a rock drill, there is some concern that it would not be capable of applying enough down force, torque or speed for drilling rock. As such, IDDO has identified an off-the-shelf rock coring Winkie Drill system, manufactured by Minex that should be a better fit for the community. The ASIG Drill (see section 2.5), also in development at IDDO, will have similar rock and ice drilling capabilities, but on a larger scale. At this point, the Koci Drill will likely be replaced operationally by a new drill system with greater capability, such as the Winkie Drill.
Technical Issues:	Performance Data – Because of the nature of the ice being drilled and the fact that conditions can vary drastically from

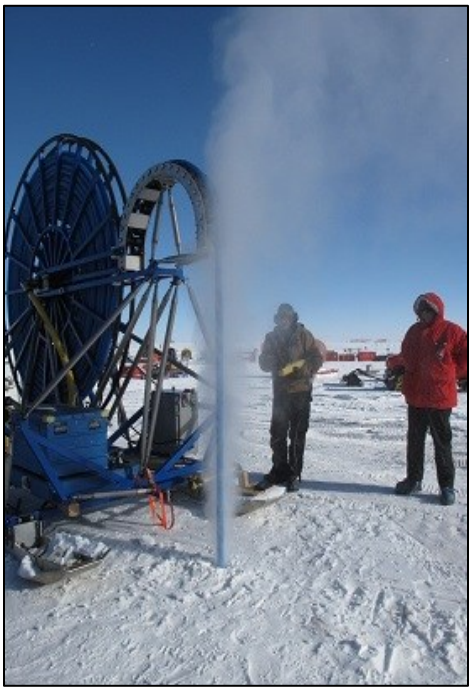
	hole-to-hole in a matter of a few meters, it would be difficult to collect anything but general performance data for this drill. Documentation – Nearly 60 system drawings for the drill have been produced and are entered into the database, as are the results of the testing of the drill; operating and maintenance procedures have not yet 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 could be better accomplished with a lightweight rock drill when logistics permit.
Plans:	1. IDDO is looking to purchase a Winkie Drill in late PY 2015 which will have expanded capability over the Koci Drill and may operationally replace the Koci Drill – PY 2015.



2.1.11 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 have typically been operated by investigators without assistance from IDDO drillers.

Current Status:	IDDO has two small hot water drills in inventory. One of the two systems requires more maintenance and upgrade than the other, however both systems are aging. One system was recently used on a two-year field project in Antarctica during the 2012-2013 and 2013-2014 field seasons. 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 has also been collected from primary users of the system. It is envisioned that this system will remain IDDO's 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 recently moved to PSL, where it is undergoing inspection and testing prior to modification and upgrade. It is anticipated that

	a system will be deployed to Antarctica for the 2015-2016 field season. Prior to that deployment, IDDO plans to refurbish the heaters, evaluate the hose, specify and procure a new nozzle kit and test and verify all modifications. 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, however, much of the equipment is aging and should be replaced. 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 will be further updated after modifications are made to the drills. 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. A pending proposal plans to use one of the drills during the 2015-2016 Antarctic field season – PY 2016. 2. Upgrade and test the drill per the study conducted by PSL, the design review and per user feedback – PY 2015 and PY 2016. 3. Update completed operating procedures as needed – Ongoing. 4. Develop procedure for preparing the drills for issue – PY 2016. 5. Develop preventive maintenance (PM) checklists for the drill system – PY 2016 and ongoing. 6. Complete other documentation and add to database – PY 2015 and ongoing.



2.1.12 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.
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 in review by Amber Whelsky, the student mentioned above, in the Cold Regions Science and Technology Journal

	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. Operating instructions are in rough draft form and will be completed prior to any future deployment of the system. Other –Techniques or equipment need to be developed 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 should be redesigned before use on any more seismic traverses.
Plans:	(The following plans for the RAM drill will require considerable time and effort and work is planned for future program years.) 1. Design a new hose reel 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-PY 2017. 3. Make desired modifications, including fabrication of new hose reel and modifications to compressors, to improve traversing – PY 2018 to PY 2020.

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. Much of this drill system is currently 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 plans to send one person back to WAIS Divide during the 2015-2016 season to complete all disassembly tasks and to extend the borehole casing to the surface for future borehole logging operations. The equipment is being flown out of WAIS Divide on flights of opportunity, with all equipment eventually planned for return to IDDO for inspection, storage and rework.

Now that the work with the DISC Drill at WAIS Divide, including the replicate coring, has been completed, the U.S. Ice Drilling Program Long Range Science Plan 2015-2025 anticipates the drill may next be assigned to a drilling site near Hercules Dome, with deployment to that site expected as early as 2018-2019. The Long Range Science Plan also anticipates that the drill may be used at a site in East Antarctica in search of 'Oldest Ice' in 2024 or later. Prior to any future deployment of the DISC Drill, the drill will need to be returned to Madison and repaired. The list of sub-systems that require repairs and maintenance includes, but is not limited to, the gantry cranes, centrifuge, screen cleaning and fluid handling systems, winch (will also require the redesign of the level wind sheave), tower (will also require the redesign of the crown sheave), sonde (redesign of aging and out-of-production components; redesign for cold operations prior to operation in East Antarctica), 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.

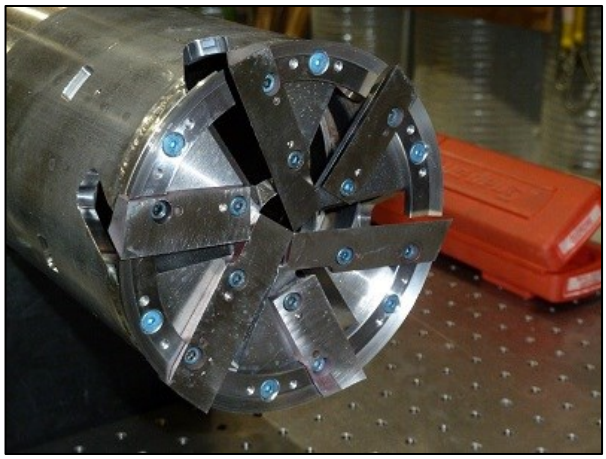
During PY 2015, IDDO began to evaluate what work would need to be done on the DISC Drill prior to its operation at any future site, with particular emphasis on repairs and modifications needed for drilling at Hercules Dome. In early PY 2015, IDPO initiated the drafting of revised science requirements for the DISC Drill, in collaboration with IDDO and with community scientists interested in using the DISC Drill. This iterative process is ongoing and has included some discussion of the feasibility of reducing the drill's logistical footprint. 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:	Much of the DISC Drill remains at WAIS Divide. Disassembly and packing of the remaining equipment is expected to occur during the 2015-2016 field season. The equipment will subsequently be returned to McMurdo Station as aircraft availability allows and all components will be shipped back to Madison in late spring 2016. The return of a couple of components may be delayed until 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. Complete disassembly and packing of the drill equipment at WAIS Divide during the 2015-2016 field season – PY 2016. 2. Extend the borehole casing to the surface with assistance from Antarctic Support Contract (ASC) personnel during the 2015-2016 field season – PY 2016. 3. Clean and store returned DISC Drill components until the next deployment of the system – Ongoing. 4. 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 2015 and ongoing. 5. Complete feasibility study and preliminary design for making the drill suitable and economical for operations at any future site, first at Hercules Dome and then in East Antarctica – PY 2015 and PY 2016. 6. Upgrade the drill system, including the capability to operate at very low temperatures, and enhance the performance and implement logistical improvements in response to the feasibility study. IDDO requires continued direction from the IDPO/SAB on future use of the DISC Drill; IDPO will work

	with IDDO and the science community to finalize the updated science requirements in PY 2015.

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 2016 and ongoing.

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 PY2014 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 installed at a site approximately 2.7 km from the South Pole Station. The 2014-2015 field season marked the first production coring season for the South Pole Ice Core (SPICE) project, where a team of seven IDDO engineers and drillers drilled to a depth of 736 m. Core handling personnel were also onsite to assist in the operations and to process the core collected.

At the end of the season, nearly 600 m of ice core was flown from the South Pole back to McMurdo, where it was placed on the cargo vessel and shipped back to Port Hueneme, CA. The cores were subsequently transported by truck to the National Ice Core Lab (NICL) in Denver, CO, where they are being processed during the 2015 summer by investigators from across the U.S. The IDDO and science teams plan to return to Antarctica in November 2015 for the second and likely final season of drilling for the SPICE Core project, at an expected final depth of approximately 1,500 m. If the drill team is unable to reach 1,500 m during the 2015-2016 field season, a provisional third season (2016-2017) has been outlined in the Operational Notice prepared and approved by the ASC and the NSF. If this occurs, IDDO will work with IDPO, the SPICE Core PIs and the NSF to determine the best course of action.

Current Status:	The drill is currently set up 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 2015 and are currently undergoing inspection, repairs, upgrades and testing. IDDO plans to ship these components back to Antarctica in late September 2015.
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 has worked extensively with the fluid manufacturer and with UW Health and Safety personnel to ensure the fluid 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 has increased ventilation within the drill tent and the control room and is continuing to investigate and purchase 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 2014-2015 SPICE Core season – PY 2015. 2. Ship repaired/modified components back to Antarctica – PY 2015. 3. Update system documentation as necessary – Ongoing. 4. Continue drilling at South Pole, starting at 736 m and finishing at a depth of approximately 1,500 m – PY 2016. 5. Conclude drilling for the SPICE Core project – PY 2016 or PY 2017.

	6. Return the drill to IDDO for inspection and assessment of necessary repairs prior to the next deployment – PY 2016 or 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 is adapting for drilling through ice and for ice coring. Ultimately, 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 also released an RFP and subsequently 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. The ASIG Drill system will now be built-up over the next year, with its first deployment to Antarctica expected in September 2016 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.

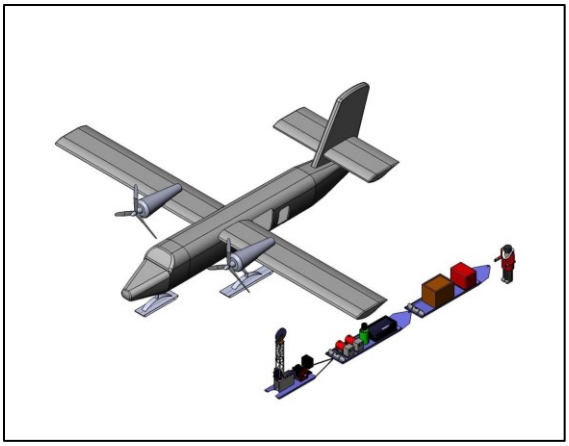
Current Status:	IDDO has received the base rig and has completed rigorous Acceptance Testing on the unit. IDDO is currently working with the manufacturer on the re-machining and/or replacement of certain parts of the system that exceeded the weights specified in the contract. The manufacturer has been very responsive. At IDDO, engineers have completed the designs for auxiliary systems including casing setting, fluid handling, filtration, ice coring, etc. In late May, 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

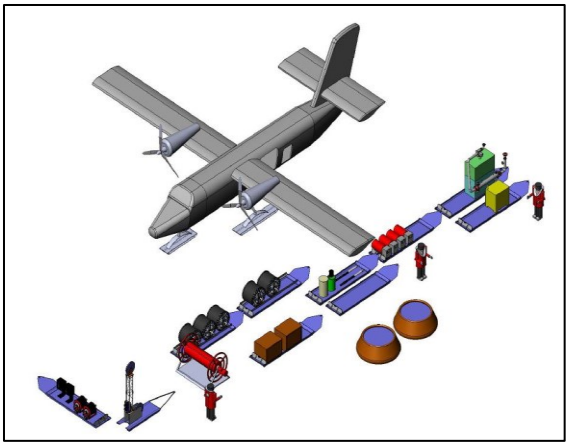
	provide feedback. IDDO is utilizing that feedback as it refines sub-system designs and looks to begin purchasing auxiliary system components. IDDO will perform periodic lab-style testing throughout the drill's development in its off-campus warehouse, but also plans for a full-scale test of the system in January 2016. It is anticipated this test will be conducted near IDDO at the UW PSL. There is currently a cased well in the ground on the PSL campus that was used during the testing of the Enhanced Hot Water Drill. IDDO plans to install additional casing inserts, a cooling loop and other equipment as needed to complete the test setup for the ASIG Drill. This smaller scale test setup may also serve as proof of concept for development of a larger-scale Test Well Facility in the future, which could prove invaluable in the testing of ice drilling equipment as well as borehole logging tools.
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 is working 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. While fabrication of the entire ASIG Drill system is in the initial stages, a good portion of the system has already been received through the purchase of the off-the-shelf base rig. Six issues were identified during Acceptance Testing of the base rig and have been communicated to the supplier, Multi-power Products. The weight of two components in particular was found to exceed that specified in the purchase contract. These items included the control console and the mast. In addition, several items were not received with the original shipment of the rig including the cold weather package, the hose and throttle cable extension package, one set of drill jaws and the final operations manual. The manufacturer has been very responsive in addressing the identified issues and IDDO has now received several items that were missing in the original shipment. The two overweight items have been returned to Multi-Power Products where they will be modified using lighter materials (i.e. aluminum) to bring the weights down to near that which was specified. IDDO does not anticipate that these issues will affect the overall ASIG development schedule's critical path.
Plans:	1. Review Integrated Detailed Final Design Review participant feedback and revise auxiliary system designs as appropriate – PY 2015.

	2. Continue resolution with manufacturer of issues identified during rig Acceptance Testing – PY 2015. 3. Request quotes and initiate purchases of auxiliary components – PY 2015. 4. Prepare for full-scale North American system test – PY 2015. 5. Conduct full-scale North American system test – PY 2016. 6. Make necessary modifications and repairs to the drill system following the North American system test – PY 2016. 7. Complete documentation for the drill system and enter it into the documentation database – PY 2015 and ongoing. 8. 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 drill 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 – The KE Drill has a long record of successful performance. 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 – A description of the KE Drill and its operation exists. With regard to IDDO's design of a new hot water access 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 and any instruments to be deployed will need to be defined for any drill to be used to access the bed of grounded ice.
Plans:	1. An internal engineering design review of the new Scalable Hot Water Drill system was completed in May 2014. This was followed up by an external scientific review in order to verify that the system design will meet all desired scientific objectives. The external review was held in late June 2014 and reviewer comments were received in September 2014. IDDO subsequently revised and updated the conceptual design document in October 2014. Due to other higher priority development and maintenance and upgrade projects, the PY 2015 IDDO budget did not include funds for work on this system's design and/or fabrication. 2. Contingent on available budget, continue the design, including evaluation of re-using KE Drill components, and initiate fabrication of the Scalable Hot Water Drill – PY 2017. 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 being designed and built by DOSECC Exploration Services, LLC (DES) under contract with the University of Minnesota-Duluth and the NSF. IDDO is not directly participating in the design, fabrication or testing of the RAID Drill, 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 have 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 2014, 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. This collaborative relationship is expected to continue as both the RAID and IDDO teams further develop, build and deploy the two drill systems.

2.8 LOGGING WINCHES

Logging Winches – Following the 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 which will be used for logging shallow and intermediate depth holes. This IDLW was first tested in the field during the 2013-2014 Antarctic field season at Siple Dome.

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.

In PY 2014, the United States Geological Survey (USGS) gifted its 4 km 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 is currently being inspected by IDDO engineers. IDDO plans to invite Gary Clow, a USGS employee and the former predominant operator of the winch, to Madison to help train the IDDO staff on the setup, operations, crating, maintenance and troubleshooting of the winch. This is expected to occur in summer 2015. Through consultation with IDPO and the borehole logging community, IDDO plans to require at least one IDDO logging winch operator be sent with the systems each time they deploy.

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. This winch was recently received in Madison where it will now be repaired and maintained.
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. IDDO will work with Clow to develop documentation for this winch (i.e. procedures, maintenance plans) where it may not exist. Documentation – Documentation for the new IDDO winches was collected throughout their development and entered into the document database. 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 – PY 2015 and ongoing.

	2. Complete minor repairs and modifications to the IDLW that were identified during its deployment to Siple Dome in 2013-2014 – PY 2015. 3. Procure spare parts for the IDLW and the DLW – PY2016. 4. Inspect the recently-received USGS logging winch and make repairs/modifications as necessary – PY 2015 and ongoing. 5. Receive IceCube logging winch at the conclusion of the WISSARD project – PY 2016. 6. Refurbish and modify, if necessary, the IceCube logging winch – PY 2017, depending on WISSARD, community needs, and available budget.

2.9 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, but because of the health risks associated with the chemical, ICDS/IDDO and the U.S. science community decided not to use it for the WAIS Divide Ice Core Project. ESTISOL-COASOL was used in the deep drilling at NEEM, in Greenland. The mixture has a disadvantage in that ESTISOL, 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 noted that they 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 UW University Health Services Industrial Hygienist (UHS IH). Additional improvements to Personal Protective Equipment (PPE) were recommended and have been implemented through the purchase of protective eyewear, new gloves and aprons to be worn over the drilling suits. These efforts have 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 is continuing 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. Despite this conclusion, IDDO does not plan to use ESTISOL 140 again after the SPICE Core project has concluded.

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 by IDDO for the DISC Drill project at WAIS Divide. The three chemicals were evaluated to assess the impact to the health and safety of the drillers as well as the logistical issues with shipping the chemicals. During this evaluation no red flags were identified that would rule out the use of any of these chemicals for this application. Safety Data Sheets were reviewed, odor testing was conducted, packing and shipping requirements were researched and chemical compatibility testing was conducted on various types of gloves. Overall, none of the possible replacements were found to raise concerns in polar drilling applications. The fluids were also found to present less of an odor issue than the ESTISOL 140 mentioned above. For more information on this testing, interested parties may contact IDDO.

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. With regard to ESTISOL 140, while the Danish team at NEEM found it satisfactory in shallow holes at relatively warm temperatures and the Aurora Basin project used it with good success during

	the 2013-2014 Antarctic season to depths of ~300 m, IDDO does not wish to continue use of ESTISOL 140 based on the side effects described above. While the properties of the ESTISOL 140 are 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, have led IDDO to likely discontinue use of the fluid after the SPICE Core project. IDPO at the Colorado School of Mines is continuing its analysis of potential drilling fluid candidates, and IDDO is continuing discussion with its international colleagues on this matter.
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. Select drilling fluid for ASIG Drill deployment in 2016-2017 field season – PY 2015. 2. Continue to work with SSEC, UW EHS, CSM and international colleagues to investigate alternative drilling fluids – Ongoing. 3. Provide proper Personal Protective Equipment (PPE) for drill system deployments and operator safety – Ongoing.

3.0 RESPONSES TO DIRECTIVES FROM THE LONG RANGE SCIENCE PLAN 2015-2025

IDDO notes the following guiding principles for development of drilling technology expressed in the U.S. Ice Drilling Program Long Range Science Plan 2015-2025:

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 Intermediate Depth Drill, the design, procurement and construction of the Agile Sub-Ice Geological Drill, the design of the Scalable Hot Water Drill, the development and modification of logging winches, and the design and construction of the Blue Ice Drill-Deep. In recent years, IDDO has begun to work 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. IDDO has also worked closely with IDPO and the science community in recent years to establish formal science requirements for several new drilling technologies though an iterative process between the scientists, IDPO and the IDDO engineers and field support personnel. 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 2015-2025

The IDPO Science Advisory Board and the broader polar science community 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 plans 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 2015-2025, 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" electro-mechanical drills, 3" electrothermal drill, 3.25" Badger-Eclipse drills, logging winches, and 30 m hot water shot hole drill."*

Science goals

200-year arrays

2,000-year array

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

2. *"Complete fabrication of the agile sub-ice rock coring drill (ASIG) capable of retrieving 10 m of rock core beneath ice up to 700 meters thick."*

Science goals

Glacial history

IDDO action: In late PY 2014, IDDO placed an order for a minerals exploration rig from Multi-Power Products Ltd. in Canada. This rig will serve as the base component for the new IDDO ASIG Drill. IDDO has focused heavily on the design of the ASIG Drill system in PY 2015 and recently completed an Integrated Detailed Final Design Review of the drill system in late May 2015. Having received the base rig in April, IDDO is now working to finalize all details of the auxiliary component designs and will fabricate the system throughout the remainder of PY 2015 and into PY 2016. The system will be tested in North America in early 2016 in preparation for shipping the drill to Antarctica in September 2016 – see section 2.5 on ASIG Drill.

There is currently one funded field project that will make use of the ASIG Drill beginning in the 2016-2017 Antarctic season. The project requires access through a couple hundred meters of ice and into the bedrock below.

3. *"Procure and modify a Winkie drill to also include conditions containing ice."*

Science goals

Subglacial geology, sediments and ecosystems

Glacial history

IDDO action: Outside of the ASIG Drill currently in development, IDDO does not currently have rock drilling capability and does not have a system in its inventory that can core the ice-bedrock interface, particularly for small projects conducted in very remote locations with very limited logistics. In PY 2015, IDDO discussed upgrade of its Koci Drill system with IDPO, the NSF and with the PIs of a project funded to collect 5-30 m of 'dirty ice' core and then collect 20 cm of rock core below. The IDDO Koci Drill was designed as a dirty ice drill, meaning ice containing sand, silt or very small rocks, however it cannot drill rock. After performing an evaluation of the Koci Drill and the field project requirements, IDPO-IDDO and the NSF concluded that upgrading the Koci Drill was not a good use of budget. To support the funded project as well as other PIs interested in shallow sub-glacial rock coring, IDDO is now planning to purchase a Winkie

Drill system in late PY 2015. IDDO is discussing the Winkie Drill's performance with Minex, the Winkie Drill manufacturer, as well as with the RAID team, who have some experience with this small rock drill. IDDO has been given approval from the NSF and IDPO to proceed with the purchase of a Winkie Drill (as it was not included in the baseline plan for PY 2015). It is expected the drill will be used for testing of the packer devices in early 2016 for both the RAID and ASIG Drill projects. The test is expected to occur outside of McMurdo Station with both RAID and IDDO personnel participating.

4. *"Maintain the DISC Drill, and establish science requirements and cost estimates for minimal upgrades for the DISC drill for use at Hercules Dome with the goal to lessen its logistics requirements while maintaining its replicate coring capability, keeping in mind upgrades to be added later for future use for Oldest Ice."*

Science goals

- 40,000-year network
- High-resolution records of the last interglacial
- Evidence from the ice sheet prior to 800,000 years B.P.
- IPICS Oldest Ice

IDDO action: IDDO plans to return all DISC Drill equipment from WAIS Divide to IDDO in spring 2016 or 2017 for inspection and temporary storage. IDDO will continue to work with IDPO and the science community on finalizing updated science requirements for the DISC Drill system, along with a discussion of which repairs and upgrades should be implemented prior to the drill's next deployment. If repairs and upgrades are made, IDDO will remain mindful of potential ways to reduce the logistical requirements of the DSIC Drill and will be attentive to potential future use of the drill in a cold environment (-50 °C or colder) in search of Oldest Ice.

5. *"Develop IDPO Science Requirements and create a conceptual design and cost estimate for adapting an agile coring drill to minimize logistical requirement for the drill, shelter and fluid plan for ice coring to approximately 900m. The system must have significantly smaller logistical requirements than the IDDO Intermediate Depth Drill (IDD) and associated infrastructure. Published lessons learned (e.g. Sheldon et al, 2014 and Triest et al, 2014) should be considered."*

Science goals

- Constrain the extent and timing of deglaciation
- 200 - 2,000 year arrays for glaciers in Alaska and elsewhere

IDDO action: IDDO's current shallow drill systems (e.g. 4-Inch Drill, Badger-Eclipse Drill, new Foro Drill) have practical depth limits of approximately 400 m. The new IDDO Intermediate Depth Drill (IDD) is capable of reaching 1,500 m, however the surface infrastructure of a drill capable of reaching such depths is not trivial.

IDDO will work with IDPO and the science community in development of science requirements in order to assess the feasibility of adapting an existing drill for this purpose. IDDO will utilize lessons learned, particularly from its international colleagues,

but cautions that a reduction in the logistical requirements of a 900 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. 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.).

Progress on this system will depend on the schedule for finalization of the science requirements, which are to be initiated by IDPO. Once the science requirements have been finalized, IDDO will work to develop and finalize engineering requirements and will begin the conceptual design, including a preliminary multi-year cost estimate for project execution. IDDO will utilize the design of the Foro Drill, the Intermediate Depth Drill or other existing drills to the extent possible.

6. *"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 microbial ecosystems and biogeochemistry

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.

In PY 2015, IDDO worked with IDPO and the science community to iterate on draft science requirements for the Sediment Laden Lake Ice Drill. All interested parties plan to continue this conversation in summer 2015, after which the science requirements are expected to be finalized. 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.

Following the 2014-2015 Antarctic field season, IDDO worked with PI Peter Doran and the NSF to have a small hot water drill unit shipped from its storage location at the MEC in McMurdo to IDDO in Madison, WI. This system, purchased years ago by Doran and used only once in the field, is now being inspected by IDDO and will be put through characterization testing in summer 2015 to determine if it might serve as a useful base unit for the Sediment Laden Lake Ice Drill.

7. *"Establish IDPO Science Requirements and repair, modify or acquire a very lightweight highly portable drill for shallow ice coring."*

Science goals

200-year arrays

IDDO action: While IDDO has made strides to reduce the size and weight of its hand auger equipment in new designs, IDDO does not currently have in inventory a power driven system that is easily backpackable.

IDDO will work with IDPO and the science community to define the science requirements for this system and will evaluate the purchase of a lightweight system, as several off-the-shelf models may serve this need. IDDO funding for purchase of this system will be included in the PY 2016 budget.

8. *"Prepare for field trials of the Rapid Access Ice Drill (RAID)[1]."*

Science goals

Temperature and heat flow measurements

Basal conditions

IDDO action: This development is being undertaken by the University of Minnesota-Duluth and DOSECC Exploration Services, LLC. IDDO helped design the initial concept for the drill and provides reviewer capacity and field testing support when requested.

9. *"Prepare WISSARD & UNL Roving drill & recovery of hot water ice cores for projects proposed in 2015[2]."*

Science goals

Sub-ice microbial ecosystems and biogeochemistry

Subglacial lakes and hydrological systems

IDDO action: The WISSARD Drill was developed by a team at the University of Nebraska-Lincoln and has since been operated by that team. In PY 2015, there has been interest by a number of PIs in using the WISSARD drills again, and proposals have been submitted to support this work under IDPO management. If these near-term projects are funded, it is likely that UNL would continue to maintain and operate the drills through these immediate deployments. The NSF, IDPO and the science community are currently working to develop a recommendation for the long-term care, maintenance and operation of the WISSARD Drill, in which IDDO may play a role in the future.

Priority 2 (needed within the next three years):

10. ***"****Continue development of a scalable, modular 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."*

Science goals

Basal conditions & geothermal flux

Sub-ice shelf mass balance

Grounding zone processes

Sub-ice microbial ecosystems and biogeochemistry

Subglacial lakes and hydrological systems

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. There are currently no proposed or funded field projects that would make use of the system, but designing and building of a scalable hot water system is a high priority to the science community. IDDO suspended detailed design of the system in PY 2015 to focus on other higher priority work in support of funded field projects, and may have to do the same in PY 2016, but plans to resume the design work in PY 2017 with the anticipation of starting fabrication as budget and future field requirements allow – see section 2.6 on Scalable Hot Water Drill.

11. *"Conduct a conceptual design and start construction of an agile shot-hole drill capable of drilling 15 holes per day up to 100 m depth in both East and West Antarctica. This may include consideration of a RAM drill upgrade, or other means. A secondary consideration is that a 15 cm diameter borehole would make this drill of interest for radio neutrino detectors as well."*

Science goals

- Basal conditions
- Remote sensing of basal conditions
- Rheological properties of ice
- Ice as platform for physics and astrophysics

IDDO action: IDDO's current hot water drill technology is limited to depths of approximately 30 m. With upgrades currently planned 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. If the new ScHWD system is envisioned for use in these purposes, finalization of the design and fabrication of the system will be planned for PY 2017-2018.

12. *"Upgrade the electrothermal drill to allow for coring to 300m through temperate and polythermal firn and ice. The drill needs to be agile and light weight (transportable by helicopter)."*

Science goals

200-year arrays

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. Due to an influx of requests for use of this drill, a second electrothermal drill will be fabricated if/when there is a need for one – see section 2.1.9 on Electrothermal Drill.

13. *"Build a replicate Blue Ice Drill for wide-diameter drilling to 200 m."*

Science goals

Pre-Quaternary atmosphere

Large-volume sampling for changes across climate transitions

IDDO action: Due to increased interest in use of the Blue Ice Drill (BID), IDDO will work with IDPO to plan for fabrication of a second BID over the next few years. 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.

Priority 3 (needed within three to five years):

14. *"Assess the potential of recovering cores to depths of 300-500 m without use of drilling fluid."*

Science goals

Address associated logistical issues

IDDO action: Current agile drill systems in IDDO inventory can core ice to nearly 400 m without the use of drilling fluid, however core quality has been found to deteriorate with increased depth. IDDO has discussed coring without drilling fluid with its international colleagues at previous IDDO Technical Advisory Board meetings, and will continue to do so in future meetings. IDDO colleagues have also attempted such depths in a dry hole, but they too have found that core quality suffers beyond the 300-400 m depth range. IDDO will plan to discuss this with the group again during the fall 2015 TAB meeting.

15. *"Develop IDPO Science Requirements for clean access drill for depths over 3,000 m."*

Science goals

Sub-ice microbial ecosystems and biogeochemistry

Subglacial lakes and hydrological systems

IDDO action: There was much talk of 'clean access' during the 2015 Science Advisory Board (SAB) meeting in April 2015. IDDO does not currently have established 'clean drilling' protocols, however certain equipment cleaning protocols have been implemented on a project-by-project basis, mostly for shallow coring systems. IDDO looks to IDPO and to the SAB and its working groups to define 'clean access' (i.e. best practices, 'X' number of live cells, metal coming off of equipment pumps, etc.). Following receipt of a clear definition of 'clean access', IDDO will work with IDPO and the community on an iterative process of developing and finalizing science requirements for a clean access drill for depths over 3,000 m.

16*. "Conduct a feasibility study to modify the Blue Ice drill to enable large-volume sampling of firn and ice up to 300 m depth."*

Science goals

Pre-Quaternary atmosphere

Large-volume sampling for changes across climate transitions

IDDO action: The current BID-Deep system has a theoretical depth capability of 200 m. Through several uses of the system, however, IDDO has found core quality to suffer below approximately 140 m in Greenland and below approximately 70 m in Taylor Valley, Antarctica. IDDO has made several design changes to the cutters and shoes between field seasons, in an effort to improve deep core quality, but further investigation is needed to understand this issue. IDDO will examine this issue further in PY 2015 or as tasked to do so by the IDPO/SAB. Modification for coring to 300 m will be considered in conjunction with investigation of the deep core quality issue and in collaboration with IDPO and the science community.

17. *"Develop IDPO Science Requirements and conduct a feasibility study for a drill capable of coring horizontally (or at low angles) several 100 m.*

Science goals

200-year arrays

Large-volume sampling for changes across climate transitions

IDDO action: IDDO currently does not have any equipment capable of drilling horizontally or at low angles to any significant depths, that is, over a few meters.

IDDO will work with IDPO and the science community to develop the science requirements for a drill to meet this need. A feasibility study will be started in PY 2018 after both the science and subsequent engineering requirements are finalized and as staff availability allows and as community need dictates.

18. *"Construct a jig to support a hand auger to facilitate horizontal coring up to 20 m into ice cliffs.*

Science goals

200-year arrays

IDDO action: IDDO does not currently have supports or jigs in inventory to support horizontal coring into ice cliffs.

IDDO will work with IDPO and the science community to define the science requirements and evaluate this proposition beginning in PY 2016. This is considered an ancillary task to IDDO's existing care, maintenance and operation of hand augers – see section 2.1.2 on Hand Augers.

[1] *This development is happening with DOSECC Exploration Services, LLC.*
[2] *If funded, this development would happen with an IDPO subaward to the University of Nebraska- Lincoln.*

4.0 FIELD SUPPORT OF SCIENCE PROJECTS

In addition to the development of new drilling equipment and the maintenance of existing ice drilling and related equipment, IDDO will continue to provide support for science projects in the field. This support generally consists of providing the drilling equipment for the project, assisting the PIs with planning the field activities, 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 2014 – Due to the government shutdown in the fall of 2013, planned activities at WAIS Divide were canceled for the 2013-2014 field season, with drill disassembly and packing as well as borehole logging operations being delayed by one year.

PY 2015 – During the 2014-2015 Antarctic field season, IDDO deployed a crew of four people to WAIS Divide with the intention of completing the disassembly and packing of the DISC Drill in the WAIS Divide Arch Facility. One of the four IDDO personnel also assisted Gary Clow (USGS), as planned, as an assistant logging winch operator in support of borehole logging operations that were postponed from the 2013-2014 field season. Due to unprecedented delays with regard to poor weather and aircraft availability, not all work was completed as planned. With an NSF and ASC-granted extension, the IDDO team was able to complete much of the work and all but one borehole logging scientist

was able to complete their science objectives. Several components of the DISC Drill were flown out of WAIS Divide on flights of opportunity and were returned to Madison in spring 2015. These items have been unpacked, inspected, dried and stored.

PY 2016 – Due to the severe delays experienced in getting to WAIS Divide during the 2014-2015 season, IDDO plans to send one person back to the site during the 2015-2016 field season to complete the remaining DISC Drill disassembly activities. This includes disassembly and packing of the yellow gantry crane, the crane rails and cable chains, palletizing of the drill control room and extension of the borehole casing to the Arch floor level. ASC personnel will assist in this effort. All DISC Drill equipment is now planned to be returned to Madison in late spring 2016 or possibly 2017, depending on aircraft availability in and out of Antarctica. 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 a deep logging winch and two operators to WAIS Divide during the 2016-2017 field season in support of borehole logging operations. One borehole logging project is currently funded for this work and several others have been proposed.

South Pole Ice Core Project – SPICE Core

PY 2014 – In early PY 2014, IDDO completed fabrication of its new Intermediate Depth Drill (IDD). The drill system was tested during a full-scale system test near Summit Station, Greenland in summer 2014 by a team of seven IDDO engineers and drillers. The IDD design is largely based on the Danish Hans Tausen drill design, so IDDO has been very fortunate to continue its close collaboration with the Danish engineers and drillers, two of whom were able to visit the IDD test. Upon returning from Greenland, the drill was repaired and certain components were modified in preparation for its use at the South Pole. In late PY 2014, the drill was shipped to Antarctica for the 2014-2015 field season.

PY 2015 – During the 2014-2015 Antarctic field season, IDDO deployed a crew of seven people to the South Pole station with the intention of installing the IDD drill tent, the entire drill system and to initiate coring for the intermediate depth SPICE Core project. Surpassing the original season goal of 700 m depth, the drill crew reached 736 m prior to the conclusion of the season. Over 600 m of ice cores have now returned to the U.S. NICL and are currently being processed. A subset of drill components, including the sondes and the control box were returned to Madison in early 2015 for repair or modification. In late PY 2015, IDDO plans to ship the returned and modified IDD components back to Antarctica for the second production drilling season.

PY 2016 – In early PY 2016, IDDO again plans to deploy a crew of seven engineers and drillers to the South Pole for completion of the SPICE Core project at an expected final depth of 1,500 m in 2015-2016. Pending availability of time, IDDO will disassemble, pack and ship out as much of the drill as possible for return to Madison. If the depth goal of 1,500 m is not reached, a provisional third season in 2016-2017 has been outlined.

PY 2017 – Following the SPICE Core project, IDDO plans to return the IDD to Madison in either mid-PY 2016 or early PY 2017. Upon its return to Madison, IDDO will clean, inspect and repair or modify all IDD equipment, as needed, to ready it 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 and the 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 will 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. Support of the project will not be limited to the field, but will also entail assisting the PIs in planning for IDDO support and in the preparation of equipment. At the end of each project, the PIs and the drillers, if any, will be 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 2015 – IDDO supported one shallow drilling and four logging projects in Antarctica during the austral summer and four shallow coring projects in Greenland during the boreal summer. IDDO also supported a number of other Antarctic investigators in 2014-2015 through the preparation and shipment of a variety of hand auger kits.

PY 2016 – IDDO plans to support three shallow coring projects in Antarctica during the 2015-2016 field season as well as a number of projects requiring hand auger equipment. Several other projects in Antarctica and Greenland are also 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 is interested 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.

PY 2018 or thereafter – IDDO will work to implement any repairs identified in PY 2016, 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 Scalable Hot Water Drill (ScHWD), IDDO is actively working on the designs and planning for two systems able to provide subglacial access through relatively thin ice (1,000 m for less). The ASIG Drill design is nearly finalized, has been reviewed both internally and externally and has now entered the fabrication phase. While there are currently no active proposals being considered for use of a new hot water drill, IDDO expects to continue with the conceptual design of the ScHWD system in response to community interest documented in the Long Range Science Plan.

PY 2014 – An external scientific review of the ScHWD system was held in June 2014, after which point further development of the system was put on hold to focus on higher priority development projects. An RFP was released in late PY 2014 for the purchase of a

base minerals exploration rig for the ASIG Drill development project. IDDO also began the detailed design of auxiliary systems for the ASIG Drill.

PY 2015 – IDDO is continuing with the detailed design of the ASIG Drill and with the testing of auxiliary components. The base rig was received in April 2015 and underwent Acceptance Testing at IDDO. The comprehensive system design was reviewed in May 2015 and is now undergoing minor changes as the IDDO engineering team works to incorporate reviewer comments and build up the entire ASIG Drill system.

PY 2016 – IDDO plans to perform a full-scale field test of the ASIG Drill, somewhere in North America and possibly very close to IDDO in Madison, during winter in early 2016. The system will then be modified and repaired as needed, in anticipation of its use on a funded field project during the 2016-2017 Antarctic field season. IDDO plans to delay work on the ScHWD in PY 2016 as there are currently no pending projects that would make use of the drill and in an effort to focus on higher priority development projects.

5.0 EXPENDITURES

Based on the current status of equipment in IDDO inventory and the plans for the development of new equipment, IDDO estimates between $11-12 million in funding will be required from PY 2015 through PY 2020 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 2015-2025. This 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. In PY 2015 approximately $450,000 was budgeted for maintenance and upgrade of ice drilling equipment in the IDDO inventory. This amount is slightly higher than in previous years due to an emphasis on making some long-requested repairs and upgrades to two of the shallow coring systems, the 4-Inch Drill and the Badger-Eclipse Drill. Work on these systems had been reduced or postponed in recent years in order to focus on several major development projects, but has now largely been completed in PY 2015. Annual expenditures for this maintenance and upgrade function have typically been between $300,000-$500,000. As the number of drills in the IDDO inventory increases, IDDO expects maintenance and upgrade costs to

increase over time. IDPO-IDDO is cognizant of this issue and is considering a variety of strategies.

Annual expenditures for operations supporting projects in the field vary depending upon the science projects funded by the NSF. Very simple projects for which IDDO supplies only a hand auger will require IDDO expenditures of less than $3,000 for preparation of the equipment and shipping. Large, multi-year projects such as the SPICE Core project generally require IDDO expenditures of $400,000-500,000 per field season.

6.0 ACRONYMS

ARA: Askaryan Radio Array

ASIG: Agile Sub-Ice Geological (Drill)

BLWG: Borehole Logging Working Group

CSM: Colorado School of Mines

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

TAB: Technical Advisory Board

ScHWD: Scalable Hot Water Drill

SHWD: Small Hot Water Drill

SIPRE: Snow, Ice and Permafrost Research Establishment

SSEC: Space Science and Engineering Center

UNH: University of New Hampshire

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							Sub-Ice Environment				
		200 year Arrays	2k Arrays	40k Network	Last interglacial	Prior to 800k	IPICS Oldest Ice	Basal Conditions and Geothermal Flux	Seismic Basal Conditions Detection	Sub-ice Shelf Mass Balance	Grounding Zone Processes	Rheological Properties of Ice	Glacial History	Conditions at Ice Sheet Bed	Sedimentary Record	Microbial Ecosystems and Biogeochemistry	Geologic and Tectonic History	Subglacial Lakes and Hydrology	Projected Year Technology Available (PY)
TECHNOLOGY	Agile Drills Maintenance and Upgrades	x	x													x			Now [1]
	Blue Ice Drill & Blue Ice Drill-Deep					x	x												Now [2]
	Koci Drill Maintenance and Upgrade													x					[7]
	Small Hot Water Drill Maintenance and Upgrade								x										2015/2016 [3]
	Rapid Air Movement Maintenance and Enhancement							x	x										2019
	DISC Drill Herc Dome/East Antarctic Modifications			x	x	x	x												2018 [4]
	Intermediate Depth Drill Development		x	x															Now
	Rapid Access Ice Drill Development			x	x	x	x	x			x	x	x	x	x	x	x	x	2016 [5]
	Logging Winches Maintenance and Upgrade		x	x	x	x	x	x											Now [1]
	Scalable Hot Water Drill Development							x	x	x	x		x	x	x	x		x	2019
	Agile Sub-Ice Geological Drill Development												x	x	x				2016
	Sediment Laden Lake Ice Drill Development															x			2016 [8]
	Modified Agile Ice Coring Drill		x										x						2020
	Borehole Preservation Technology Development		x	x	x			x				x							[6]

[1] Hand augers, Badger-Eclipse Drills, 4-Inch Drills and logging winches are available at present
[2] Current theoretical capability of 200 m depth; ability to go deeper (300 m) may be developed later, as directed.
[3] Modifications planned to make logistics and operation easier; re-design concept completed in PY 2013 with feedback from users; modifications and upgrade to begin in PY 2015.
[4] Feasibility study briefly begun in PY 2015 to determine modifications, repairs and upgrades to system necessary for operation on next project, likely at Herc Dome; should the drill be needed for drilling at colder sites in east Antarctica, further conceptual study time and maintenance/modification time will be required; IDDO anticipates needing two full years of maintenance and modification time prior to deploying the DISC Drill for its next project.
[5] Being developed by DOSECC Exploration Services (DES) for the University of Minnesota – Duluth; based on original concept by IDDO (RAID system).
[6] Is being addressed by the Borehole Logging Working Group, a sub-committee of the IDPO Science Advisory Board.
[7] The Koci Drill has not been repaired since its last deployment in 2009-2010 and will not be repaired unless called for in the Long Range Science Plan.
[8] IDDO is currently working with IDPO and the science community on drill requirements.

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 2015	PY 2016		PY 2017		PY 2018		PY 2019		PY 2020		PY 2021
Equipment	2015 Arctic	2015-16 Antarctic	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
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 projects		1proposed project +additional transit time								
Chipmunk Drill												
DISC Drill	(Feasibility Study)											
DISC – Replicate Coring System	(Feasibility Study)											
Drill Fluid Development												
Foro Drill												
Intermediate-Depth Drill												
Koci Drill												
Logging Tower												
Logging Winch - Deep												
Logging Winch - USGS**												
Logging Winch - IceCube***												
Logging Winch - Intermediate												
Modified Agile Ice Coring Drill^^												
Prairie Dog												
RAM (Rapid Air Movement) Drill												
Sediment Laden Lake Ice Drill												
Small Hot Water Drill 1												
Small Hot Water Drill 2												
Scalable Hot Water Drill												
Thermal Drill												
Winkie Drill												
Sidewinder (4 available)	1in use	1funded/ 1proposed	2 proposed		1proposed	1proposed						
Hand Auger, 3" PICO (7 available)	1in use					Phased out						
Hand Auger, 4" PICO (2 available)	1in use	2 proposed				Phased out						
Hand Auger, 3" IDDO (8 available)	1in use	1funded/ 2 proposed	3 proposed	1proposed	1proposed	3 proposed						
Hand Auger, 4" IDDO				1proposed								
Hand Auger, SIPRE (6 available)	1in use	1in use				Upgrade or phase out						

* System will be repaired and refurbished at a later date if user-demand necessitates three drills deploy at the same time.

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

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

^ Solar/wind power capabilities available.

^^ Conceptual study to be conducted for coring to depths of 900 meters. Drill may be similar to IDD, but with reduced logistics.

Appendix 3
Estimated Costs for Equipment Development and Maintenance & Upgrade Projects
PY 2015 - PY 2020

Development or Maintenance & Upgrade Project	PY 2015 (Current)	PY 2016	PY 2017	PY 2018	PY 2019	PY 2020	Total (PY 2015-2020)
2- Inch Drill (or other highly portable drill)		65,800					**65,800**
4-Inch Drill	144,067	10,000	20,000	20,000	20,000	20,000	**234,067**
Agile Sub Ice Geologic Drill	689,672	745,000	125,000	50,000	50,000	50,000	**1,709,672**
Badger-Eclipse Upgrades	51,451	102,000	60,000	15,000	15,000	15,000	**258,451**
Blue Ice Drill – Enhanced Capabilities [2]	94,095	47,000	27,000	214,000	189,000	14,000	**585,095**
Contribute to science requirements for 3,000m clean access drill				20,000			**20,000**
Deep Logging Winch	37,665						**37,665**
DISC Drill – East Antarctic Enhancements	40,677	125,000	600,000	600,000	250,000	175,000	**1,790,677**
Foro Drill	[1]	100,000	147,000	150,500	140,000	10,000	**547,500**
Hand Augers [3]	42,966	42,000	20,000	65,000	20,000	20,000	**209,966**
Intermediate Depth Drill	228,719	159,000	80,000	60,000	60,000	60,000	**647,719**
Koci Drill	52,890						**52,890**
Horizontal Coring for Several 100 m						20,000	**20,000**
Logging Winches	28,474	68,850	48,000	15,000	15,000	15,000	**190,324**
Modified Agile Ice Coring Drill		20,000			150,000	850,000	**1,020,000**
RAM Drill – Enhanced Capabilities		50,000		200,000	800,000	800,000	**1,850,000**
Scalable Hot Water Access Drill			755,000	470,000	345,000	60,000	**1,630,000**
Sediment Laden Lake Ice Drill		40,000	10,000	2,500	2,500	2,500	**57,500**
Small Hot Water Drill	120,000	106,000	30,000	15,000	15,000	15,000	**301,000**
Thermal Drill [4]	10,000		5,000	30,000	5,000	5,000	**55,000**
Winkie Drill [5]	42,579	15,000	5,000	5,000	5,000	5,000	**77,579**
TOTAL COSTS	**1,583,255**	**1,695,650**	**1,932,000**	**1,932,000**	**2,081,500**	**2,136,500**	**11,360,905**

[1] Included in 4-Inch Drill Maintenance & Upgrade
[2] PY2018 and PY2019 costs include building a second BID per the Science Plan 2015-2025
[3] PY 2018 funds include the design and fabrication of a jig to facilitate horizontal coring into ice cliffs (see Science Plan 2015-2025)
[4] PY 2018 funds include upgrading the Thermal Drill to allow coring to 300m (see Science Plan 2015-2025)
[5] Will be purchased in late PY 2015 using the $52,890 in Koci Drill PY 2015 funds along with a $42,579 supplement from NSF

	Equipment Development
	Maintenance & Upgrade