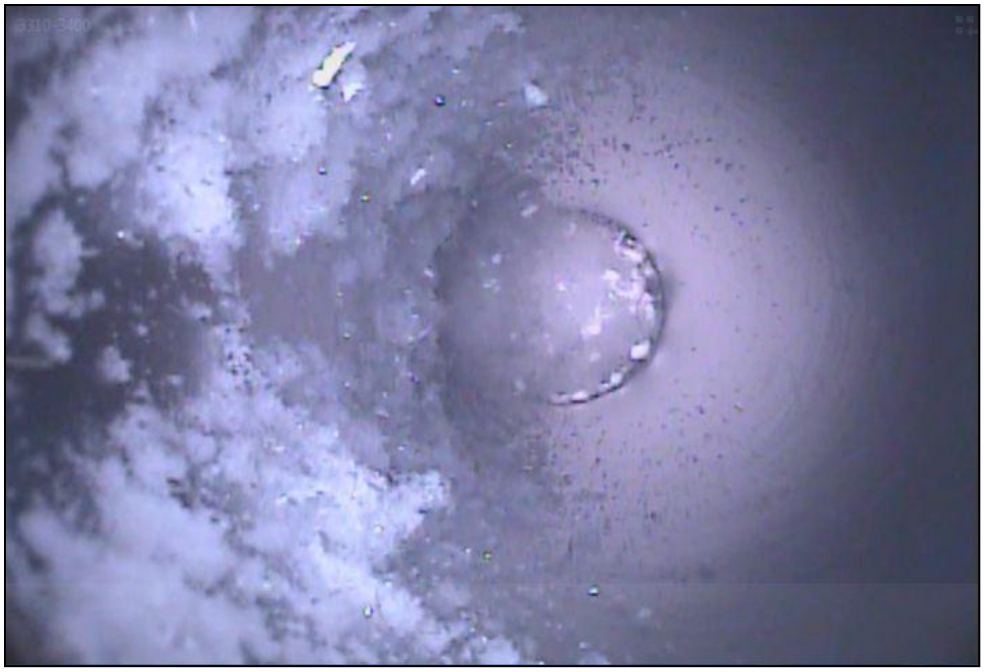
Ice Drilling Design and Operations

Long Range Drilling Technology Plan



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

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Cover photo: Bottom of the WAIS Divide deep borehole. 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:

- Maintain and update the existing agile coring/drilling capabilities, including addition of clean, easily portable hand and shallow coring devices.
- Purchase/construct two winches for borehole logging: first priority is a 1.5-km winch; second priority is a 4-km winch.
- Develop replicate coring capability. This task is being developed for WAIS Divide.
- Purchase/construct a versatile intermediate-depth (1,500 m) drill. This task is underway.
- Develop drills that will allow rapid access to the base of ice sheets and ice shelves. Holes of different diameter are needed for specific projects and so modular designs are preferable. The proposed RAID (Rapid Access Ice Drill) drill is a step in this direction. Existing hot water access drills need to be maintained, and new hot water drills capable of drilling 500 to 2,500 m are urgently needed.
- Design and develop methods and protocols for clean access for sampling of subglacial environments.
- Identify a drilling fluid that is environmentally acceptable and can be used at temperatures down to -55°C.
- Develop methods to sample large quantities (10's of meters of core) of subglacial bedrock.

Note: Items are not listed in 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. Before the end of calendar 2012, IDDO will develop a documentation matrix showing the status of documentation for all its drilling systems.

Agile Drills

Agile coring and drilling capability was seen by the IDPO Science Advisory Board as one of the seven high priority investments in drilling technology needed in the next five years. 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 field testing 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 Kovacs (5-inch). In addition, IDDO has constructed two prototypes of a 3-inch hand auger for testing. The 3-inch models take cores 1 m long, the 4-inch auger can be configured to take either one-meter or half-meter cores, and the 5-inch auger takes a half-meter core. 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 distributed by the BFC (Berg Field Center); 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 hand augers are aging and IDDO has developed a replacement that was tested in Antarctica during the 2011-12 season. One of the prototypes was modified based on that testing and is being provided to a field investigator for evaluation 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 informing modifications currently being made. Documentation – Most drawings have been completed; operating manuals and a maintenance procedure have been written and are 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. Fabricate 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 2012 and FFY 2013. 3. Solidify process whereby hand augers are directly packed and labeled for use by specific investigators even when issued by the Berg Field Center. This will allow for the normal IDPO-IDDO procedure for feedback from users. 4. Improve hand augers based on feedback from users – Ongoing 5. Investigate very lightweight "backpack drills" for alpine shallow coring. 6. Investigate clean technologies for such lightweight drills for shallow coring to study microbes in the ice. 7. Continue distribution of a post-field season questionnaire to get information from investigators on hand auger performance.

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 now a contract driller 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.
Technical Issues:	Performance Data – Few exist because of infrequency of use. Documentation – System drawings near completion; operator's manual available Other – None known; more experience with drill needed
Plans:	1. Replace lost Prairie Dog drill 2. Prior to replacing the lost drill: review design of drill, including potential hazards, and determine modifications needed – FFY 2012 or 2013 3. Modify and construct one or more drills (determined by project need) - FFY 2012 or 2013 4. Review other documentation available and determine needs; update and create documentation as needed and enter into database – FFY 2012 or 2013 5. 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 in conjunction with the distribution of a post-season hand auger performance questionnaire. Documentation – Systems drawings near completion; operating procedures for the Sidewinder have been developed and are reviewed annually. It has been suggested that an operator DVD be developed and a hardcopy of the system layout and necessary instructions included with this system. 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 – FFY 2012 and ongoing 2. Modify Sidewinder systems per design evaluation – FFY 2012 and ongoing 3. Review documentation, update and enter into database – FFY 2012 and ongoing 4. Modifications – As recommended by users 5. Repairs – Ongoing

Blue Ice Drill –An agile drill capable of retrieving cores of approximately 9-1/2 inch diameter to depths up to 25 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.

Current Status:	The Blue Ice Drill is undergoing minor modifications as a result of the past field season and is scheduled to be ready for use in Greenland in 2013 and in Antarctica in the 2013-14 field season if needed.
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 drill to enable testing in firn and ice to a depth of 100+ meters 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 capabilities as needed.

2-Inch Drill – The 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.

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 and is not ready for issue.
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

Technical Issues: (continued)	making modifications to the drill, some "reverse engineering" has been completed and a few drawings produced; over 100 drawings are currently in progress or contained in the database. Operating and maintenance manuals need to be completed. Other – Improvements to instrumentation and the control system need to be made 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. Repairs and general maintenance to make the drills usable for their next scheduled use in the Arctic in summer 2013 – FFY 2012 2. Ready third Eclipse drill system for issue – FFY 2012 and FFY 2013 3. Develop procedure, including bill-of-materials checklist, for preparing drill for issue – FFY 2012 4. Analyze project performance data, develop (if possible) preliminary performance baseline, institute guides for data collection. Continue to collect, analyze data and update performance – FFY 2013 and thereafter 5. Standardize components of the drills to the extent desirable and practicable * – FFY 2012 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 2012 8. Determine desired evolution of Badger-Eclipse drills in general * 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 Antarctic field season, or during 2012 in the Arctic. General maintenance and minor modifications were implemented on the drills during FFY 2011 and continue in FFY 2012. Budget requests for FFY2012 and beyond will include upgrade costs.

Current Status:	IDDO plans to have two 4-Inch Drills available for use on field projects, with a third kept in reserve for possible refurbishment. Two drills are currently being refurbished, including the replacement of some components. Winch and cable inventory includes one at 400 m, two at 200 m and one at 100 m.
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 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 40 drawings exist in the database. Up-to-date drawings will be completed in 2013. Operating and maintenance manuals need to be 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.

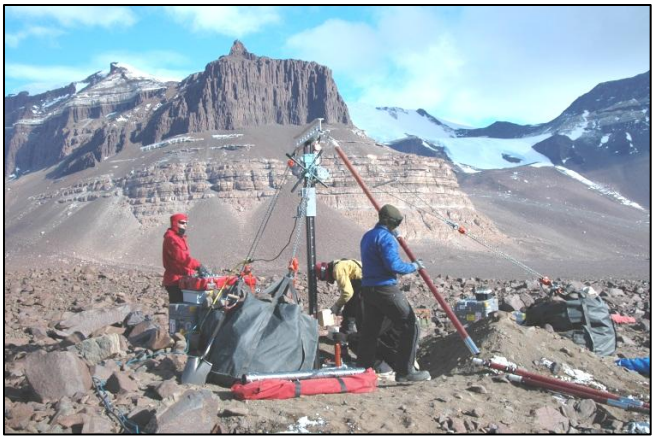
Plans:	1. Make use of existing stock of barrels and begin migration of drill to design allowing barrels of common design with IDD. 2. Upgrade and refurbish winches to have one each of 100-, 200-, and 400-meter capability. 3. Analyze drill performance data and establish a performance baseline if possible; define data collection procedure – FFY 2013 and thereafter 4. Complete development of operating and maintenance procedures and documentation – FFY 2012 5. Update drill system drawings and enter into database – FFY 2012 – FFY 2013 6. Perform general maintenance and repairs – Ongoing and as necessary 7. Study feasibility/need of modifying drills for submersible drilling – FFY 2012 & FFY 2013 8. Modify drill(s) for submersible drilling if feasible/necessary and test – FFY 2012 – FFY 2013 9. Determine desired evolution of 4-inch drills in general: sonde similar to IDD? Replace motors, gearboxes etc.? FFY 2012

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 recently 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.

Current Status:	IDDO has one electrothermal drill. It was repaired, including a new barrel, in 2011: IDDO hoped to test the drill on a project during the summer of 2011 in Greenland, but was unable to do so due to timing of associated field project.

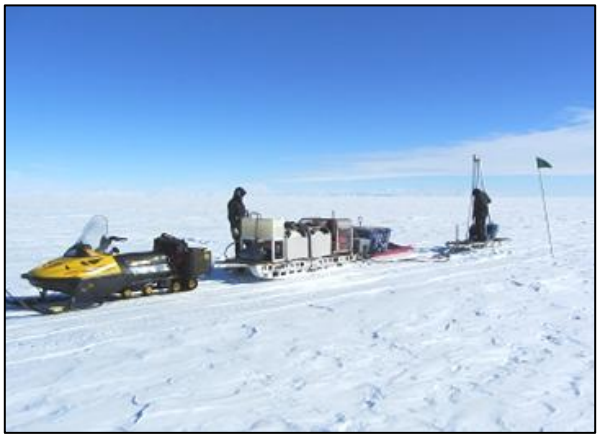
Technical Issues:	Performance Data – Some data from two projects have been collected; these data need to be analyzed both to determine the drill's usefulness and to develop some preliminary performance specifications. Procedures for more consistent recording of data during projects need to be defined and used. Documentation – Drawings and models for the new 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. Operating and maintenance manuals need to 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.
Plans:	1. Develop procedure for preparing drill for issue – FFY 2012 2. Analyze drill performance data and establish a performance baseline if possible; define data collection procedure – FFY 2013 and continuing 3. Ascertain availability of replacement parts – FFY 2012 4. Complete operating and maintenance instructions and enter into database – FFY 2012 5. Complete/update drawings and enter into database – FFY 2013 6. Perform general maintenance and repairs – ongoing and as needed 7. Investigate the possibility of collaborating with others in developing a new IDDO electrothermal drill – FFY 2013.

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.



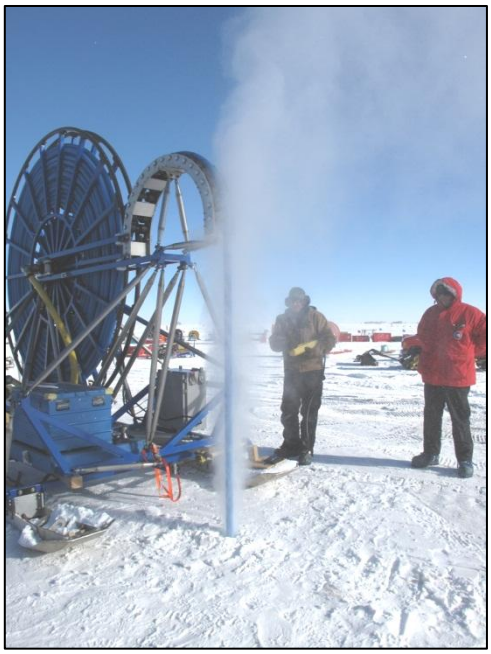
The drill bit is rotated via a rigid drill string by a surface-mounted electric motor mounted to a tower. Drill penetration is controlled by a feed system on the drill tower to account for varying ice conditions. The drill produces 76-mm (3-inch) diameter cores a few tenths of a meter long. It was tested 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.

Current Status:	The Koci Drill is the only drill of its type and is under continued development. The drill was used successfully in Beacon Valley during the 2008-09 and 2009-10 field seasons; it has not been used since, however, recently there is renewed interest in its use by the scientific community.
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 – 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 2013 2. Complete feasibility study of improving drill for rocky ice and bedrock drilling – 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 has recently been received back in Madison after three field seasons (2+ years) in Antarctica. It has been unpacked and a list of needed repairs prepared. Several inquiries have been received for projects requiring 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. 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. Standardize and modularize drill – FFY 2013 or when funding is available. After that: 2. Complete operating and maintenance procedures –FFY 2013 3. Develop procedure for preparing drills for issue – FFY 2013 4. Complete 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. It has been tried out once in East Antarctica (at South Pole) with lesser success (see "Current Status" box). 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. 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.
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 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 and maintenance instructions need to be completed. 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. Investigate means of sealing off the firn to prevent air loss FFY 2014 2. If necessary, perform study with the aid of appropriate research scientists to better understand and quantify air losses in firn FFY 2014 3. Make needed modifications, including new hose reel and modifications to compressors to improve traversing FFY 2015

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 drilling on New Year's Eve after five production seasons. The drilled depth as of January 1, 2012, is 3405 meters. The DISC Drill will remain at WAIS Divide for replicate coring in 2012-13.

The DISC Drill system design is a dynamic process, and it is going through continuous modifications and enhancements. The modifications undertaken during FFY2011 in preparation for the 2011-12 field season were: new weight-on-bit (WOB) system with a sealed housing and a compression spring with LVDT position sensor, new sealant used for motor sections, new Teflon jacket for wiring in motor sections, extension of spindle bearings on two motor sections to accommodate additional side loading anticipated during replicate coring, removal of oil temp thermistor while maintaining function of cutter and pump motor thermistors, new plating of the bores of the compensator piston housings, fill line indicator added on pump grease pistons, new method developed for joining furcation tubing to drill cable fibers during fiber optic termination, new drill cable cleaner designed and fabricated based on the cable cleaner used by the Danes at NEEM, new fitting procured and machined for joining the drill fluid hose to the borehole casing, and new carbide-tipped cutters designed and fabricated. The majority of the modifications proved successful during operations at WAIS Divide during the 2011-12 field season.

The Long Range Science Plan 2012-2022 anticipates that, after 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 2014, 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).

Current Status:	The DISC Drill is at WAIS Divide, where it will be used for replicate coring in 2012-13. As usual, some modifications and repairs are being made to components of the drill between field seasons.
Technical Issues:	Performance Data– Data are being collected while the drilling progresses at WAIS Divide. These data provide information useful in making modifications to the drill that will improve its performance. Data gathered on subsequent DISC Drill projects will be used in a similar way. Documentation – The DISC Drill is being documented as it is being developed. IDDO makes use of an Engineering Change Notification process to ensure that documentation is updated to reflect changes to the equipment. Documentation is maintained in the SSEC Documentation database. Other – The obsolescence and the resulting inability to get replacement components – particularly electronics – is an ongoing challenge that will be faced 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. Make modifications and general repairs identified during 2011-12 field season -- FFY 2012 2. Determine components that need to be replaced to make the drill ready for East Antarctica and test components as necessary –FFY 2014 3. Complete study comparing DISC with EPICA type deep drill for future deep coring projects – FFY 2012 4. Develop plan for continuous upgrading of drill system, including the upgrade to drill at -55ºC and performance and logistical improvements that can be realized through modifications such as longer core lengths and faster tripping speeds; requires decision from IDPO/SAB on future use of DISC Drill – FFY 2014

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 sample 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 a 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 insight into what is occurring deep within the borehole using the new borehole camera. They verified that the sonde will find a desired orientation with a repeatability of ±15° and can find the uphill side of the borehole. However, it could not create a ledge, the first step toward a deviation hole. Three major issues identified: axial stick-slip, whereby the sonde and drill cable did not move smoothly down the hole; system rigidity – flexure in the sonde prevented the cutters from contacting the borehole wall with sufficient force to allow the effective starting of a deviation; cutter geometry – needs fine tuning to cut more effectively.

Current Status:	Modifications of the replicate coring system and considerable testing for the DISC Drill are under way. It is anticipated that the system will be ready to recover replicate cores beginning in the 2012-13 field season at WAIS Divide.
Technical Issues:	Performance Data – There are no performance data on replicate coring. However, data collected during testing during the 2011-12 field season was analyzed to define the problems associated with initiating the borehole deviation and potential solutions. Documentation – All work on the replicate coring system is being documented according to SSEC standards and archived in

Technical Issues: (continued)	the control document database. 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, no one has developed a system specifically to replicate ice cores at any chosen depth and at any chosen azimuth within an existing borehole.
Plans:	1. Complete modifications of replicate coring system for use in deep borehole at WAIS Divide – FFY 2012 2. Carry out production replicate coring season at WAIS Divide – FFY 2013 3. Analyze data obtained from WAIS Divide replicate coring and develop plan for future development of technology – FFY 2013

Drill 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 and that the Chinese are planning to use one as a drilling fluid in the East Antarctic interior. 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.

With the drilling of both deep and intermediate depth holes in very cold regions in East Antarctica a likely prospect in the future, IDPO will continue study of drill fluids. The FFY2013 IDPO budget will include funding for the continued search for an appropriate drilling fluid.

Current Status:	While there are currently available drilling fluids, none are ideal for drilling at very cold sites. Several papers have been published about potential new fluids and an up-to-date summary has recently been issued 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 is reportedly conducting experiments on a new drilling fluid (ESTISOL 140) as this report is being written (May, 2012).
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. Define the science requirements for a new drill fluid; IDPO will oversee the project – FFY 2012 2. Explore possibility of collaborating with Europeans on the development of a drill fluid; IDPO will supervise and subcontract the project if needed – FFY 2012 and FFY 2013 3. Conduct drill fluid study (IDPO) – FFY 2012 and FFY 2013

Intermediate Depth Drill (IDD) - Many of the coring objectives given 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 an initial feasibility study has been completed. The design and fabrication of an intermediate depth drill is currently underway at IDDO. 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 use beginning in 2014.

Current Status:	IDDO is currently in the midst of designing the IDD. A conceptual design was completed last year and estimates of cost, size, and extent of required logistical support have been made.
Technical Issues:	Because a drill fluid is needed to keep the borehole open, suitable fluids must be identified for the drilling locations anticipated.

Plans:	1. Complete detailed design - FFY 2013. 2. Fabrication of drill – FFY 2013 3. Field test in Greenland in 2014; prepare drill for 2014-15 scientific drilling in Antarctica – FFY 2014 4. Deploy drill to Antarctica-- FFY 2014

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 (~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. Depending on the science requirements, which are yet to be defined, and the condition of the various components, the new drill could make use of some of the KE Drill.

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 2013 2. Develop conceptual design for hot water rapid access drill – FY 2013 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.

The limitations inherent in current deep drilling systems indicate the need for a mechanical drill that can provide rapid access to depths up to 4 km. The new drilling system should be able to produce arrays of semi-permanent, uniform-diameter holes with minimal thermal disturbance, allowing a wide range of experiments to be conducted within each borehole over a number of years. It should also be capable of allowing access at depth to an ice coring drill that can acquire continuous cores of usable diameter at greater depths and of sampling subglacial basal materials (at least where environmental conditions permit). The system should be both modular and flexible so that new tools can be easily added to satisfy future research needs.

IDDO completed a feasibility study (including the logistical requirements) and conceptual design for a mechanical rapid access drill (RAID) in early 2012 based on science requirements calling for a drill capable of coring at least 25 meters of bedrock beneath ice as deep as 3300 meters. RAID would be capable of retrieving short ice cores greater than 1.4 inches in diameter and would leave the borehole in a condition suitable for borehole logging. The RAID concept is based on a commercially available minerals exploration diamond-bit drilling rig and the drill could be adapted for some projects requiring larger diameters of ice core at shorter depths by changing drill rod sizes. Once RAID has been completed and utilized successfully for its first project(s), IDDO would evaluate the equipment requirements and logistic burden for science projects with differing requirements.

Current Status:	No mechanical rapid access drills capable of drilling up to 4 km through cold polar ice and then collecting tens of meters of bedrock core exist. IDDO has produced a conceptual design for such a drill, based on conventional mineral drilling rigs that use straight pipe (rods) from the surface with automated joint make-and-break. A proposal to build a Rapid Access Ice Drill (RAID) based on that design has been submitted to NSF/OPP. A science requirements document has been drawn up by IDPO and representatives of the science community.
Technical Issues:	A drilling fluid is needed to keep the borehole from closing. The consequent fluid-transport logistical burden even for small diameter holes is non-trivial.
Plans (assuming funds available)	1. Design RAID drill – FFY 2014 – FFY 2015 2. Fabricate mechanical rapid access drill – FFY 2015 - 2016 3. Test drill– FFY2016 4. Follow up on needed modifications indicated by the test – FFY 2017 5. Deploy drill to Antarctica– FFY 2018

Logging Winches - The IDPO-SAB recommended that IDDO purchase or develop at least two logging winches and make them available for use by the science community. The first, and higher priority, is a 1.5-km winch, which would 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 has prepared a white paper that is being used for guidance in procuring the logging winches. IDDO has identified a manufacturer for a portable, off-the-shelf, 1.5 km logging winch and has a purchase order in place as this report is being written (May, 2012). 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 is being 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 would be developed and entered into the document database as they are purchased and modified.
Plans:	1. Purchase and modify as necessary a 1.5-km winch – FFY 2012 2. Purchase and modify as necessary a 4-km winch – FFY 2013 3. Both 1.5-km and 4-km logging winches available for deployment to Antarctica – FFY 2014 4. Acquire and refurbish/modify, if necessary, IceCube logging winch – FFY 2013 or FFY 2014, 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 2012-2022:

"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."

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 designs for the new intermediate depth drill.

Recommended technology investments

The IDPO Science Advisory Board identified the following high-priority investments in drilling technology that are needed to achieve the science goals*:*

1. Maintain and update the existing agile coring/drilling capabilities, including addition of clean, easily portable hand and shallow coring devices;

A major focus of this Plan – see pp. 4 - 17

2. Purchase/construct two borehole logging winches: first priority is a 1.5-km winch; second priority is a 4-km winch;

The specific requirements for a logging winch are still a matter of discussion in the logging community – see pp. 25 - 26

3. Develop replicate coring capability. This task is being developed for WAIS Divide;

A major focus of current IDDO activity – see pp. 20 - 21.

4. Purchase/construct a versatile intermediate-depth (1,500 m) drill. This task is underway;

A feasibility study for the intermediate depth drill, including sizes and cost estimates, was completed and design and construction are underway– see pp. 22-23.

5. Develop drills that will allow rapid access to the base of ice sheets and ice shelves. Holes of different diameter are needed for specific projects and so modular designs are preferable. The proposed RAID drill is a step in this direction… New hot water drills capable of drilling 500 to 2,500 m are urgently needed;

Completion of this project is still some years in the future; the RAID feasibility study, conducted in FFY 2012, is a start. See pp. 23 - 25.

6. Design and develop methods and protocols for clean access for sampling of subglacial environments;

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.

7. Identify a drilling fluid that is environmentally acceptable and can be used at temperatures down to -55°C.

This is a matter under discussion with the Technical Advisory Board; some promising approaches have been found and IDPO is conducting further research into those approaches. Identification of potential fluids continues -- see pp. 21 - 22.

8. Develop methods to sample large quantities (10's of meters of core) of subglacial bedrock.

The proposed RAID drill will be particularly suitable for bed access under thick ice; for drilling under thin ice a smaller, lighter, more portable system would be more suitable. IDPO will work with the community to establish science requirements for such a system in FFY 2013, after which IDDO will complete a conceptual design and establish a budget and timeline for rock drilling under shallow ice.

FIELD SUPPORT OF SCIENCE PROJECTS

In addition to the development of new and existing ice drilling and related equipment and its maintenance, 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 five or six 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

IDDO will continue drilling with the DISC Drill replicate coring system at WAIS Divide in Antarctica during the 2012-13 season.

FFY 2012 – The 2011-12 field season was very successful with regard to the completion of the main borehole after five production drilling seasons and a final depth of 3405 m was attained. No difficulties associated with warm ice were encountered; the temperature at the final depth was estimated to be -6º C. IDDO also supported the borehole logging activities at WAIS Divide during the 2011-12 field season.

FFY 2013 – During the 2012-13 field season, IDDO expects to start and complete replicate coring in the WAIS Divide hole. Plans call for 252 meters of replicate core while making total of five deviations at four depth levels. Preliminary sampling depths have been outlined by Chief Scientist, Jeff Severinghaus. No borehole logging operations are planned for the 2012-13 field season.

FFY 2014 – For the 2013-2014 field season, IDDO plans to send a small crew of staff and contractors to remove the DISC Drill from the WAIS Divide Arch facility, package the system and ready it for return to the US. IDDO also anticipates assisting with borehole logging as necessary.

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 works 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 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 2012 – IDDO supported three shallow drilling projects in Antarctica during the 2011-12 field season and is supporting two others in Greenland and Alaska. In addition, IDDO provided support to eight investigators by issuing hand augers and Sidewinder power drive systems to them.

FFY 2013- 2023 -- IDDO will continue to support science projects approved by OPP.

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 2012 – IDDO is in the process of preparing and shipping casing extensions to Summit Camp, Greenland, for extension of the GISP2 borehole casing.

FFY 2013 – 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 2014 – 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. There are no current proposals calling for the development and use of a new hot water drill, however there is much community interest in such drills and development and fabrication is anticipated in FFY 2014.

FFY 2014 **–** If design and fabrication of a hot water access drill can be fitted within the IDPO/IDDO budget, it will proceed**.**

FFY 2015 – If requested, IDDO plans to deploy the drill to Antarctica for use during the 2014-15 field season.

FUNDING

Based on the current status of equipment in IDDO inventory and the plans for the development of new equipment, IDDO estimates that approximately $11 million of funding will be required from FFY 2012 through FFY 2017 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 is 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 2012 approximately $600,000 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 $1,000 for preparation of the equipment and shipping. Large, multi-year projects such as the WAIS Divide Ice Core Projects will require IDDO expenditures of over $500,000 per field season.

Ice Drilling Design and Operations

Appendix 1

Science Projects Matrix

		PROJECTS																			
		DISC Drill modifications	WAIS Divide drilling	Replicate development	Replicate drilling	DISC modifications for East Antarctica	East Antarctica deep drilling	Logging winch development	Shallow drilling projects	Agile drill maintenance	Preserve ice core boreholes	Hot water subglacial access drill development	Hot water subglacial access drilling	Blue Ice Drill development	Blue Ice Drill drilling	Mechanical rapid access drill development	Mechanical rapid access drilling	Intermediate depth drill development	Intermediate depth drilling	RAM Drill modifications	RAM Drill drilling	Drill fluid development
SCIENCE	**Climate**																					
	200 year arrays								x	x												
	2k arrays		?	x	x			x	x	x	x							x	x			
	40k network	x	x	x	x	x	x	x			x					x	x	x	x			x
	Last interglacial			x	x	x	x		x		x					x	x					x
	Prior to 800k years			x	x	x	x	x						x	x	x	x					x
	IPICS oldest ice				x	x	x	x						x	x	x	x					?
	Ice Dynamics & Glacial History																					
	Basal conditions & geothermal flux							x			x	x	x			x	x			x	x	
	Seismic basal conditions detection																			x	x	
	Sub-ice shelf mass balance											x	x									
	Grounding zone processes											x	x			x	x					
	Rheological properties of ice		x		x		x	x			x					x	x					
	Glacial history											x	x			x	x					
	Conditions at ice sheet bed											x	x			x	x					
	Sub-Ice Environment																					
	Sedimentary record											x	x			x	x					
	Microbial ecosystems & biogeochem											x	x			x	x					
	Geologic & tectonic history											x	x			x	x					
	Subglacial lakes & hydrology											x	x			x	x					

Appendix 2
Long Range Project Schedule
FFY 2012-FFY 2017

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

	FFY 2012	FFY 2013		FFY 2014		FFY 2015		FFY 2016		FFY 2017	
Equipment	2012 Arctic	2012-13 Antarctic	2013 Arctic	2013-14 Antarctic	2014 Arctic	2014-15 Antarctic	2015 Arctic	2015-16 Antarctic	2016 Arctic	2016-17 Antarctic	2017 Arctic
2-Inch Drill*											
4-Inch Drill 1											
4-Inch Drill 2											
4-Inch Drill 3*											
Badger-Eclipse 1											
Badger-Eclipse 2											
Badger-Eclipse 3*											
Blue Ice Drill											
Chipmunk Drill											
DISC Drill				TBD modifications for -55°C drilling in East Antarctica							
DISC – Replicate Coring System											
Drill Fluid Development	In conjunction with IDPO										
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**											
Logging Winch - IceCube***											
Logging Winch - Intermediate											
Prairie Dog											
Preserve Ice Core Boreholes											
RAM (Rapid Air Movement) Drill											
RAID (Rapid Access Ice Drill)											
Thermal Drill											
Sidewinder (4 available)											
Auger, 5" Kovacs (1 available)											
Hand Auger, 3" PICO (7 available)						Phased out					
Hand Auger, 4" PICO (2 available)						Phased out					
Hand Auger, 3" IDDO		2 available	6 available			10 available					
Hand Auger, 4" IDDO						3 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
Cost Estimates for Planned Development Projects
FFY 2012-FFY 2017

Equipment Development Project	FFY 2012 (Current)	FFY 2013	FFY 2014	FFY 2015	FFY 2016	FFY 2017	Total FY 2012-2017
DISC - Replicate Coring	681,985						681,985
Intermediate Depth Drill	369,768	973,292					1,343,060
Intermediate Depth Logging Winch	85,989						85,989
Mechanical Rapid Access Drill (RAID)*	79,017		950,000	3,325,000	1,800,000	800,000	6,954,017
Hot Water Rapid Access Drill			700,000	700,000			1,400,000
Deep Logging Winch		150,000					150,000
Blue Ice Drill - Enhanced Capabilities		106,022	61,431				167,453
Total Development	1,216,759	1,229,314	1,711,431	4,025,000	1,800,000	800,000	10,782,504

* RAID will be aimed at gathering samples of bedrock under thick ice; plans for drilling bedrock under thin ice will be developed after the science requirements are identified in FFY 2013.

ACRONYMS

ARA: Askaryan Radio Array

DISC: Deep Ice Sheet Coring

DVD: Digital Video Disc

FFY: Federal Fiscal Year

ICD: Ice-Coring Drill

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