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 first replicate core recovered at WAIS Divide Camp, Antarctica.
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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:

- Complete Intermediate Depth Drill.
- Maintain and update the existing drills for up to 400 m deep.
- Continue feasibility studies for new generation hot-water drill.
- Evaluate technologies and design and build an agile shot hole drill.
- Develop agile, modular drills that allow rapid access to the base of ice sheets and ice shelves.
- Continue to develop drilling technologies, methods, and protocols for clean drilling into subglacial environments.
- Develop the capability of retrieving bedrock samples beneath ice 300 to 1000 meters thick.
- Develop a clean, agile hot water drill for creating 5-inch holes through 6 meters of silt-laden lake ice.
- Assess upgrades for the DISC drill that lessen its logistics requirements and ready it for East Antarctica conditions.
- Build or acquire a lightweight backpack drill.
- Construct jig to support hand auger to facilitate horizontal coring to 20 meters.
- Develop a drill capable of coring temperate and poly-thermal ice.
- Modify Blue Ice Drill to sample firn and ice up to 300 meters deep.
- Develop a drill capable of coring horizontally or at low angles several hundred meters.

Note: Items are summarized and listed in rough Science Plan priority order.

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 indications 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, its condition, and the availability of documentation such as component specifications, fabrication drawings, operating instructions, maintenance manuals, etc. 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.

IDDO is working to update a documentation matrix showing the status of documentation for all its drilling systems.

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 meters; 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 has a newly designed hand auger in the late field testing and production and fabrication stage.

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 project (for which it was designed) at Pakitsoq, West Greenland, in 2003 and 2004, and for several demonstrations of ice coring for the public in the U.S.

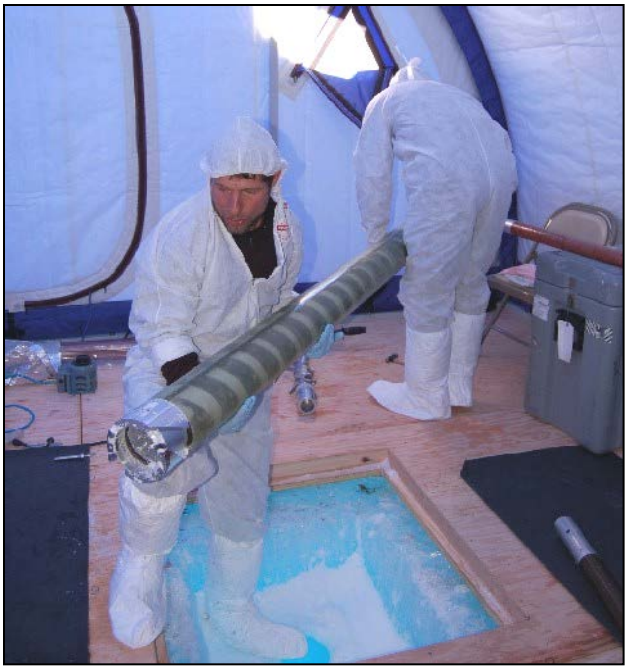
Current Status:	Drill is workable, but improvements are needed: -- Fix wobble due to the looseness of the bayonet mount -- Strengthen springs that hold the barrel in place on the mount -- One of the three bayonet pins tends to pop out
Technical Issues:	Performance Data – None; system has only been deployed once; need future IDDO testing to characterize performance Documentation – Exists, but will be reviewed for currency when needed Other – None known
Plans:	1. There have been no requests for field use of the drill 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 the 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), and a newly developed IDDO (3-inch core) system. The 3-inch models take cores 1 m long and the 4-inch auger can be configured to take either one-meter or half-meter cores. The maximum depth to which hand augers without power assistance (see section on Sidewinder) can be used is approximately 20 meters.

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**

Current Status: (Continued)	**(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. Existing PICO hand augers in inventory are aging and IDDO has developed a replacement and fabricated several copies of the new model, which was first tested in Antarctica during the 2011-12 season and subsequently tested by a field investigator in Greenland during the summer of 2012. Several sizes of coring hand augers are available commercially.**
Technical Issues:	Performance Data – Collected for the new auger in Antarctica during the 2011-12 field season and in Greenland in 2012. These data were utilized in modification of the IDDO prototype and played an important role in the auger's final 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.
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. Complete fabrication and deploy for use the new version of the hand auger/phase out PICO and SIPRE hand augers. Investigate reasons some users prefer SIPRE augers so positive features are not lost – FFY 2013 and FFY 2014. 3. Improve hand augers based on feedback from users – Ongoing 4. Investigate very lightweight "backpack drills" for alpine shallow coring. 5. Investigate clean technologies for such lightweight drills for shallow coring to study microbes in the ice. 6. Continue distribution of a post-field season questionnaire to Arctic field teams to get information from investigators on hand auger performance. 7. 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. Limit of depth of use is approximately 40 meters (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.

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 lost in transit between Lake Vida and McMurdo Station have not been located. Replacement of all missing components is nearing completion and the system will be ready for field issue during summer 2013.
Technical Issues:	Performance Data – Few exist because of infrequency of use. Documentation – System drawings near completion; operator's manual updated in 2013. Other – None known; more experience with drill needed
Plans:	1. Replace lost Prairie Dog drill -- FFY 2013 2. Review other documentation available and determine needs; update and create documentation as needed and enter into database – FFY 2013 or 2014 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 updated annually 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 further modifications as necessary– FFY 2013 and ongoing 2. Modify Sidewinder systems per design evaluation – FFY 2013 and ongoing 3. Review documentation, update and enter into database – FFY 2013 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 diameter to depths up to 30 meters in solid ice. 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.

Current Status:	The BID is undergoing modifications to extend its depth capability to 200 m (BID-Deep). BID-Deep is scheduled to be ready for use in Greenland in 2014 and in Antarctica in the 2014-15 field season if needed. The standard BID will be used on Taylor Glacier in 2013-14.
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. Modifications to the drill to enable testing in firn and ice at Summit, Greenland in 2013. 2. Carry out further shallow and deep coring. 3. Build a new BID, or modify the existing one, to have additional deep coring capabilities as needed. FFY 2013-14

2-Inch Drill – This drill is a highly portable electromechanical coring drill that can be powered by batteries, solar cells, or a generator; cable is wound up and paid out using a hand-powered winch. It 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 meters.

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 electromechanical and takes an 81 mm core to depths of approximately 400 meters. 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 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-meter 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 been modified to varying degrees, are available for use. The third Eclipse drill, which arrived from UNH in June 2010, has not yet been refurbished but is planned to be in FFY 2015.

Technical Issues:	Performance Data – Data from several projects have been collected; these data 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 much engineering documentation for the drill although in making modifications to the drill, some "reverse engineering" has been completed and a few drawings 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; however, some variation between the drills may be desirable to accommodate differing project requirements.
Plans:	1. Complete new instrumentation and control system. FFY 2014 and FFY 2015 2. Ready third Eclipse drill system for issue – FFY 2015 3. Develop procedure, including bill-of-materials checklist, for preparing drill for issue – FFY 2014 and FFY 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 – FFY 2013 and thereafter 5. Standardize components of the drills to the extent desirable and practicable * – FFY 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 FFY 2014 8. Determine desired evolution of Badger-Eclipse drills in general - Ongoing * Participants at the 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 down to approximately 400 meters. Winches with 100-, 200-, and 400-meter 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 drills were not used during the 2011-12 or 2012-13 Antarctic field seasons, but one was used during 2013 in the Arctic. 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 with be designed in FFY 2014 and fabricated for three systems during the FFY 2014 – FFY 2016 period.

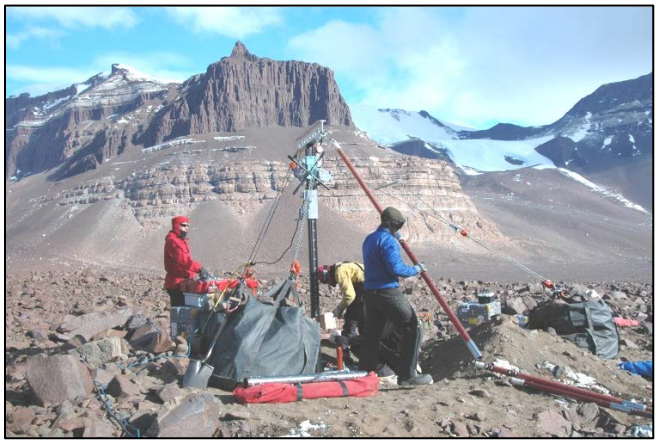
Current Status:	IDDO plans to have three 4-Inch Drills available for use on field projects using the IDD-based sonde design. The drills are currently being refurbished, including the replacement of some components. New set of barrels of the existing design have been procured and will be ready for field use by the end of FFY 2013 to allow the availability of at least one system while the new sonde are being designed and built. Winch and cable inventory includes one 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.
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 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.

Technical Issues: (continued)	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 some 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 winch sleds. Improvements to the instrumentation and control system for the drills are also desired to improve reliability and reduce weight.
Plans:	1. Upgrade and refurbish winches to maintain at least one each of 100-, 200-, and 400-meter capability. 2. Upgrade drill sondes to a new IDD-based design. FFY 2014, FFY 2015, FFY 2016. 3. Replace instrumentation and controls with new design. FFY 2014, FFY 2015, FFY 2016. 4. Analyze drill performance data and establish a performance baseline if possible; define data collection procedure – FFY 2013 and thereafter 5. Complete development of operating and maintenance procedures and documentation – FFY 2014 6. Update drill system drawings and enter into database –FFY 2014 7. Perform general maintenance and repairs – Ongoing and as necessary 8. Determine desired evolution of 4-inch drills in general FFY 2013 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 10º C. It takes a 3-inch core. It is particularly useful in ice close to the pressure melting point, where electromechanical drills suffer risk from melting and refreezing of the ice. Much

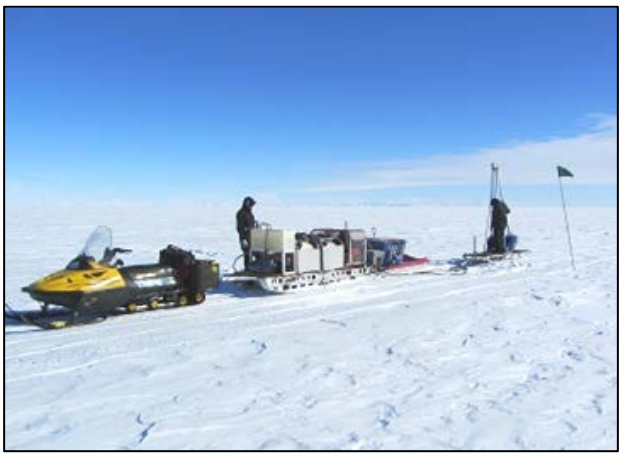
simpler than the electromechanical drills, the electrothermal drill has performed well in British Columbia and Alaska. Using a scaled-down, lightweight setup, the drill was tested by an investigator on McCall Glacier, Alaska, in spring, 2012. The drill was most recently deployed and used successfully to drill through firn aquifer layers in SE Greenland during spring 2013.

Current Status:	IDDO has one electrothermal drill. It was repaired, including new barrels and new stainless steel heads, in 2011. The drill is available for use.
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 a new barrel 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 meters are desired. For depths shallower than 30 meters, a simpler tripod assembly for operation of the drill is available.
Plans:	1. Analyze drill performance data and establish a performance baseline if possible; define data collection procedure – FFY 2014 and continuing 2. Complete operating instructions and enter into database – FFY 2014 3. Complete/update drawings to the extent practicable and enter into database – FFY 2014 4. Perform general maintenance and repairs – ongoing and as needed 5. Investigate the possibility of collaborating with others in developing a new IDDO electrothermal drill – FFY 2014 or as the need arises



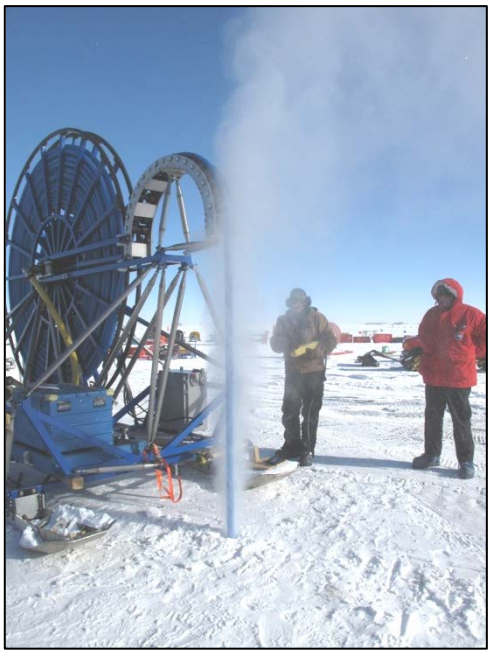
Koci Drill – The drill, named after the late drilling engineer Bruce Koci, is an electromechanical, single-barrel, coring drill designed to operate in ice containing sand, silt and small sedimentary rocks. The system includes cutters with replaceable carbide inserts for drilling in mixed media ice. A non-coring rock bit and auger is used for penetrating large rocks 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 in the 2006-07 Antarctic field season and again, after repair and modification, in the 2008-09 and 2009-10 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 in two proposals for its use in 2015-16 and 2016-17.
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 drilling medium (probably air), but logistical and environmental constraints often limit options.
Plans:	1. Make repairs and minor modifications to drill to make it field-ready – FFY 2014 and FFY 2015. 2. More fully define requirements for the drill to guide future development – FFY 2014.



Portable 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 been used also for access holes through a thin ice shelf. These drills are transportable by light aircraft and helicopter.

Current Status:	IDDO has two portable hot water drills. One is currently in Madison and requires maintenance and upgrade prior to deployment, while the other is currently wintering in Antarctica in between seasons of a two-year project. IDDO has 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 portable hot water drills.
Technical Issues:	Performance – Reliable and efficient to a depth of 25-30 m 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 FFY 2013. 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 hopes to standardize and modularize a basic portable hot water drill so one or more could be used as needed.
Plans:	1. Employ one drill for shot hole drilling in 2013-14 in Antarctica, where it is spending the winter. Proposals have been received for use of a drill in 2014-15 and 2015-16. 2. Standardize and modularize drill – FFY 2014 and FFY 2015. 3. Add completed operating procedures to the document database and update as needed – FFY 2013 and ongoing. 4. Develop procedure for preparing drills for issue – FFY 2013 5. Complete other documentation and add to database – FFY 2013



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 2009-10 field season, when it routinely attained depths of 90 m. The Askaryan Radio Array (ARA) project, funded by 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.

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 2009-10 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 2009-10 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.
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; this is not well understood. Documentation – Documentation for the drill is partially complete in that drawings for the hose reel and its sled and the

Technical Issues: (continued)	drill sondes have been completed; these need to be added to the SSEC document control database, however. Material lists and several drawings exist for the compressor packages; "as-built" drawings should be completed. Operating instructions are currently being drafted. Other – The loss of air in firn needs to be better understood and techniques or equipment developed to minimize losses and, hence, determine the number/size of compressors needed. The hose reel presents logistical problems and should be replaced before use on any more seismic traverses.
Plans:	The following plans for the RAM drill will be implemented only in the event of a demand for the drill; they would require considerable time and effort. 1. A study has been initiated by a research scientist to better understand and quantify air losses in firn - FFY 2014 2. Investigate means of sealing off the firn to prevent air loss – FFY 2014 3. Make needed modifications, including new hose reel and modifications to compressors, to improve traversing – FFY 2015 and FFY 2016.

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 4000m with variable core lengths up to a design limit of 4 meters. (The drill is currently able to recover cores up to 3.5 meters long.) The DISC Drill consists of four major mechanical drilling subsystems and several supporting on-surface activities. The mechanical drilling subsystems are a drill sonde, a drill cable, a tower, and a winch. Critical on-surface activities are core handling, screen cleaning, and ice chips and drill-fluid handling. 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 3405 meters.

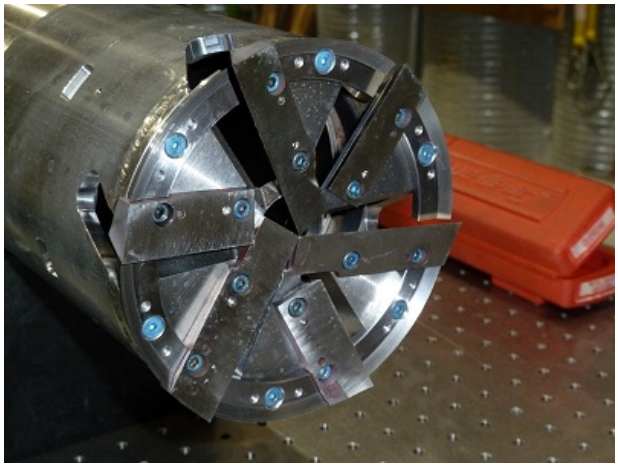
The Long Range Science Plan 2013-2023 anticipates now that the work with the DISC Drill at WAIS Divide, including the replicate coring, has been completed, the drill will next be assigned to a drilling site in East Antarctica. This means that the drill will have to operate at down-hole temperatures at least as cold as -50C and perhaps as cold as -58C. During FFY 2015, IDDO will evaluate the ramifications for the DISC Drill of operating at such cold temperatures (and perhaps altitudes approaching 4000 m). Included in this evaluation will be not only how the drill needs to be modified to work at such low temperatures, but the whole question of finding a new drilling fluid (see section "Drill Fluid," below) and the feasibility of reducing the drill's logistical footprint.

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 traversed back to McMurdo Station and shipped back to Madison in late spring 2016.
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 for the DISC Drill 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 – FFY 2013 and FFY 2015 3. Determine components that need to be replaced to make the drill ready for East Antarctica and test components as necessary – FFY 2014 4. Complete feasibility study and preliminary design for making the drill suitable and economical for operations in East Antarctica and – FFY 2015.

Plans: (continued)	5. Upgrade the drill system, including the upgrade to drill at -55C and performance and logistical improvements that can be based on the feasibility study; requires decision from IDPO/SAB on future use of DISC Drill – FFY 2016, FFY 2017, and FFY 2018.

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 very unevenly distributed, with the ice core archive being completely depleted in depth intervals of high scientific interest, whereas in other intervals more than 50% of the ice remains. The ability to obtain additional volumes of ice samples in selected intervals, termed replicate coring, will address these concerns and add value to the scientific return from ice coring. It is important that the taking of replicate cores not compromise other scientific activities, in particular borehole logging.

The design of the IDDO replicate coring system for the DISC Drill incorporates as its essential concept the tilting and forcing of the sonde against the drill hole wall by "actuators" that push against the wall upon command from the surface. Drilling then gradually deviates 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 2011-12 field season. No core was obtained, but IDDO engineers were able to gain valuable insight into what is occurring deep within the borehole. Using that insight they made extensive modification to the sonde and carried out many tests in a mock-up of the borehole back in Madison. The upshot of that work was total success in replicate coring during the 2012-13 field season at WAIS Divide where 285 meters of high quality replicate core was collected.

Current Status:	The replicate coring system is an integral part of the DISC Drill and with it awaits the next call for deep drilling.
Technical Issues:	Performance Data – Extensive data were collected during production replicate coring at WAIS Divide and operational

Technical Issues: (continued)	techniques were honed through use of the data. Documentation – All work on the replicate coring system has been documented according to SSEC standards and archived in the control 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. Analyze data obtained from WAIS Divide replicate coring and develop plan for future development of technology – FFY 2015 2. Disassemble and pack the drill equipment at WAIS Divide during the 2014-2015 field season. 3. Clean and store returned DISC Drill components until the next deployment of the system.

Drilling Fluid - With the phase-out and banning of 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 have had a disadvantage in that they are difficult to remove from surfaces. However, members of the TAB have indicated that silicone oils are now available that do evaporate cleanly from ice surfaces. Both the silicone oils and the ESTISOL-COASOL mixture have the

major disadvantage of being much 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. >1000 m) drilling in very cold regions in East Antarctica likely in the near future, IDPO 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 a year and a half ago 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).
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. Test the Estisol 140 during the IDD drill test in Central Greenland in May, 2014. 2. Review results of Estisol-140 from the Australian East Antarctic Aurora basin ice core in the austral 2013-2014 field season. 3. If results from Greenland and Antarctica are favorable, use Estisol-140 for the South Pole 1500m ice core in 2014-2015 and 2015-2016 Antarctic field season.

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 attainable in many locations with an intermediate-depth drill, meaning one that can collect core from a fluid-filled hole down to a depth of 1500 meters. IDDO does not at present have an intermediate-depth drill, but science requirements have been agreed to and a design for an IDD has been 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 is modifying the existing design of the Hans Tausen intermediate depth drill to build a new system ready for field testing in Greenland in 2014 and production coring in Antarctica beginning in the 2014-2015 field season.

Current Status:	Fabrication is currently underway at IDDO
Technical Issues:	A drilling fluid is needed to keep the borehole open; Estisol 140 has been chosen for the drill test in Greenland and likely for drilling at South Pole as well.
Plans:	1. Fabrication of drill – FFY 2013 & 2014 2. Field test in Greenland in 2014; 3. Prepare drill for 2014-15 scientific drilling in Antarctica 4. Deploy drill to Antarctica- FFY 2014 5. Commence 1500 m drilling at South Pole – FFY 2015 6. Conclude drilling at South Pole – FFY 2016

Hot Water Rapid Access Drills

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. 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.

IDDO has recently received several inquiries about providing an access hole through an Antarctic ice shelf, so it is planning to regain that capability by designing and building a

modular hot water drill with the flexibility to create holes of various sizes and depths. Science requirements for the new drill remain to be defined.

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.
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 in operating the drills. Documentation – A description of the KE drill and its operation exists. 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. Define science requirements – FFY 2014 2. Develop conceptual design for hot water rapid access drill – FFY 2014 3. Complete design, including evaluation of re-using KE drill components, and fabrication of the hot water drill – FFY 2014 & FFY 2015 4. Deploy drill in Antarctica -- FFY 2016

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 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 the light of IDDO's other commitments.

Winches – Following the IDPO-SAB recommendation, IDDO purchased and modified two logging winches and will make them available for use by the science community. The sleds for these winches were designed, fabricated, and mounted to the base units. The first is a 1.5-km winch, which will be the more portable and used on shallow and intermediate depth holes. The second is a winch capable of logging to 4 km.

Current Status:	The logging community prepared a white paper that was used for guidance in procuring the logging winches. IDDO has purchased a portable, off-the-shelf, 1.5 km logging winch. Components for the deep (4 km) logging winch have been purchased and are being assembled by IDDO. In addition, IDPO-IDDO have arranged for the transfer of the IceCube logging winch to IDDO; it 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.
Technical Issues:	Performance History – None; users such as Gary Clow and Ryan Bay have provided information regarding their experience with various types of winches. Documentation – Documentation for the winches is being collected throughout their development and will be entered into the document database as components are purchased and modified.
Plans:	1. Finish constructing both winch systems – FFY 2013 2. Deploy both 1.5-km and 4-km logging winches to Antarctica – FFY 2015 3. Acquire and refurbish/modify, if necessary, the IceCube logging winch – FFY 2014 or FFY 2015, depending on WISSARD needs

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 2013-2023:

"1. Designs should be such that the supporting logistical requirements do not impede the execution of the science;

"2. Science requirements need to be balanced by consideration of logistical issues including weight, size, costs and time frame for development. All issues need to be clearly defined at the initial stage of planning, and changes during the engineering design and fabrication process must be reassessed by the IDPO.

"3. Drills and accompanying technology should be developed with consideration of potential use in possible future projects. They must be versatile and adaptable.

"4. Engineering design teams should include individuals with field experience using ice core drills 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 design and construction of replicate coring capability, the design, procurement and modification of logging winches, the design and construction of the Blue Ice Drill, and the design and fabrication of the new Intermediate Depth Drill.

Recommended technology investments

The IDPO Science Advisory Board identified high-priority investments in drilling technology that are needed to achieve the science goals. 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 together with the corresponding IDDO action taken or to be taken.

***1**. Maintain and upgrade the existing drills for coring to 400m (on-going).*

Science goals

200-year arrays

2,000-year array

IDDO action: This is a major focus of this Plan – see pp. 4 – 17

***2.** Complete design, development, and testing of the intermediate-depth drill [IDD] and infrastructure. The drill is designed for coring 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 of the IDD has been completed, and its construction is under way with field testing planned for Greenland in 2014. Production drilling is scheduled to start at South Pole in 2014-15 – see pp. 22-23

3. *Modify the "blue ice" drill [BID] to enable large-volume sampling of firn and ice to 300 m depth.*

Science goals

Pre-Quaternary atmosphere
Large-volume sampling for changes across climate transitions

IDDO action: Partially modified BID tested in firn in Greenland during 2013 and is being modified for depths of 200 meters for Greenland project in 2014 – see pp. 9 Modification for coring to 300 meters will be addressed as science requirements are developed.

4. *Assess upgrades for the DISC drill that lessen its logistics requirements and ready it for East Antarctic conditions, 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: Assessment will be made in FFY 2015 and upgrades completed, if necessary, in 2018.

5. ***"****Continue feasibility studies for a new generation of hot water drill"* and *"Develop drills that will allow rapid access to the base of ice sheets and ice shelves. Holes of different diameter from 500 to 2,500 m depth are required for various projects. A modular design that can be helicopter-deployed is needed."*

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 and IDPO believe that developing a modular hot water drill should be their next big project. One science proposal that would use such a drill is being considered for the 2015-16 season. Feasibility study will be completed in early FFY 2014 with actual development taking place in FFY 2014-15.

6. *Develop the capability of retrieving bedrock samples beneath ice 300- to 1000 m thick. Different projects require access through ice of different thickness; design should be modular.*

Science goals

Glacial history

IDDO action: One proposal being considered for field in 2015-16 requiring access through a few hundred meters of ice. Start design of Agile Basal Material Recovery Drill in FFY 2014, fabricate in FFY 2015, ready for use in FFY 2016. Further development will depend on field results and definition of requirements.

7. "*An agile shot-hole drill is needed. Tasks include evaluation of existing RAM drill, evaluation of the new generation of hot water drill, and designing and building a 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: More detailed definition of requirements in FFY 2013-14 with feasibility study/conceptual design in FFY 2014. If determined to be best approach, upgrade of RAM drill in FFY 2014-16. If hot water drill proves to be best approach, build shot hole drill based on new generation hot water drill in FFY 2014-16. Start conceptual design of Rapid Hole Maker drill capable of drilling deeper in FFY 2015 with possible design and fabrication in FFY 2016-18.

8*. "Develop a coring drill capable of drilling in wet ice in warm alpine glaciers."*

Science goals

200-year arrays

IDDO action: Existing electrothermal drill already can do this. A second electrothermal drill will be fabricated when there is a need for one - see pp. 13-14

9. "*Build or acquire a lightweight backpack drill for shallow coring."*

Science goals

200-year arrays

IDDO action: Define requirements and evaluate – FFY 2014; may be covered with modification of existing agile drills.

10*. "Develop 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: Define requirements and evaluate – FFY 2014; considered as an ancillary to existing hand augers.

11. "*Develop a very agile, clean hot water drill for creating 5" holes through up to six meters of sediment-laden lake ice."*

Science goals

Sub-ice microbial ecosystems and biogeochemistry

IDDO action: Evaluate – FFY 2014; design and build in FFY 2014-15.

12. "*Design and develop drilling technologies, methods and protocols for clean drilling 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.

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 usually 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 eight 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

FFY 2013 – During the 2012-13 field season, IDDO completed drilling in the WAIS Divide main borehole with the DISC Drill replicate coring system, 285 meters of replicate core were collected from a total of five deviations at four depth intervals. No borehole logging operations were undertaken during the 2012-13 field season.

FFY 2014 – In light of budget constraints on the Antarctic program, IDDO plans to send only one staff engineer and one driller to WAIS Divide. The engineer will assist with setup of logging sheaves both on top of and inside of the Arch and will also assist the logging teams in navigating the interior of the Arch, as parts of the DISC Drill were already disassembled during the 2012-13 season. The IDDO driller will again serve as logging winch operator alongside Gary Clow.

FFY 2015 – For the 2014-15 field season, IDDO plans to send a small crew of staff and contractors to disassemble and pack the DISC Drill in the WAIS Divide Arch Facility. The system will then await traverse transport back to McMurdo by the logistics provider.

FFY 2017 – All DISC Drill equipment is planned to be returned to Madison in late spring 2017. 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 approval of a project, IDDO and IDPO 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 make the equipment ready for use on the next project.

FFY 2013 – IDDO supported six shallow coring projects in Greenland and Alaska during the boreal summer and two shallow drilling and one logging project, in addition to the WAIS Divide project, in Antarctica during the austral summer.

FFY 2014 – IDDO plans to support borehole logging operations at WAIS Divide as well as three shallow drilling projects during the austral summer in Antarctica. IDDO also plans to support three shallow drilling projects in Greenland as well as conduct a full system

test of the new IDDO Intermediate Depth Drill at the Isi site near Summit Station, 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 Taylor Dome 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.

FFY 2014 or thereafter – IDDO will undertake evaluation of the situation in the GISP2 borehole and, as staff time permits, develop and implement a plan for the restoration of unimpeded access to it.

FFY 2015 or thereafter – IDDO will seek opportunities to evaluate the situations at Taylor Dome and Siple Dome.

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 the section Hot Water Rapid Access Drills, IDDO is planning to design and build a new hot water drill to provide subglacial access through relatively thin ice. Proposals calling for the development and use of a new hot water drill are currently being reviewed and there is much community interest in such drills. Development and fabrication is anticipated in FFY 2015.

FFY 2014 – If funds are available in the IDDO budget, design and fabrication of a hot water access drill will begin and will continue into FFY 2015**.**

FFY 2016 – If requested, IDDO plans to deploy the drill to Antarctica for use during the 2015-16 field season.

EXPENDITURES

Based on the current status of equipment in IDDO inventory and the plans for the development of new equipment, IDDO estimates that approximately $11.9 million of funding will be required from FFY 2013 through FFY 2018 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 FFY 2013 approximately $650,000 was budgeted for maintenance and upgrade of ice drilling equipment and future annual expenditures for this function can be expected to be of a similar magnitude.

Annual expenditures for operations supporting science 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 an IDDO expenditure of less than $2,000 for preparation of the equipment and shipping. Large, multi-year projects such as the WAIS Divide Ice Core Project or the upcoming Intermediate Depth Drill Project will require IDDO expenditures of $300,000-500,000 per field season.

ACRONYMS

ARA: Askaryan Radio Array

DISC: Deep Ice Sheet Coring

DVD: Digital Video Disc

FFY: Federal Fiscal Year

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

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				
		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 (FFY)
TECHNOLOGY	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
	Portable Hot Water Drill Maintenance and Upgrade								x										Now [3]
	Rapid Air Movement Maintenance and Enhancement							x	x										2016
	DISC Drill East Antarctic Modifications			x	x	x	x												2018
	Intermediate Depth Drill Development		x	x															2015
	Mechanical Rapid Access Drill Development			x	x	x	x	x			x	x	x	x	x	x	x	x	[4]
	Logging Winch Development		x	x	x	x	x	x											2014
	Hot Water Rapid Access Drill Development							x		x	x		x	x	x	x		x	2015
	Agile Basal Material Recovery Drill Development												x	x	x				2015
	Sub-Lake-Ice Hot Water Drill Development															x			2015
	"Rapid Hole Maker" Development							x											2018
	Bore Hole Preservation Technology Development		x	x	x			x				x							

[1] Hand augers, Badger-Eclipse Drills, 4-Inch Drills available at present; equipment will be enhanced for taking horizontal cores; this could be available by the end of FFY 2014.cc
[2] Ability to go to 200 meters depth available in early 2014; ability to go deeper (300 meters) will be developed later if necessary.
[3] Modifications planned to make logistics and operation easier; first drill with modifications should be available FFY 2014 or earlier.
[4] Being developed at University of Minnesota – Duluth based on concept by IDDO.

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	

	FFY 2013	FFY 2014		FFY 2015		FFY 2016		FFY 2017		FFY 2018		FFY 2019
Equipment	**2013 Arctic**	**2013-14 Antarctic**	**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**
2-Inch Drill*												
4-Inch Drill 1												
4-Inch Drill 2												
4-Inch Drill 3*												
Agile Basal Material Recovery Drill												
Badger-Eclipse 1												
Badger-Eclipse 2												
Badger-Eclipse 3*												
Blue Ice Drill			Enhanced	Enhanced	Enhanced	Enhanced						
Chipmunk Drill												
DISC Drill												
DISC – Replicate Coring System												
Drill Fluid Development	IDPO task											
HWD (Hot Water Drill), Portable 1												
HWD (Hot Water Drill), Portable 2												
HWD, TBD (Subglacial Access)												
Intermediate-Depth Drill												
Koci Drill												
Logging Tower												
Logging Winch - Deep**				Secondary		Secondary						
Logging Winch - IceCube***	In use by WISSARD											
Logging Winch - Intermediate												
Prairie Dog												
RAM (Rapid Air Movement) Drill												
Rapid Hole Maker												
Shallow Biological Sampling Drill												
Thermal Drill												
Sidewinder (4 available)	3 in use											
Hand Auger, 3" PICO (7 available)	3 in use					Phased out						
Hand Auger, 4" PICO (2 available)	1 in use					Phased out						
Hand Auger, 3" IDDO (8 available)	1 in use											
Hand Auger, 4" IDDO						3 planned available						
Hand Auger, SIPRE (6 available)						Phased out						

* Extensive work is required to ready this system for field use. Work will be scheduled if a project calls for the system's use in the near future.

** This system will be procured from an outside vendor and modified to meet the science requirements at a later date and prior to planned use in the field.

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

Appendix 3
Estimated Cost Equipment Development and Upgrade Projects
FFY 2013-FFY 2018

Equipment Development Project	FFY 2013 (Current)	FFY 2014	FFY 2015	FFY 2016	FFY 2017	FFY 2018	Total FY 2013-2018
DISC – Replicate Coring	196,000						**196,000**
Deep Logging Winch	281,000						**281,000**
Intermediate Depth Drill	984,000	685,000					**1,669,000**
Blue Ice Drill – Enhanced Capabilities	172,000	80,000					**252,000**
Hot Water Rapid Access Drill		700,000	700,000				**1,400,000**
Agile Basal Material Recovery Drill		160,000	160,000				**320,000**
RAM Drill – Enhanced Capabilities		80,000	550,000	950,000			**1,580,000**
Shallow Biological Sampling HW Drill		20,000	20,000				**40,000**
DISC Drill – East Antarctic Enhancements			80,000	550,000	950,000	400,000	**1,980,000**
Rapid Hole Maker			80,000	250,000	1,100,000	1,650,000	**3,080,000**
4-Inch Drill Upgrades	19,000	195,000	179,000	149,000			**542,000**
Badger-Eclipse Upgrades	138,000	130,000	102,000				**370,000**
Hand Auger Upgrades	61,000	10,000	10,000	20,000			**101,000**
Portable Hot Water Drill Upgrades	16,000	40,000	20,000				**76,000**
Total Development	**1,867,000**	**2,100,000**	**1,901,000**	**1,919,000**	**2,050,000**	**2,050,000**	**11,887,000**