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 Intermediate Depth Drill (IDD) system, tested in Greenland in spring 2014. Photo credit: IDDO

INTRODUCTION

The IDPO (Ice Drilling Program Office) Long Range Science Plan lays out recommended directions for U.S. ice coring and drilling science. This companion Long Range Drilling Technology Plan begins with a discussion of the drills and technologies needed to successfully implement the Science Plan. It then discusses field projects that would use the drills. Finally the Technology Plan addresses briefly the funding allocated for its implementation.

High priority tasks and investments identified by the IDPO Science Advisory Board (SAB) as needed to achieve identified science goals (see IDPO Long Range Science Plan) are shown below.

Recommended technology investments (prioritized by time):

Priority 1 (needed this year):

- Complete the Intermediate-depth drill and infrastructure, including repair after the first field season. The drill is designed for coring up to 1,500 m depth.
- Maintain and upgrade the following existing equipment: hand augers, 4-inch electromechanical drills, 3-inch electrothermal drill, 3.25-inch Badger-Eclipse drills, and logging winches.
- Develop an agile sub-ice rock coring drill capable of retrieving 10 m of rock core beneath ice up to 700 m thick. The drill should be agile and transportable by helicopter sling-load at least for shallow ice.
- Create an agile shot-hole drill capable of drilling 15 holes per day up to 100 m depth in both East and West Antarctica.
- Develop science requirements, conceptual design and cost estimate of an agile ice coring drill for coring 50 to 700 m that has less logistics requirements than the Intermediate Depth Drill and its surface infrastructure.
- Develop science requirements, conceptual design and build an agile, clean hot-water drill for creating 5-inch holes through up to 6 m of sediment-laden lake ice.
- Complete testing and repair of the Blue Ice drill to enable large-volume sampling of firn and ice up to 200 m deep.
- Continue engineering of the Rapid Access Ice Drill (RAID). (This development is happening with DOSECC Exploration Services, LLC. IDDO helped design the initial concept for the drill but now only serves in a reviewer capacity when requested.)

Priority 2 (needed within the next three years):

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

- Continue 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.
- Continue to develop drilling technologies, methods and protocols for clean drilling deeper than 200 m into subglacial environments for access and sampling.
- Establish science requirements and cost estimates for minimal upgrades for the DISC drill for use at Hercules Dome, and additional later upgrades for conditions in East Antarctica, with the goal to lessen its logistics requirements while maintaining its replicate coring capability.
- Build or acquire a lightweight backpack drill (e.g. http://www.icedrill.ch/) for shallow coring.

Priority 3 (needed three to five years) in the future:

- Construct a jig to support a hand auger to facilitate horizontal coring up to 20 m into ice cliffs.
- Develop the ability to recover ice cores to depths of 300-500 m without use of drilling fluid.
- 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 the science requirements and conduct a feasibility study for a drill capable of coring horizontally (or at low angles) several 100 m.

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.

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 will 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, it usefulness to the scientific investigators.

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. These drills, which include hand augers, are the smaller systems that can drill holes to maximum depths of approximately 350-400 m; most are drills 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 recently designed and fabricated a new hand auger system, incorporating many user-requested upgrades into former designs.

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:	Drill is functional, but improvements are needed: -- Fix wobble due to the looseness of the bayonet mount, -- Strengthen springs that hold the barrel in place on the mount, -- And one of the three bayonet 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 of this drill from private sector groups, there have been few requests for polar field use of the drill for NSF-funded projects since the original project – improvements to the drill will be made when required for a field project.

Hand Augers – The 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 newly 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 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 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; 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 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. 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 2011-12 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; operating 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; threading or ridged sections become stuck together when liquid water refreezes at the connection.
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 2014. 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 – PY 2014 and PY 2015. 5. Improve hand augers based on feedback from users – Ongoing 6. Investigate purchase of a very lightweight "backpack drill" for alpine shallow coring. 7. Construct a jig to support a hand auger to facilitate horizontal coring up to 20 m into ice cliffs – PY 2015 and PY 2016. 8. Investigate clean technologies for such lightweight drills for shallow coring to study microbes in the ice. 9. Continue distribution of a post-field season questionnaire to hand auger users to get information from investigators on hand auger performance. 10. Continue to work with IDPO to expand questionnaire distribution to include Antarctic science teams.

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, *q.v.*). 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 recently used in both Wyoming and Montana for ice patch coring.

Current Status:	A portion of the equipment was lost during the 2010-2011 Antarctic field season – stuck in the ice at Lake Vida and abandoned rather than risk environmental damage to the site, which is in the Dry Valleys Specially Protected Area. Additional components were lost in transit, between Lake Vida and McMurdo Station, and have not been located. Replacement of all missing components is now complete and the system is ready for issue.
Technical Issues:	Performance Data – Few exist because of infrequency of use. Documentation – System drawings near completion; operator's manual updated in 2013. 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 drill.
Plans:	1. Review other documentation available and determine needs; update and create documentation as needed and enter into database – PY 2015. 2. Investigate use of carbide cutters or inserts to aide in drilling of dirty, silty or sandy ice. 3. General maintenance and modification - Ongoing as needed.

Sidewinder – The Sidewinder is not a drill, but a drive/lifting system used in conjunction with hand augers. It is driven by an electric motor (power hand drill) and a winching system to help retrieve the drill string. 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 the 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 modified Sidewinder, including review of safety concerns and design required modifications as necessary – PY 2014 and ongoing. 2. Modify Sidewinder systems per design evaluation – PY 2014 and ongoing. 3. Review documentation, update and enter into database – PY 2014 and ongoing. 4. Modifications – As recommended by users. 5. Repairs – Ongoing

Blue Ice Drill (BID) – An agile drill capable of retrieving cores of approximately 9-1/2 inch (241mm) diameter to depths up to 30 m in solid ice in its original design. The drill, developed for the University of California at San Diego, was used with great success to collect samples of “Blue Ice” on Taylor Glacier during the 2010-11 and 2011-12 Antarctic field seasons. Modifications to the drill for use in firn were tested successfully in Greenland in 2013. Beginning in PY 2014, the system is being 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 and the control box was modified. The system will now be 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.

Current Status:	Modifications to extend the depth capability of the system to 200 m (BID-Deep) are ongoing. The BID-Deep system was tested in Greenland in 2014 with positive results and is planned for use during the 2014-2015 Antarctic field season. The standard BID, utilizing a ropes setup for coring, will also be used on Taylor Glacier in 2014-2015 for shallow coring.
Technical Issues:	Performance Data – Comprehensive accounts of the drill's performance are contained in the drillers' End-of-Season reports.

	Documentation – Documentation for the drill has been completed and entered in the SSEC document control database.
Plans:	1. Continued modifications to the drill to enable drilling in firn and to depths down to 200 m. 2. Carry out further shallow and deep coring. 3. Build a new BID, or modify the existing one, to have additional deep coring capabilities to 300 m – As needed.

2-Inch Drill – This 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 to which the drill in IDDO's inventory has cored is 42 m.

Current Status:	Needs repairs and possible modification before being deployed for use.
Technical Issues:	Performance Data – None, because of lack of use. Documentation – Some from manufacturer. If drill is to be used, documentation should be more fully developed. Other – Engineers/drillers believe that the drill requires extensive modification to be a truly useful tool.
Plans:	1. There have been no requests for the drill since its use on the US-ITASE project and there are no plans to make modifications unless there is a project on which it would be used. It would take considerable time and effort to make the drill usable.

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 core to depths of approximately 400 m. The drill system is transportable by small aircraft or helicopter. There has been an increased demand for use of the drills on field projects and a third (original) 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.

Current Status:	The two Badger-Eclipse drills, which have had limited modifications are available for use. The third Eclipse drill, which arrived from UNH in June 2010, has not yet been refurbished, but will be completed 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 lacked 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 progress or contained in the database. Operating and maintenance manuals are currently being completed. Other – Improvements to instrumentation and the control system have been evaluated and need to be 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 need to be replaced.
Plans:	1. Complete new instrumentation and control system - PY 2014 and PY 2015. 2. Ready third Eclipse drill system for issue – As needed. 3. Develop procedure, including bill-of-materials checklist, for preparing drill for issue – PY 2014 and PY 2015. 4. Analyze project performance data, develop (if possible) preliminary performance baseline, institute guides for data

	collection. Continue to collect and analyze data and update performance – PY 2014 and thereafter. 5. Standardize components of the drills to the extent desirable and practicable* – PY 2014 and ongoing. 6. General maintenance and repairs – Ongoing. 7. Complete documentation and enter into database – Ongoing with goal of having complete, up-to-date versions in database by the end of PY 2015. 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.

4-Inch Drill – This is an electromechanical ice coring drill that takes a 104 mm 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 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 on the drills between FFY 2011 and FFY 2013 and are ongoing. Budget requests for FFY 2012 and since have included, and will include, upgrade costs. New drill sondes, based on the Intermediate Depth Drill design, will be designed starting in PY 2014 and fabricated during the PY 2015 – PY 2016 period. Using the IDD sonde design spreads design costs over multiple projects, strengthens component availability, and promises to reduce future operations and maintenance costs (by reducing the number of different parts).

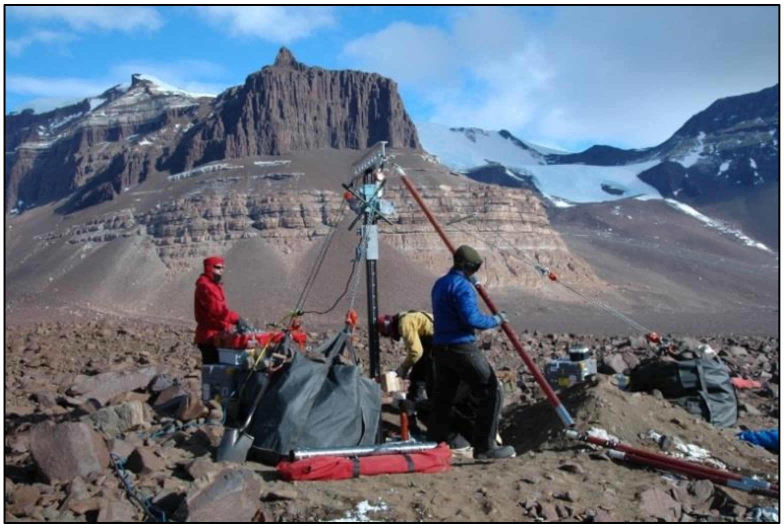
Current Status:	IDDO currently has two 4-Inch Drill systems ready for issue and plans to have three 4-Inch Drills available for use on field projects after the design and fabrication of an IDD-based sonde. The drills are currently being refurbished, including the replacement of some components. A new set of barrels of the existing design have been procured and will be ready for issue after the final machining is done. Winch and cable inventory includes one system at 400 m, two at 200 m and one at 100 m. Most of the maintenance and upgrades planned for the system during FFY 2013 were postponed due to the reprioritization of IDDO's projects for FFY 2013. Additionally, several upgrades planned for the system have been postponed during PY 2014.
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 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 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 have been made; approximately 50 drawings exist in the database. Operating manuals are currently being completed. Other – The 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, but participants in the Drillers' Workshop doubted that huge weight savings could be gained by modifying the sleds. Improvements to the instrumentation and control system for the drills are also desired to improve reliability and reduce weight.
Plans:	1. Perform the final machining on a new set of procured barrels (the existing design) – PY 2014. 2. Upgrade and refurbish winches to maintain at least one each of 100-, 200-, and 400-meter capability – Ongoing. 3. Upgrade drill sondes to a new IDD-based design - PY 2014, PY 2015, PY 2016. 4. Replace instrumentation and controls with new design – PY 2014, PY 2015, and PY 2016. 5. Analyze drill performance data, establish a performance baseline if possible, and define data collection procedure – PY 2015 and thereafter. 6. Complete development of operating and maintenance

	procedures and documentation – PY 2014 and ongoing. 7. Update drill system drawings and enter into database – Ongoing. 8. Perform general maintenance and repairs – Ongoing and as necessary. 9. Determine desired evolution of 4-inch drills in general – PY 2014 and ongoing.

Electrothermal Drill – This drill melts an annulus around the core. It supplements the 4-Inch drills and can be substituted for the 4-Inch sonde, using the same winching system, 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 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.

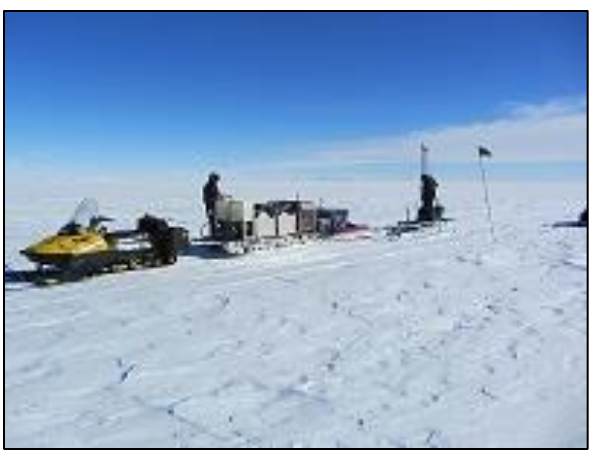
Current Status:	IDDO has one electrothermal drill that is available for use. Relatively minor upgrades will improve the performance of this drill, including a new cable, a smaller winch for use in very remote field locations, and upgraded melting heads.
Technical Issues:	Performance Data – Some data from previous projects have been collected and are available in the End-of-Season reports; these data need to be analyzed both to determine the drill's usefulness and to develop some preliminary performance specifications. Procedures for more consistent recording of data during projects need to be defined and used. Documentation – Drawings and models for the new barrels are done, but otherwise no drawings or procedures 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. A draft of an operating manual is currently under final review and will be completed and entered into the

	database. 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. For depths shallower than 30 m, a simpler tripod assembly for operation of the drill is available.
Plans:	1. Implement minor upgrades prior to next field use – PY 2015. 2. Analyze drill performance data and establish a performance baseline if possible and define data collection procedure – PY 2015 and continuing. 3. Complete operating instructions and enter into database – PY 2014. 4. Complete/update drawings to the extent practicable and enter into database – PY 2014. 5. Perform general maintenance and repairs – Ongoing and as needed. 6. Upgrade the drill to improve its performance capability to 300 m depth – PY 2016.



Koci Drill – The 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.

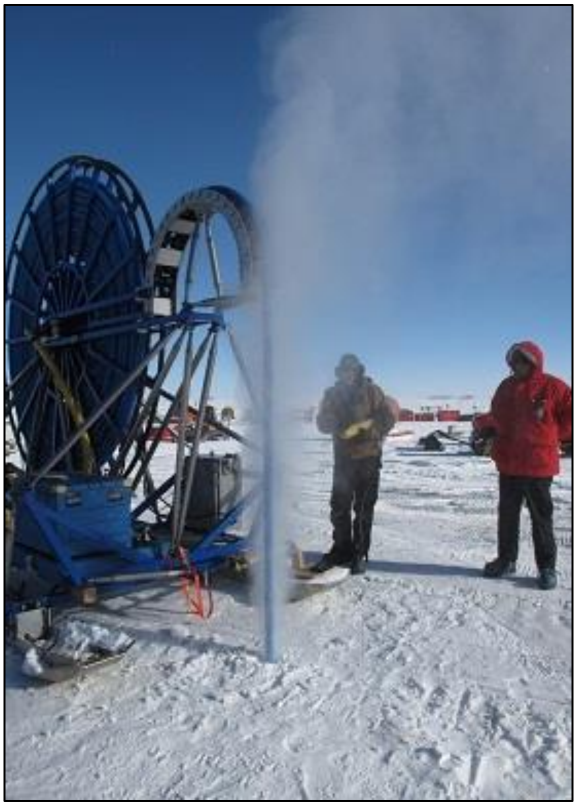
Current Status:	The Koci Drill is the only drill of its type and is considered a drill under continued development. It has not been used since 2010; however, recently there is renewed interest in its use by the scientific community, including two proposals for its use in 2015-16 and 2016-17. The ASIG drill would perform better in these circumstances and may be used instead.
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 will 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 permits.
Plans:	1. Make repairs and minor modifications to drill to make it field-ready – PY 2015. 2. More fully define requirements for the drill to guide future development or pursue retirement of the drill system if it is not needed for projects or if it is replaced by newer technology (e.g. ASIG Drill) – PY 2014 and thereafter.



Small Hot Water Drills – These drills 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. 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 FFY 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. The Scalable Hot Water Drill (see pages 24-25), once developed and built, will serve as IDDO's scalable and deep hot water drilling system.
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 operations manual for the systems was updated in PY 2014 and 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. IDDO plans to standardize and modularize a basic small hot water drill so one or more could be used as needed.
Plans:	***1.*** Proposals have been received for use of a drill in 2016-2017. ***2.*** Upgrade, standardize and modularize drill – PY 2015 and PY 2016. ***3.*** Establish science requirements (IDPO) and begin upgrades per the science requirements and the study conducted by PSL – PY 2015 and PY 2016. ***4.*** Evaluate adding additional system enhancements to enable drilling through up to 6 m of sediment laden lake ice – PY 2015. ***5.*** Add completed operating procedures to the document database and update as needed – PY 2015 and ongoing. ***6.*** Develop procedure for preparing drills for issue – PY 2016. ***7.*** Complete other documentation and add to database – PY 2015 and ongoing.

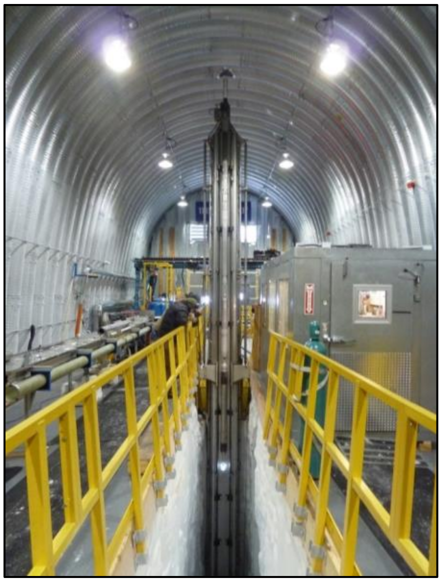


Rapid Air Movement (RAM) Drill – The RAM drill was developed for a particular seismic program. It is a system in which high-velocity air drives rotating cutters and blows the ice chips from the hole. The cutting drill motor hangs on a hose that carries the air from the surface and is reeled out as the 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 2010-11 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 2009-2010 season. IDDO is collaborating with IDPO on a study to better understand return air losses in firn. Past operators of the RAM Drill are also providing input to this study which is being carried out at Dartmouth College. The study shows 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 in Annals of Glaciology 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 losses at depths in high-permeability firn. The number/size of compressors required for firn conditions needs to studied and determined. The hose reel presents logistical problems and should be redesigned before use on any more seismic traverses.
Plans:	1. A numerical study has been conducted by an engineering student (A. Whelsky) and submitted to Annals of Glaciology to explain the air losses in firn – PY 2014. (The following plans for the RAM drill will require considerable time and effort and work is planned for future program years.) 2. Investigate means of sealing off the firn to prevent air loss – PY 2015. 3. Make needed modifications, including new hose reel and modifications to compressors, to improve traversing – PY 2017 – PY 2019.



DISC Drill – The Deep Ice Sheet Coring (DISC) Drill developed by Ice Coring and Drilling Services (ICDS) under contract with the US National Science Foundation 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-the-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 the MECC ISO container. 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.

Now that the work with the DISC Drill at WAIS Divide, including the replicate coring, has been completed, the Long Range Science Plan 2014-2024 anticipates the drill may next be assigned to a drilling site in East Antarctica. A drilling site near Hercules Dome has also been suggested. 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 (extensive redesign), and numerous surface control system electrical and software redesigns and upgrades. Several aging components or components that are no longer in production would be replaced and upgraded. 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.

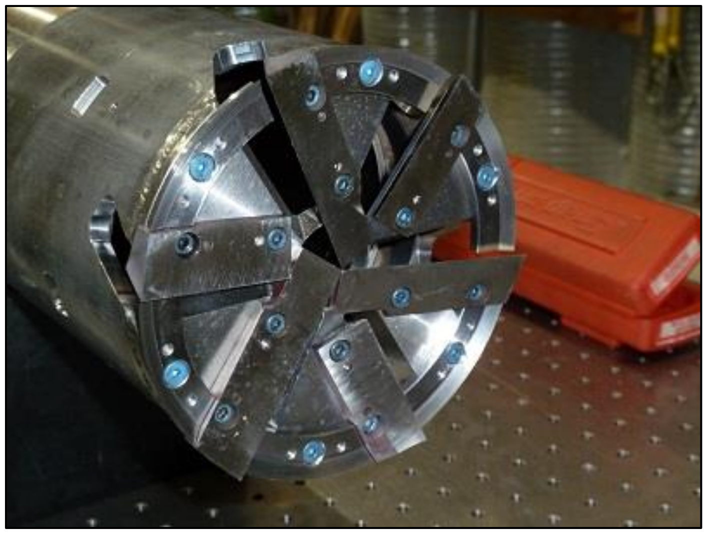
During PY 2015, IDDO will evaluate the ramifications for the DISC Drill of operating at any future site, including minimal changes needed for Hercules Dome and also with attention to operations at such cold temperatures and perhaps altitudes approaching 4000 m. Included in this evaluation will be not only the feasibility of reducing the drill’s logistical footprint, but also how the drill needs to be modified to work at such low temperatures, and the question of finding a new drilling fluid (see section "Drill Fluid").

The evaluation will also determine how much time IDDO would need to make the system field ready for any future field projects.

Current Status:	The DISC Drill is at WAIS Divide and will be fully disassembled and packed during the 2014-2015 field season. The equipment will subsequently be returned to McMurdo Station as aircraft availability allows and components shipped back to Madison in late spring 2016 or 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. Disassemble and pack the drill equipment at WAIS Divide during the 2014-2015 field season. 2. Clean and store returned DISC Drill components until the next deployment of the system – Ongoing. 3. Determine components that need to be replaced to make the drill ready for Hercules Dome and other field sites in East Antarctica and test components as necessary – PY 2015. 4. 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. 5. 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 direction from IDPO/SAB on future use of the DISC Drill – PY 2017, PY 2018, and PY 2019; IDPO will work with the science community to develop the science requirements in the fourth quarter of PY2014

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 wall.



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 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 depth levels. A total of 285 m of replicate ice core was recovered in the first coring of its kind.

Current Status:	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. Disassemble and pack the drill equipment at WAIS Divide during the 2014-2015 field season. 2. Clean and store returned DISC Drill components until the next deployment of the system – Ongoing. 3. Conduct a feasibility study on compatibility of the existing Replicate Coring System with the upgraded DISC Drill system – PY 2015 and ongoing.

Intermediate Depth Drill (IDD) - Many of the coring objectives outlined in the Long Range Science Plan, such as those in the IPICS 2k array and 40k network, are achievable in many locations through use of an intermediate-depth drill, meaning one that can collect core from a fluid-filled hole down to a depth of 1,500 m. IDDO recently 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, 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 recently field-tested outside of Summit Station, Greenland in spring 2014 and production coring in Antarctica is expected to begin mid-November and December of 2014.

Current Status:	Fabrication and full-scale field testing have been completed. The drill has been returned from Greenland to Madison, where repairs and modifications will be made to ready the system for drilling at South Pole Station during the 2014-2015 and 2015-2016 field seasons.

Technical Issues:	A drilling fluid is needed to keep the borehole open; ESTISOL 140 was chosen for the drill test in Greenland and has been purchased and shipped for drilling at South Pole as well. Further toxicology tests are being completed with the ESTISOL.
Plans:	1. Continued development, modifications, and repair of drill – PY 2014 and PY 2015. 2. Prepare drill for 2014-2015 scientific drilling in Antarctica. 3. Deploy drill to Antarctica – PY 2014 PY 2015. 4. Commence 1500 m drilling at South Pole – PY 2015. 5. Conclude drilling at South Pole – PY 2016 or PY 2017.

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 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 1000 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 there (~1998). In May 2012, the majority of NSF-owned Kamb-Engelhardt equipment was transferred from 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. 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, has 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 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. 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 in development 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 it is expected that the reviewers will provide comments to IDDO by early August 2014. The conceptual design for the hot water access drill is due to be completed in PY 2014. 2. Continue design, including evaluation of re-using KE drill components, and fabrication of the hot water drill – PY 2015 and PY 2016. 3. Deploy drill in Antarctica - as funding of projects dictates.

Mechanical Rapid Access Drills – The science behind core drilling does not necessarily require continuous cores from the ice sheet surface. As cores covering the last 100k years of earth history become more numerous, the option of obtaining rapid access to depths below which older ice can be cored becomes increasingly attractive.

IDDO completed a feasibility study (including the logistical requirements) and conceptual design for a mechanical rapid access ice drill (RAID) in early 2012. That study led to an award from the National Science Foundation to the University of Minnesota – Duluth to pursue development of the RAID. IDDO declined to bid on the resulting contract, viewing the contract schedule as too accelerated in light of IDDO's other commitments. The RAID Principal Investigators subsequently awarded a study contract to DOSECC Exploration Services. The project has completed its initial study phase and proposed construction of the drill. The award of this project is pending (as of this writing).

In addition, IDDO is pursuing the purchase of a mechanical access drill referred to as the Agile Sub-Ice Geologic (ASIG) Drill. Science requirements for the system have been developed and IDDO is working on completing a Request For Proposals (RFP) for purchase of an agile minerals exploration rig. IDDO also plans to design auxiliary key components for use with the purchased system, such as an ice chip removal and fluid recirculation system. IDDO has been notified that a field project requiring use of the ASIG will likely be funded during the 2016-2017 Antarctic field season. As such, IDDO is fast-tracking development of this system and related components.

Logging Winches – Following the IDPO-SAB recommendation, 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, which will be the more portable winch and will be used on shallow and intermediate depth holes. This Intermediate Depth Logging Winch was first tested in the field during the 2013-2014 Antarctic field season at Siple Dome.

The second logging winch is capable of logging to 4 km. IDDO has completed all auxiliary work on this system and it is crated and ready for issue. Recently, IDDO has also been working with Principal Investigators to test communications and compatibility of their logging tools with this winch.

Current Status:	The logging community prepared a white paper that was used for guidance in procuring the logging winches. IDDO responded by purchasing a portable, off-the-shelf, 1.5 km logging winch. Components for the deep (4 km) logging winch have been purchased and assembled by IDDO. 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 2500 m. The IceCube logging winch was used for logging operations at NEEM in Greenland during summer 2012; it will be transferred to IDDO when it is no longer in use by the WISSARD project. In 2014, Gary Clow worked with IDDO to transfer the USGS deep logging winch, which is typically operated by Gary, to IDDO at the University of Wisconsin, as the USGS no longer wishes to maintain this winch. This winch is currently in winter storage in Antarctica and will be used to log the DISC Drill borehole at WAIS Divide during the 2014-2015 field season, after which it will be returned to Madison, repaired and maintained.
Technical Issues:	Performance History – With only one deployment of the IDLW, minimal performance data has been collected; users such as Gary Clow and Ryan Bay have provided information regarding their experience with various types of winches. Documentation – Documentation for the winches has been collected throughout their development and will be entered into the document database as components are and modified.

Plans:	1. Maintain and upgrade winch systems – PY 2014 and ongoing. 2. Procure spare parts for the IDLW and IDDO Deep Logging Winch – PY2015. 3. Receive USGS deep logging winch back from Antarctica; inspect and make repairs and modifications as necessary – PY 2015 and ongoing. 4. Refurbish/modify, if necessary, the IceCube logging winch – PY 2016, depending on WISSARD needs.

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 US and the Japanese programs in the past, but because of the health risks associated with the chemical, ICDS/IDDO and the US 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, the oils are difficult to remove from surfaces. However, members of the 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. Now, however, there is a new candidate for drilling fluid: ESTISOL 140, which is dense enough to balance the hole without a densifier and also, reportedly, has only a modest increase in viscosity at temperatures as low as -55°C.

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 and a summary was 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). The Danish team at NEEM conducted experiments on ESTISOL 140 and found it satisfactory (but that was in shallow holes at relatively warm temperatures). The Aurora Basin project used ESTISOL 140 during the 2013-2014 Antarctic season to depths of ~300m with good success, and IDDO used ESTISOL 140 during a full-scale test of the new Intermediate Depth Drill (IDD) system outside of Summit Station, Greenland in 2014. 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 question continued use of the fluid. More data is needed on this new fluid and IDDO, in cooperation with IDPO, is arranging for further study of the ESTISOL's toxicology. ESTISOL 140 has already been purchased and shipped to the South Pole Station for use with the IDD's SPICE Core drilling project in 2014-2015 and 2015-2016.
Technical Issues:	Fluid should, among other things, be non-hazardous, have low viscosity at very low temperatures, and not inhibit or complicate biological studies.
Plans:	1. Work with IDPO and external lab sources to further determine the toxicological properties of ESTISOL 140 – PY 2014. 2. Consult with international colleagues to investigate alternative drilling fluids – Ongoing. 3. Provide proper Personal Protective Equipment (PPE) for drill system deployment and operator safety – Ongoing.

RESPONSES TO DIRECTIVES FROM THE LONG RANGE SCIENCE PLAN

IDDO notes the following guiding principles for development of drilling technology expressed in the IDPO Long Range Science Plan 2014-2024:

- *"1. Designs must be such that the supporting logistical requirements do not impede the 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 are adaptable 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 considered 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 Geologic 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 be useful for the broader community and not just for a particular investigator. IDDO has on staff several 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 2014 Long Rang Science Plan

The IDPO Science Advisory Board identified high-priority investments in drilling technology that are needed to achieve the science goals (see pages 3-4). While IDDO attempts to plan its investments in technology within the time frames suggested in the Long Range Science Plan, the schedule for these IDDO activities is tempered by a number of factors:

- Timing of funded and planned proposals to be supported by IDDO
- 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 identified in the Long Range Science Plan, together with the corresponding IDDO action taken or to be taken.

1. "*Complete the Intermediate-depth drill and infrastructure, including repair after the first field season. The drill is designed for coring up to 1500 m depth."*

Science goals

40,000-year network

South Pole deep or intermediate ice core

Exploration of basal ice formation processes

IDDO action: Design and construction of the IDD has been completed. A field test was completed near Summit Station, Greenland in May-June 2014. Equipment will be repaired and modified as needed. Production drilling is scheduled to start at South Pole in 2014-2015 – see pp. 23-24.

2. *"Maintain and upgrade the following existing equipment: hand augers, 4" electromechanical drills, 3" electrothermal drill, 3.25" Badger-Eclipse drills, and logging winches."*

Science goals

200-year arrays

2,000-year array

IDDO action: This is a major focus of this Plan – see pp. 4-19, 26.

3. *"Develop an agile sub-ice rock coring drill capable of retrieving 10 m of rock core beneath ice up to 700 m thick. The drill should be agile and transportable by helicopter sling-load at least for shallow ice."*

Science goals

Glacial history

IDDO action: IDDO does not currently have rock drilling capability, and does not have a system in its inventory that can core the ice-bedrock interface.

One proposal being considered for field work in 2016-2017 requires access through a couple hundred meters of ice and into the bedrock below. IDDO is working through the RFP process to purchase a minerals exploration rig. Additional design work on this system will begin in PY 2014 and continue in PY 2015. Fabrication will take place in PY 2015, the system field tested early in PY 2016 and the system ready for field project use in late PY 2016 – see pp. 25-26, 37.

4. *"Create an agile shot-hole drill capable of drilling 15 holes per day up to 100 m depth in both East and West Antarctica."*

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. The system is 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.

Upon finalization of science requirements (IDPO) for this system, complete conceptual design in PY 2015. Much of this work is expected to be completed through upgrade of the Small Hot Water Drill systems, for which a conceptual design was completed through cooperation with PSL in FFY 2013. If, however, 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 hot water drill proves to be the best approach, build a shot hole drill based on new generation of Small Hot Water Drill in PY 2015 and PY 2016 – see pp. 16-17.

5. *"Develop science requirements, conceptual design and cost estimate of an agile ice coring drill for coring 50 to 700m that has less demanding logistical requirements than the Intermediate Depth Drill and its surface infrastructure."*

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 system (e.g. 4-Inch Drill, Badger-Eclipse 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 small.

Work with IDPO and Science Community in development of science requirements. Develop and finalize engineering requirements based on science requirements and begin conceptual design, including preliminary multi-year cost estimate for project execution. Utilize design of the Intermediate Depth Drill to the extent possible. Work progress on this system will depend on the schedule for finalization of the science requirements, which are to be initiated by IDPO in PY 2015.

6. *"Develop science requirements, conceptual design and build an agile, 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.

Work with IDPO and Science Community in development of science requirements during summer 2014. Develop and finalize engineering requirements based on science requirements and begin conceptual design, including preliminary multi-year cost estimate for project execution. It is likely that building of the system would have to be postponed until a later program year, with all of the preparatory work to be done in PY 2015. This work may be completed through upgrade of the Small Hot Water Drill system, which is planned for PY 2015 – see p. 16-17, or may be completed through modification to existing hand auger technology.

7. *"Complete testing and repair of the Blue Ice drill to enable large-volume sampling of firn and ice up to 200m deep."*

Science goals

Pre-Quaternary atmosphere

Large-volume sampling for changes across climate transitions

IDDO action: Greenland test of new BID-Deep components completed May-June 2014. Drill will be repaired for use and deployed to Taylor Glacier, Antarctica for both shallow and deep production coring in fall 2014. – see pp. 9-10. Modification for coring to 300 m will be addressed as science requirements are developed by IDPO/IDDO in collaboration with the science community.

8. "Continue engineering of the Rapid Access Ice Drill (RAID)."

Science goals

Temperature and heat flow measurements

Basal conditions

IDDO action: This development is happening with DOSECC Exploration Services, LLC. IDDO is not currently involved in this work. IDDO helped design the initial concept for the drill but now only serves in a reviewer capacity when requested.

***9**. “Upgrade the electrothermal drill to improve its performance for coring to 300m through temperate and poly-thermal firn and ice. The drill needs to be agile and lightweight (transportable by helicopter).”*

Science goals

200-year arrays

IDDO action: Evaluate existing electrothermal drill for its capability of reaching 300 m depth and implement minor upgrades. Determine improvements to barrel and heat ring design as needed. A second electrothermal drill will be fabricated if/when there is a need for one - see pp. 14-15.

***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.”*

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 Caltech 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 of high priority to the science community. Detailed design will resume in PY 2015 with fabrication planned to begin in PY 2015 and ramp up in PY 2016 – see pp. 24-25.

***11.** “Continue to develop drilling technologies, methods and protocols for clean drilling deeper than 200 m into subglacial environments for access and sampling.”*

Science goals

Subglacial microbial ecosystems and biogeochemistry

IDDO action: Such a design was well advanced during UW’s involvement in WISSARD, but IDPO/IDDO has no science projects planning to access the environmentally sensitive bed of the grounded ice and, consequently, IDDO has not further developed the design of clean access technology. IDDO will resume development as required by future projects.

***12.** “Establish science requirements and cost estimates for minimal upgrades for the DISC drill for use at Hercules Dome, and additional later upgrades for conditions in East*

Antarctica, with the goal to lessen its logistics requirements while maintaining its replicate coring capability."

Science goals

2,000-year array

40,000-year network

High-resolution records of the last interglacial

Evidence from the ice sheet prior to 800,000 years BP

IDDO action: A feasibility study will be conducted beginning in PY 2015 and upgrades completed, if necessary, in PY 2017-PY 2019 – see pp. 20-22.

13. "*Build or acquire a lightweight backpack drill (e.g. http://www.icedrill.ch/) for shallow 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.

Define requirements and evaluate purchase of a lightweight system – PY 2015; may be covered through modification of existing agile drills – see pp. 6-7

14*. "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.

Define requirements and evaluate – PY 2015; considered as an ancillary task to existing hand augers – see pp. 6-7.

15. *"Develop the ability to recover ice 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 plans to discuss coring without drilling fluid with international colleagues at the upcoming Technical Advisory Board Meeting in late PY 2014.

16. *"Develop the 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.

Work with IDPO and Science Community in development of science requirements. A feasibility study will be started once requirements are finalized, as staff availability allows and as community need dictates.

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 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 – For the 2014-2015 field season, IDDO plans to send a small crew of staff to disassemble and pack the DISC Drill in the WAIS Divide Arch Facility. In addition, IDDO will also provide Gary Clow with an assistant logging winch operator, in support of borehole logging operations that were postponed from the 2013-2014 field season. The DISC Drill system, once disassembled and packed, will then await transport back to McMurdo by the logistics provider.

PY 2016 and PY 2017 – All DISC Drill equipment is planned to be returned to Madison in late spring 2016 or 2017, depending on aircraft availability in and out of Antarctica. Upon its return to Madison, IDDO will clean, inspect and store all DISC Drill equipment until such time as it is needed for a future drilling project.

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 2014 – IDDO supported five shallow coring projects in Greenland during the boreal summer and three shallow drilling and one logging project in Antarctica during the austral summer.

PY 2015 – IDDO plans to support borehole logging operations at WAIS Divide and Roosevelt Island (auxiliary equipment only), SPICE Core drilling at South Pole Station using the Intermediate Depth Drill as well as one shallow drilling project during the austral summer in Antarctica. IDDO also plans to support at least three shallow drilling projects in North America and Greenland.

Preserving Ice Core Boreholes for Logging Science

The Long Range Science Plan points out that the casings in the boreholes at GISP2, Siple Dome and other locations are in danger of collapsing. Direct visual evidence of serious damage to the casing in the GISP2 borehole at Summit, Greenland is available; 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. Much science remains to be carried out in these boreholes if access is preserved. The borehole logging community is a strong proponent for repairing and maintaining boreholes at Summit Station, Greenland (GISP2), Siple Dome, Antarctica and other boreholes. Identifying which boreholes need maintenance and determining methods of repair are activities that need urgent attention.

PY 2015 or thereafter – IDDO will undertake evaluation of the situation in the GISP2 borehole, if tasked by IDPO, and, as staff time permits, develop and implement a plan for the restoration of unimpeded access to it.

PY 2016 or thereafter – IDDO will seek opportunities to evaluate the situations at Taylor Dome and other boreholes, if tasked to do so.

Succeeding years – IDDO will complete any needed work at Taylor and Siple Domes as access to the sites becomes available.

Subglacial Access

As mentioned in both the section on the Scalable Hot Water Drill as well as the section on Mechanical Rapid Access Drills, IDDO is planning to design and build two systems able to provide subglacial access through relatively thin ice (1,000 m for less). While there are currently no active proposals being considered for use of a new hot water drill, IDDO is continuing with the conceptual design of the system in response to community interest documented in the Long Range Science Plan.

A proposal is currently under consideration for use of the Agile Sub-Ice Geologic (ASIG) Drill and there has been much interest in this drill by the broader science community. The system will be comprised of an off-the-shelf minerals exploration rig with many auxiliary components designed by IDDO in order to enable drilling in the polar regions. Development and fabrication of the ASIG Drill is anticipated in PY 2015.

PY 2014 – Plan to complete the conceptual design of the Scalable Hot Water Drill. An external scientific review of the system was held in June 2014, after which point further development of the system will be put on hold to focus on higher priority development projects. An RFP will be posted for purchase of a minerals exploration rig for the ASIG Drill development project.

PY 2015 – Purchase of an off-the-shelf minerals exploration rig is expected late in PY 2014 or early in PY 2015. IDDO will continue with the design and testing of auxiliary components. The first field deployment of the drill system is anticipated during the 2016-2017 Antarctic field season. Work will also continue on the design of the Scalable Hot Water Drill system. Fabrication will begin on the hot water system as funding and staff time permits.

EXPENDITURES

Based on the current status of equipment in IDDO inventory and the plans for the development of new equipment, IDDO estimates that approximately $11.7 million of funding will be required from PY 2014 through PY 2019 for the design, fabrication, and testing of ice drilling and related equipment associated with the science projects outlined in the IDPO Long Range Science Plan. Appendix 3 summarizes the expected expenditures by fiscal 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 2014 approximately $375,000 was budgeted for maintenance and upgrade of ice drilling equipment. This amount is lower than in previous years due a greater emphasis on several major development projects in PY 2014. Future annual expenditures for this maintenance and upgrade function can be expected to be between $400,000-$600,000.

Annual expenditures for operations supporting projects in the field vary depending upon the science projects funded by NSF. Very simple projects for which IDDO supplies only a hand auger will require IDDO expenditures of less than $2,000 for preparation of the equipment and shipping. Large, multi-year projects such as the upcoming SPICE Core project will require IDDO expenditures of $300,000-500,000 per field season.

ACRONYMS

ARA: Askaryan Radio Array

ASIG: Agile Sub-Ice Geologic (Drill)

DISC: Deep Ice Sheet Coring

FFY: Federal Fiscal Year (term used prior to start of new IDPO CA on Nov. 1, 2014)

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 (term used after Nov. 1, 2014 to signify that the IDPO-IDDO fiscal year does not sync with the Federal Fiscal Year)

RAM: Rapid Air Movement

SAB: Science Advisory Board

TAB: Technical Advisory Board

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				
TECHNOLOGY	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)
Agile Drills Maintenance and Upgrades	x	x													x			Now [1]
Blue Ice Drill Enhancements including Deep					x	x												2014 [2]
Koci Drill Maintenance and Upgrade					x								x					2015
Small Hot Water Drill Maintenance and Upgrade								x										2016 [3]
Rapid Air Movement Maintenance and Enhancement							x	x										2016
DISC Drill East Antarctic Modifications			x	x	x	x												2018 [4]
Intermediate Depth Drill Development		x	x															Now
Mechanical Rapid Access Drill Development			x	x	x	x	x			x	x	x	x	x	x	x	x	[5]
Logging Winch Development		x	x	x	x	x	x											Now [1]
Scalable Hot Water Drill Development							x		x	x		x	x	x	x		x	2015
Agile Sub-Ice Geologic Drill Development												x	x	x				2017
Shallow Lake Ice Drill															x			2015
New Agile Ice Coring Drill												x						2018
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 ability to reach 200 m depth; ability to go deeper (300 m) will be developed later if 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 to begin in PY 2015 to determine modifications, repairs and upgrades to system necessary for operation on next project; suggested sites are Herc Dome or areas in east Antarctica
[5] Being developed at University of Minnesota – Duluth based on concept by IDDO (RAID system).
[6] Will be addressed by the Borehole Logging Working Group, a sub-committee of the IDPO Science Advisory Board

Appendix 2
Long Range Project Schedule

Legend:

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

	PY 2014	PY 2015		PY 2016		PY 2017		PY 2018		PY 2019		PY 2020
Equipment	**2014 Arctic**	**2014-15 Antarctic**	**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**
2-Inch Drill*												
4-Inch Drill 1			2 projects									
4-Inch Drill 2			2 projects									
4-Inch Drill 3*												
Agile Sub-Ice Geologic Drill												
Badger-Eclipse 1^												
Badger-Eclipse 2^												
Badger-Eclipse 3**												
Blue Ice Drill/Blue Ice Drill-Deep				2 projects								
Chipmunk Drill												
DISC Drill		Feasibility Study										
DISC – Replicate Coring System		Feasibility Study										
Drill Fluid Development	IDPO task											
Small Hot Water Drill 1												
Small Hot Water Drill 2												
Scalable Hot Water Drill												
Intermediate-Depth Drill												
Koci Drill												
Logging Tower												
Logging Winch - Deep		Secondary										
Logging Winch - USGS***												
Logging Winch - IceCube****	WISSARD											
Logging Winch - Intermediate												
Prairie Dog												
RAM (Rapid Air Movement) Drill												
New Agile Ice Coring Drill^^												
Thermal Drill												
Sidewinder (4 available)	2 in use	1 in use		1 in use								
Hand Auger, 3" PICO (7 available)	1 in use					Phased out						
Hand Auger, 4" PICO (2 available)						Phased out						
Hand Auger, 3" IDDO (8 available)	2 in use	1 in use		1funded/ 3 proposed								
Hand Auger, 4" IDDO												
Hand Auger, SIPRE (6 available)			1 in use		1 in use	Upgrade or phase out						

* Plan to upgrade 4-Inch sonde to IDD-style sonde in PY 2015.

** System will be repaired and refurbished at a later date and prior to planned use in the field.

*** Winch transferred from USGS to IDDO inventory on April 2, 2014.

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

^ Solar/wind power capabilities available.

^^ System to be developed to core to depths of 700 meters. Similar to IDD, but with reduced logistics.

Appendix 3
Estimated Costs for Equipment Development and Upgrade Projects
PY 2014 - PY 2019

Development or Upgrade Project	PY 2014 (Current)	PY 2015	PY 2016	PY 2017	PY 2018	PY 2019	Total PY 2014-2019
Intermediate Depth Drill	1,137,000	220,000	128,000	64,000	64,000	64,000	**1,677,000**
Scalable Hot Water Access Drill	64,000	250,000	1,055,000	150,000			**1,519,000**
Agile Sub Ice Geologic Drill	328,000	300,000	225,000	70,000	70,000	50,000	**1,043,000**
Blue Ice Drill – Enhanced Capabilities	249,000	86,000	27,000	14,000	14,000	14,000	**404,000**
RAM Drill – Enhanced Capabilities		80,000	30,000	200,000	550,000	950,000	**1,810,000**
DISC Drill – East Antarctic Enhancements		125,000	50,000	970,000	850,000	500,000	**2,495,000**
Thermal Drill		20,000	5,000	5,000	5,000	5,000	**40,000**
New Agile Ice Coring Drill		40,000	20,000	100,000	330,000	300,000	**790,000**
Deep Logging Winch	18,000	40,000					**58,000**
4-Inch Drill Upgrades	147,000	150,000	179,000	149,000	60,000	60,000	**745,000**
Badger-Eclipse Upgrades	61,000	100,000	102,000	53,000	53,000	53,000	**422,000**
Hand Auger Upgrades	3,000	70,000	50,000	40,000	30,000	30,000	**223,000**
Small Hot Water Drill Upgrades	1,000	150,000	46,000	20,000	10,000	10,000	**237,000**
Clean Sampling Methods Study			60,000	20,000			**80,000**
Shallow Lake Ice Drill		20,000					**20,000**
Koci Drill		50,000					**50,000**
Prairie Dog Drill		5,000	2,500	2,500	2,500	2,500	**15,000**
Logging Winches		25,000	10,000	10,000	10,000	10,000	**65,000**
Total Costs	**2,008,000**	**1,731,000**	**1,989,500**	**1,867,500**	**2,048,500**	**2,048,500**	**11,693,000**

(green)	Equipment Development
(orange)	Maintenance & Upgrade