Ice Drilling Design and Operations

Long Range Drilling Technology Plan

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

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Cover photo: Drilling with the DISC Drill at WAIS Divide. Credit: *Photo courtesy of Kendrick Taylor (DRI, 2008)*

INTRODUCTION

The IDPO Long Range Science Plan lays out recommended directions for U.S. ice coring and drilling science. This companion Long Range Drilling Technology Plan provides an overview of the multifaceted system of drills and technology needed to advance the science. The report 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 needed for its implementation.

ICE DRILLING SYSTEMS AND TECHNOLOGIES

IDDO notes the following guiding principles for development of drilling technology expressed in the IDPO Long Range Science Plan 2010-2020:

1. "*Planning for drilling technology needs to include consideration of the cost and availability of logistics, beginning with the earliest stages of planning and continuing as decisions are made throughout the engineering design and fabrication process.*
2. *"Drills and accompanying technology should be developed with an eye for use in a variety of projects in different remote locations.*
3. *"Designs should be developed so that the necessary supporting logistics do not impede the execution of the science*."

These principles have been and are being adhered to in the course of IDDO's ongoing major development projects -- the design and construction of replicate coring capability, the design and construction of the large-diameter "Blue Ice" drill, and the designs for the WISSARD project.

The high-priority investments identified by the Ice Drilling Program Office Science Advisory Board (SAB) and documented in the Ice Drilling Program Office Long Range Science Plan that are needed to enable scientific discovery include (not in priority order):

- *Maintain quality agile coring/drilling capability* - A major focus of this Plan (pp. 4-14 of this report).
- *Obtain two logging winches: 1 km and 4 km, with first priority on 1 km winch acquisition* – The specific requirements for a logging winch is still a matter of discussion in the logging community (pp. 21-22).
- *Develop replicate coring capability* – A major focus of current IDDO activity (pp. 16-17).
- *Purchase or construct an agile intermediate-depth ice coring drill* – The process of developing the science requirements for this drill are still in the early stages (p. 18).
- *Develop a design for rapid access through the ice sheet with a narrow hole* – This project is still some years in the future; current plans call for beginning feasibility studies in FFY 2012 (pp. 20-21).
- *Identify needed upgrades to the DISC drill to enable use in East Antarctica* – Identification of the needed upgrades will begin next year (pp. 15-16).
- *Develop a design for clean access through the ice sheet with a hole large enough to deploy subglacial rovers* – This design is well advanced as part of the WISSARD project (pp. 18-20).
- *Identify an appropriate drilling fluid to be utilized at in situ temperatures below -30C* – This is a matter of some urgency -- the search will begin early in FFY 2011(pp. 17-18).

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.

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.

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 are the smaller systems that can drill holes to 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 one in the development stage.

IDPO sponsored and IDDO hosted a workshop for drillers using IDDO's agile drills. The purpose of the workshop was to discuss improvements that the operators of the drill equipment believe to be needed in the equipment itself as well as the various programs supporting the design, maintenance, and operation of the drills. Feedback from the drillers is incorporated as appropriate.

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.

Relevant to Science Section(s): I.5, I.6	
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; need process to get user feedback (core quality, etc.) Documentation – Exists, but will be reviewed for currency when needed Other – None known
Plans:	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 hand augers come in two different diameters: 3-inch and 4-inch. The 3-inch model takes cores 1 m long; 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.

Relevant to Science Section(s): I.1, I.2	
Current Status:	Hand augers to be sent to the field are inspected and repaired as needed; in the past a number have been provided to RPSC for issue through the Berg Field Center. PICO hand augers have been modified to use cutter inserts and cutter holders similar to SIPRE. Drawings, operating instructions, and maintenance procedures have been written. PICO and SIPRE hand augers are aging. Several sizes of coring hand augers are available commercially.
Technical Issues:	Performance Data – None; need process for quantitative as well as qualitative feedback from users Documentation – Most drawings have been completed; operating manuals and a maintenance procedure written. However, feedback from users of the equipment indicates that the current procedures are difficult to use in the field. Other – Some quality problems, e.g. alignment of mounting holes, parts not fitting properly.
Plans:	1. Review and modify as necessary procedure for preparing hand augers for issue – FFY 2010. 2. Correct quality problems of existing hand augers "one hand auger at a time" as they are prepared for issue – Ongoing as necessary 3. Design and test a new, more effective hand auger, as current equipment is worn and not interchangeable – FFY 2011. 4. 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. 5. Develop and distribute questionnaire to solicit feedback regarding equipment and its use from hand auger users – prior to 2010-2011 Antarctic field season. 6. Institute process whereby hand augers are directly assigned to specific investigators rather than providing BFC hand augers for issue, thus allowing the normal IDPO-IDDO procedure for feedback from users – fully implemented by the 2011-2012 Antarctic field season. 7. Improve hand augers based on feedback from users - Ongoing

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). The drill has been used almost exclusively by Jay Kyne, its designer, who is now a contract driller with IDDO.

Relevant to Science Section(s): I.1, I.2	
Current Status:	Drill is workable; drill was used during the 2010 Greenland field season and has been requested for 2010-2011 Antarctic field season; recent higher demand.
Technical Issues:	Performance Data – Few exist because of infrequency of use; however, with increased interest in the drill's use, more data should become available.. Documentation – Drawings exist but need to be reviewed and entered in document control database; approved version of operating procedures manual to be available summer of 2010 Other – None known; more experience with drill needed
Plans:	1. Make project-specific modifications as needed – FFY 2010 2. Review and modify as necessary procedure for preparing hand augers for issue – FFY 2010. 3. Finalize and issue operating procedures – FFY 2010 4. Review design of drill, including potential hazards, and determine modifications needed – FFY 2011 5. Review other documentation available and determine needs; update and create documentation as needed and enter into database – FFY 2011 6. General maintenance and modification - Ongoing as needed 7. Modify and construct additional Prairie Dog drills – Determined by project need

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.

Relevant to Science Section(s): I.1, I.2	
Current Status:	Three working systems are available.
Technical Issues:	Performance Data – Information regarding performance should be systematically collected from users. Documentation – Drawings exist, but need to be reviewed and entered into document control database. Operating procedures for the Sidewinder have been developed and are available; however, feedback from users of the equipment indicates that the current procedures are difficult to use in the field. 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 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. Review and modify as necessary procedure for preparing hand augers for issue – FFY 2010. 2. Develop and distribute questionnaire to solicit feedback regarding equipment and its use from hand auger users – prior to 2010-2011 Antarctic field season. 3. Institute process whereby hand augers are directly assigned to specific investigators rather than providing BFC hand augers for issue, thus allowing the normal IDPO-IDDO procedure for feedback from users – fully implemented by the 2011-2012 Antarctic field season. 4. Evaluate design and operation of modified Sidewinder, including hazard analysis, and design required modifications – FFY 2011 5. Modify Sidewinder systems per design evaluation – FFT 2011 6. Review documentation, update and enter into database – FFY 2011 7. Modifications – As recommended by users 8. Repairs – Ongoing 9. Review safety concerns (ladder use, loosening chuck)

Blue Ice Drill – IDDO is developing an agile drill capable of retrieving cores of approximately 9 1/2 inch diameter to depths up to 15 meters in solid ice. The drill, being developed for the University of California at San Diego, will be transportable by light aircraft or helicopter and is planned to be used to collect samples of "blue ice" on Taylor Glacier during the 2010-2011 and 2011-2012 Antarctic field seasons.

Relevant to Science Section(s): I.5, I.6, I.7	
Current Status:	The Blue Ice Drill is in the construction stage and is scheduled to be ready for use in the 2010-2011 Antarctic field season.
Technical Issues:	Performance Data – Being a drill in development, there are no performance data. IDDO plans on having two drillers/engineers in the field when the drill is used during the 2010-2011 and 2011-2012 field seasons; one of their responsibilities will be to document the drill's performance. Documentation – Documentation for drill will be completed as part of the development process and entered in the SSEC document control database. Other – The major challenges involved with the development of the drill are designing an effective means of breaking the large diameter core and keeping the system light enough to be transported in one helicopter load or less.
Plans:	1. Complete design, fabrication and testing – FFY 2010 2. Repair and make modifications after 2010-2011 field season as necessary – FFY 2011

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.

Relevant to Science Section(s): I.1	
Current Status:	Needs repairs and possible modification before being released 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:	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.

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 has been transferred from the University of New Hampshire to IDDO.

Relevant to Science Section(s): I.1, I.2	
Current Status:	Two drills will be available after repairs necessitated by the operation during the 2009-2010 Antarctic field season and general wear. The two Eclipse Drills purchased from Icefield Instruments have been modified to varying degrees. The third drill arrived from UNH in June, 2010.
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. Operating and maintenance manuals need to be updated. 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 user preferences.
Plans:	1. Repairs and general maintenance to make the drills usable for the 2010-2011 Antarctic field season – FFY 2010. 2. Develop procedure, including bill-of-material checklist, for preparing drill for issue – FFY 2011 3. Analyze project performance data, develop (if possible) preliminary performance baseline, institute guides for data collection. Continue to collect, analyze data and update performance – FFY 2011 and thereafter 4. Improve instrumentation and control boxes – FFY 2011 5. Standardize components of the drills to the extent desirable and practicable * – FFY 2011 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 2011 * Participants at the Drillers' Workshop suggested making downhole

	equipment interchangeable and surface equipment distinct; 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 for 100, 200, and 400 meter cables are available. The drill is of a mature design and has been used very successfully for many years. It is particularly useful on projects requiring a larger diameter core. The drill can be transported by light aircraft or helicopter.

The 4-Inch drills were not used during the 2009-2010 field season and no general maintenance or modifications were implemented on the drill during FFY 2009. Repairs and minor modifications were made in 2010 for two summer projects. Repair and maintenance of the drills is essential and will be routinely carried out before and after each field use. Budget requests for FFY2011 and beyond will include upgrade costs.

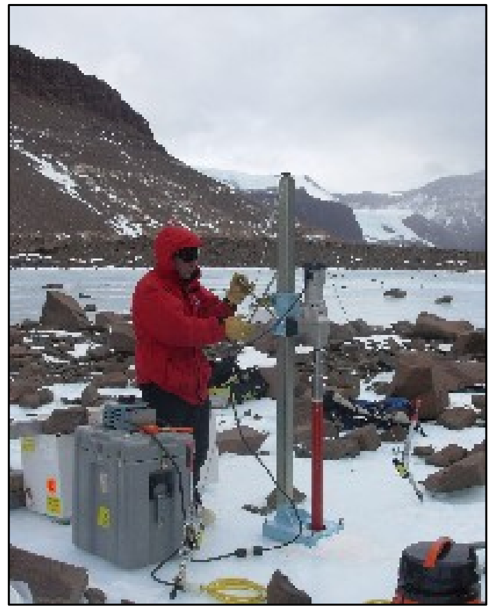
Relevant to Science Section(s): I.1, I.2	
Current Status:	IDDO plans to have two 4-Inch Drills available for use on field projects, with a third kept in reserve for possible refurbishment. Two drills are currently available for field use, but will require the replacement of some components in the near future.
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. 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; participants in Drillers' Workshop doubted that huge weight savings could be gained by modifying winch sleds.
Plans:	1. Develop procedure for preparing drills for issue – FFY 2011 2. Replace barrels and other components as necessary – FFY 2010 – 2011 and periodically thereafter 3. Improve or replace drill controls – FFY 2011 4. Review winch needs – how many to maintain in inventory and of which lengths of cable – FFY 2011 5. Analyze drill performance data and establish a performance baseline if possible; define data collection procedure – FFY 2010 and thereafter 6. Study feasibility of making lighter winch sleds that would be more easily transported by light aircraft - FFY 2011

	7. Develop operating and maintenance procedures – FFY 2011 8. Update drill system drawings and enter into database – FFY 2011 – FFY 2012 9. Perform general maintenance and repairs – Ongoing and as necessary 10. Study feasibility/need of modifying drills for submersible drilling – FFY 2011 11. Modify drill(s) for submersible drilling if feasible/necessary and test – FFY 2012 – FFY 2013

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 electromechnical drills, the electrothermal drill has required little maintenance, yet has performed well recently in British Columbia and Alaska.

Relevant to Science Section(s): I.1, I.2	
Current Status:	IDDO has one electrothermal drill. It was repaired in 2010 for use on a project during the summer of 2010. A smaller diameter model was being developed by Western Washington University for use on Mt. Waddington.
Technical Issues:	Performance Data – Some data from two projects have been collected; these data needs 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 – The electrothermal drill was designed and built by PICO and AutoCad drawings probably exist but are out-of-date; they need to be updated and entered into the document control 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).
Plans:	1. Develop procedure for preparing drills for issue – FFY 2011 2. Analyze drill performance data and establish a performance baseline if possible; define data collection procedure – FFY 2010 and continuing 3. Ascertain availability of replacement parts – FFY 2010 4. Complete operating and maintenance instructions and enter into database – FFY 2011 5. Complete/update drawings and enter into database – FFY 2011 6. Perform general maintenance and repairs – ongoing and as needed 7. Manufacture second system – FFY 2011

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 rock and silt. The system includes cutters with replaceable carbide inserts for drilling in rocky/silty 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/rock conditions. The drill produces 76-mm (3-inch) diameter cores 0.4 meter long. It was tested and used to collect scientific samples in Beacon Valley in the 2006-2007 Antarctic field season and again, after repair and modification, in the 2008-2009 and 2009-2010 field seasons



Relevant to Science Section(s): I.5, I.6	
Current Status:	The Koci Drill is the only drill of its type and is under continued development. The 2008-2009 test of the drill resulted in damage more extensive than anticipated and also indicated additional modifications that needed to be made; repairs and modifications were made during FFY 2009. The drill was used successfully in Beacon Valley during the 2009-2010 field season.
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 limit options.
Plans:	1. There are no plans at present to repair or continue development of the Koci Drill. Substantial improvement in drill performance in very rocky ice would require a different type of drill and it is unclear whether the development of a new drill is warranted. The Koci Drill could be repaired and modestly modified if a project in which the PIs were content with the type of performance of which the Koci Drill is capable eventuated.

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.

Relevant to Science Section(s): II.3, II.4	
Current Status:	One portable hot water drill is currently assigned to a project for the next three years and a second if necessary could be assembled from existing components; 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 – 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. Prepare second drill for use – FFY 2011 or earlier if necessary 2. Complete operating and maintenance procedures – FFY 2010 – FFY 2011 3. Develop procedure for preparing drills for issue – FFY 2011 4. Complete documentation and enter into database – FFY 2011 – FFY 2012 5. Standardize and modularize drill – probably not earlier than FFY 2012 and when funding is available

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 air flow to overcome air losses in the firn. In the first season the RAM drill consistently reached over 60 meters of depth and in one trial it drilled 90 meters (the depth being limited by the length of the hose). It was used for the second and third times in West Antarctica during the 2008-2009 and 2009-2010 field seasons. During the latter season it routinely attained depths of 90 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 no 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. Once those methods are discovered, this drill, outfitted with a standard hose reel and level wind, could likely be a valuable tool for rapidly accessing depths that would be limited only by hole closure -- hundreds of meters or even a thousand, depending on englacial temperatures. This drilling technology shows promise as a partial solution to the community request for Rapid Access Drilling.

Relevant to Science Section(s): II.2, II.3, II.4	
Current Status:	The RAM drill was successfully used in West Antarctica for seismic work again during the 2009-2010 field season after being repaired during the summer of 2009. The drill system experienced greater than anticipated damage during the traverse to the project site during the 2008-2009 field season. While the drill was repaired to allow work during the 2009-2010 season, additional modifications are needed to make the drill more reliable on longer traverses. IDDO will not repair the drill following the 2009-2010 season. However, the Askaryan Radio Array (ARA) project, funded by OPP, will borrow the drill for the 2010-2011 through 2012-2013 Antarctic field seasons to test methods of producing holes for radio antennae at South Pole and will make necessary repairs and, potentially, modifications needed to drill to 200 meters depth. Inasmuch as both ARA and IDPO-IDDO have an interest in determining methods to allow deeper drilling with the RAM Drill, IDPO-IDDO will contribute ideas for testing of the drill.
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 medium 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, the number/size of compressors needed. The hose reel presents logistical problems and should be replaced before use on any seismic traverses.
Plans:	1. Lend drill to ARA project for testing of system at South Pole - 2010-2011 and possibly 2011-2012 and 2012-2013 2. Evaluate results of ARA tests and determine testing and modifications needed – no earlier than FFY 2012 3. If necessary, perform study with the aid of appropriate research scientists to better understand and quantify air losses in firn – FFY 2012 at earliest 4. Make needed modifications, including new hose reel and modifications to compressors to improve traversing – no earlier than FFY 2013

DISC Drill

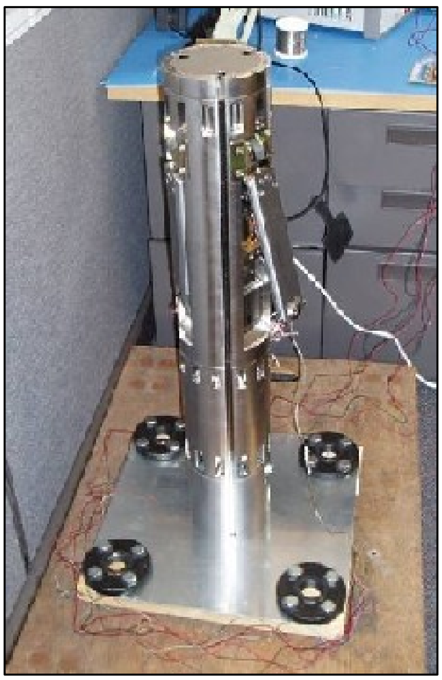
The Deep Ice Sheet Coring (DISC) Drill developed by Ice Coring and Drilling Services (ICDS) under contract with the US National Science Foundation is a tilting-tower electromechanical drill designed to take 122 mm diameter ice cores to depths of 4000m with variable core lengths up to a design limit of 4 meters. The drill is currently able to recover cores up to 3.5 meters. 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 drill-fluid handling. This drill system is currently at WAIS Divide in Antarctica and has been used there for three production seasons. The drilled depth as of February, 2010, is 2564 meters.

The DISC Drill system design is a dynamic process, and it is going through continuous modifications and enhancements. The major modifications undertaken during FFY2009 in preparation for the 2009-10 field season were: new winch level wind control, motor hand off operation, and level wind tracking; new thin kerf core barrels and cutter head for the sonde (to reduce the volume of chips produced, thereby allowing for longer cores to be collected before the chip chambers are full); improved sonde and winch software. IDDO also performed all necessary maintenance and repair of the system's components. The modifications were successfully tested at WAIS Divide during the 2009-2010 field season.

The Long Range Science Plan 2010-2020 indicates that, after the work with the DISC Drill at WAIS Divide, including the replicate coring, if relevant, 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 downhole temperatures at least as cold as -50C and perhaps as cold as -58C. During FFY 2011 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)

Relevant to Science Section(s): I.3, I.4, I.5, I.7,	
Current Status:	The DISC Drill is being used for the WAIS Divide drilling and modifications and repairs are made to the drill between the 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 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. Fabricate additional thin kerf barrels – FFY 2010 2. Analyze cutter head failure and design and fabricate two new cutter heads – FFY 2010

	3. Complete design and fabrication of motor controller modules – FFY 2010 4. Continue use of thin kerf core barrel for remainder of main borehole – 2010-2011 field season. 5. Make modifications and general repairs identified during field seasons (e.g., control upgrades) – during and after field seasons 6. Determine components that need to be replaced to make the drill ready for East Antarctica and test components as necessary – FFY 2011 and FFY 2012 7. Modify DISC Drill for use at high, cold sites in East Antarctica – FFY 2013



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.

In FY2009, IDDO worked on the conceptual design of a non-drill-specific, passive replicate coring system. The FY2010 IDDO budget includes funding of the engineering design of a replicate coring system for the DISC Drill. As of April, 2010, the engineering design was advanced to the point where the testing of major subsystems was being conducted. The design 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.

Implementation of replicate coring at WAIS Divide in any given year is dependent not only on development of the technology needed for replicate coring, but also on the timing of completion of drilling of the main hole, the lifetime of the surface support infrastructure at the drill site, and the availability of logistics for transport to and from the site. As of this writing, discussions continue between IDPO, the WAIS Divide Executive committee, the research community, IDDO, and the logistic support organization on trade-offs (between science, engineering, logistics, time, and funding) on a number of issues. These issues include an updated assessment of the surface infrastructure and logistics, and scheduling of borehole logging vis a vis replicate coring.

The Science Plan also envisions the need for a replicate coring drill that can be used in smaller diameter holes – either existing or yet to be drilled with drills such as the Hans Tausen Drill. Based on the concept developed for a replicate coring system in FFY 2009 and the experience gained with the design of the DISC replicate coring system and the planned replicate coring at WAIS Divide during the 2011-12 austral field season, IDDO – pending the input on the science requirements for the drill from the science community – could incorporate replicate coring capabilities into the new intermediate depth drill it plans to acquire or build (see Intermediate Drill below.)

Relevant to Science Section(s): I.2, I.3, I.4, I.5, I.7	
Current Status:	Replicate coring capability does not exist. IDDO completed the conceptual design of a replicate drilling system that can be adapted to any deep or intermediate-depth drill and is in the process of designing the replicate coring system for the DISC Drill. It is anticipated that the system will be used to recover replicate cores beginning in the 2011-2012 field season at WAIS Divide.
Technical Issues:	Performance Data – There are no performance data on replicate coring. Documentation – All work on the replicate coring system will be documented according to SSEC standards and archived in the control document database. Other – While the Russians have successfully deviated their boreholes around stuck drills, no one has developed a system specifically to replicate ice cores at any depth within an existing borehole.
Plans:	1. Complete design of replicate coring system for use with DISC Drill – FFY 2010 2. Fabricate replicate coring system for DISC Drill – FFY 2011 3. Complete design of light weight replicate coring system – FFY 2012 4. Complete fabrication of light weight replicate coring system – 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 a number of 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 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 and the US science community decided to abandon its use at the start of the WAIS Divide Ice Core Project (WDICP). Dimethyl siloxane oils have been suggested as a possible ice drilling fluid but have not been used; the oils have a disadvantage in that they are difficult to remove from surfaces. ESTISOL-COASOL is being used in the NEEM Project in Greenland; the mixture has a disadvantage in that ESTISOL, a coconut extract, could compromise biological experiments because it is a nutrient. Both the dimethyl siloxane oils and the ESTISOL-COASOL mixture have the major disadvantage of being much more viscous at low temperatures than either n-butyl acetate or the Isopar K-HCFC 141b mixture used at WAIS Divide.

In 2003, ICDS undertook a study to identify a drilling fluid for WDICP (Drilling Fluid Observations and Recommendations for U.S. Polar Program, WAISCORES Drilling Project, ICDS, 2003). A number of laboratory experiments were undertaken, but the study was not completed before the decision was made to use the Isopar K-HCFC 141b mixture. With the drilling of both deep and intermediate depth holes in very cold regions in East Antarctica a likely prospect in the future, IDDO will resume ICDS' study of drill fluids. The FFY2011 budget will include funding for a search for an appropriate drilling fluid.

Relevant to Science Section(s): II.3, II.4, II.5, II.7	
Current Status:	While there are currently available drilling fluids, none are ideal for drilling at very cold sites. ICDS had started a study to identify a new drilling fluid for use at WAIS Divide, but the study was not completed when the decision was made to use a two-part fluid essentially the same as that being used at the time by EPICA and the Danes. Several papers have been published about potential new fluids and the Europeans are reportedly beginning a new study for a suitable drilling fluid.
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. Explore possibility of collaborating with Europeans on the development of a drill fluid – FFY 2010 – FFY 2011 2. Conduct drill fluid study – FFY 2011 – FFY 2012

Intermediate Drill

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 depths of 1000 - 1500 meters. IDDO does not at present have an intermediate-depth drill, but the need exists. In addition, the IDPO-SAB , in their Long Range Science Plan, puts substantial emphasis on obtaining "agile" drills. These are needed to retrieve ice cores in situations that are not conducive to significant on-site infrastructure or heavy logistics. Applying this concept to replicate sampling, IDDO anticipates a charge to develop a relatively light-weight replicate coring system, based on the intermediate-depth drill, but with extended depth capabilities to reach to the bottom of existing deep boreholes.

Relevant to Science Section(s): I.2, I.3	
Current Status:	IDDO does not currently have an intermediate depth coring drill in inventory. The Danish Hans Tausen Drill is a successful design of an intermediate drill that the NZ program is in the process of modifying for its needs. Requirements for the US version of an intermediate drill need to be defined.
Technical Issues:	Science requirements for the US intermediate drill will be developed by early FFY 2011. Discussions within the IDPO-SAB indicate that the drill must require minimal logistical support and that the capability for replicate coring should be designed into the drill. The Hans Tausen and the NZ drills do not presently have the electronics necessary for the instrumentation and control needed for the replicate coring system developed by IDDO and a version of the Hans Tausen Drill would need to be modified to include the necessary electronics. Because a drill fluid is needed to keep the borehole open, suitable fluids must be identified for the drilling locations anticipated.
Plans:	1. Complete feasibility study (including definition of science requirements) for the acquisition of intermediate drill including a cost estimate – April 2010 and start design - late FFY 2011. Anticipated work load with the existing staff would limit work to the definition of the science requirements and subsequently to the development of the engineering requirements (general engineering specifications) and perhaps the beginnings of a conceptual design. 2. Complete design and begin fabrication of drill – FFY 2012 3. Complete fabrication; field test; prepare drill for 2013-14 scientific drilling – FFY 2013 4. Deploy drill to Antarctica-- FFY 2014

Hot Water Fast-Access Drills

The polar research community currently has two types of ice drills that can penetrate at least a kilometer of ice: ice-coring drills and hot-water drills. These drilling systems are suited for recovering high quality cores and for gaining quick access without cores to depths of up to 3 km, respectively.

Many research projects do not require continuous ice core; for these, hot-water drills can provide rapid access to depths of 1.0–1.5 kilometers. Although scalable to greater depths, the power requirements are such that hot water drills can be very large for depths beyond 1.5 km. The Enhanced Hot Water Drill in use at South Pole to support the IceCube project is capable of reaching 3 km and weighs several hundred tons. Obviously, the portability of such a drill is limited. Hot water drilling systems in the 1-km-depth class are relatively portable if the bore diameter is kept small, and can be used to drill an array of holes in a single season. These drills can be excellent tools for investigating conditions at the base of a relatively thin ice sheet, providing short-term access to the oceanographic environment beneath an ice shelf, and installing sensors frozen-in at depth (e.g. stress sensors, vertical strain gauges, photomultiplier tubes). Using special tooling, hot water drill systems can acquire short ice cores as well as sub-glacial sediment samples.

Although the fact that hot water holes generally freeze shut in 2–3 days can be an advantage for some experiments, it is usually a distinct disadvantage: periodic recalibration is impossible because sensors are at present unrecoverable (the ANDRILL project has plans for developing a recovery system for cables frozen into the ice), and moving expensive instruments to acquire data at different depths or for use in other boreholes is similarly problematic. Deploying geophysical experiments requiring repeated logging over several years in a semi-permanent access hole (e.g. borehole tilt) is impractical in hot-water boreholes. In addition, the large thermal overprint imposed by hot water drilling obviates bore-paleothermometry measurements at the precision required for paleoclimate reconstruction. The somewhat irregular diameter intrinsic to hot water boreholes makes any measurements requiring a regular, cylindrical bore-wall impossible.

ICDS (IDDO's predecessor) received the Kamb-Engelhardt Hot water drill from Caltech in 2002. It was built for rapid boring to over 1000 meters and has been used with a special cool-water coring head to recover short cores. The Kamb-Engelhardt drill has been idle since its last deployment (~1998); despite 'mothballing', it would require extensive and critical inspection and probably a great deal of repair and upgrading to be fit for mission-critical Antarctic service.

A scientific field project (WISSARD - Whillans Ice Stream Subglacial Access Research Drilling) planned for the 2012-2013 and 2013-2014 Antarctic field seasons requires the use of a hot water drill approximately three times more powerful than the Kamb-Engelhardt system, and approaching 85% of the power rating of the IceCube drilling system. New requirements imposed by the Antarctic Treaty for biological-and chemical-contaminant-free drilling to access sub-glacial lacustrine and marine environments essentially mean that neither the Kamb-Engelhardt system, nor the components of the Enhanced Hot Water (IceCube) drill system, are suitable. Moreover, the WISSARD system must be traversable to and from the field site, must withstand saltwater contact, and must be capable of running with a small crew via modern control systems consistent with health and safety.

The current proposed foundation of the WISSARD hot-water drilling system rests in a commercial-type Thermal Fluids Heater. This 10-million-BTU/hr heater will heat a fluid ("oil") in a closed loop using an on-ratio modulating burner, firing JP-8 fuel oil under autonomous programmable logic control. A shell-and-tube heat exchanger draws the heat required for the drilling water from the thermal fluid and will employ saltwater-resisting alloys. Circulation of the thermal fluid ("oil") through the shell-and-tube heat exchanger can be controlled to an extremely fine degree via a separate, autonomous programmable-logic controller, yielding highly stable output water temperatures regardless of input flow rate and input temperature (within design limits, of course).

Because the proposed WISSARD project, "LISSARD" (Lake and Ice Stream Sub-glacial Access Research Drilling) will enter a sub-glacial lake protected under the terms of the Antarctic Treaty, ICDS and the science team will collaborate to develop the necessary processes for purifying the drilling water and cleaning the borehole instruments. IDDO will complete fabrication of any equipment necessary for cleaning in time to have it, along with a portion of the hot water drill itself, available for testing during the 2011-2012 field-testing season near McMurdo (probably Windless Bight).

Relevant to Science Section(s): II.1, II.5, II.6, II.7, III.1, III.2, III.3, III.4	
Current Status:	The Kamb-Engelhardt Hot water drill is in IDDO inventory, but it is impractical to field for the WISSARD project, as it would require extensive inspection, repair, and modification. The WISSARD Project requires a drill approximately 3 times the power rating of the KE drill. The KE drill and the IceCube systems are not adaptable to the current requirements of traversing, saltwater exposure, cleanliness, and modern automation / safeties. While the WISSARD hot water drill is being developed outside of the IDPO and IDDO cooperative agreements, the drill equipment will be placed into the IDDO inventory on completion of the project.
Technical Issues:	Performance History – Hot-water-drilling thermodynamics and heat transfer are well known; it is possible to predict the performance of a particular drill configuration by calculation. IDDO would institute a process for logging all relevant data in operating the drills, including any ice or sediment coring. Documentation – A description of the KE drill and its operation exists. Documentation of the new WISSARD hot water drill will comply with SSEC's controlled-document procedures. Other – The degree of cleanliness of the drill water and the instruments prior to deployment is not well defined, and there is a need to define requirements both from an environmental-stewardship standpoint and from a scientific integrity standpoint. Development of the definitions will come from close collaboration with the science project team.
Plans SEE FOOTNOTE	1. Complete procurement and testing of water filtration module – FFY 2010. 2. Complete design and fabrication of the hot water drill itself – FFY 2011 3. Test complete hot water drill module near McMurdo –2011-2012 Antarctic field season 4. Repair and modify equipment as necessary – FFY 2012 Wisconsin summer 5. Return to McMurdo, fit any modifications, traverse across Ross Ice Shelf, complete drilling for LISSARD and GBASE - 2012-2013 field season 6. Complete drilling for RAGES and GBASE – 2013-2014 field season

N.B. As of July 12, 2010, All ICDS/IDDO work on the WISSARD project was terminated as the projected costs were higher than the science project Principal Investigators were willing or able to pay.

Mechanical Rapid Access Drills

As a by-product of their operation, ice-coring drills (ICDs) produce semi-permanent boreholes in which various properties of the surrounding ice can be determined using geophysical logging methods; the uniform hole diameter produced by ICDs facilitates these measurements. Geophysical measurements in ICD holes currently include borehole 'tilt' and closure, high-precision temperature, sonic velocity, and optical scattering/absorption. These logs provide valuable information about how horizontal velocities, shear-strain rates, temperature, ice fabric, dust concentration, and entrained sediment vary from the bed to the surface of an ice sheet. This information can in turn be used to improve the understanding of ice rheology, regional ice dynamics, ice-bed interactions, climate history, and geothermal flux. Short bedrock cores have also been obtained with ICDs, although ICDs were not really designed with this in mind. But ICDs are both slow and expensive to operate, limiting the ability to obtain these types of glaciological, geologic, and paleoclimatic data to just a few sites in the polar regions. In addition, the sites selected for

ICD holes are rarely the best locations for geologic and many other studies. Finally, conditions in and around ICD boreholes are not ideal for some types of geophysical measurements such as high precision temperature.

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 of 1–4 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 ICD that can acquire continuous cores of usable diameter at greater depths and of sampling sub-ice 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.

The Long Range Science Plan cites many scientific objectives that would benefit from a rapid-access mechanical drill, but they can generally be divided into two categories -- those that require only a hole and those that aim at the recovery of ice from a large depth. The former, which involve either logging of the hole or the emplacement of instruments within the hole or the subglacial bed, can be attained with a hole of small diameter – 3" is commonly cited. For the latter, on the other hand, especially since the targeted ice will be of special interest, a core diameter of at least 4" probably will be called for, which in turn means a hole diameter of at least 5". That scales up the amount of ice that needs to be removed, hence the power consumed, the amount of fluid needed to fill the hole, and other factors that scale as the volume of the hole, by a factor of approximately three. The logistical implications of this scaling are at least qualitatively apparent.

IDDO will evaluate the feasibility, cost, and logistic burden of rapid access concepts, keeping the dichotomy just outlined in mind. Also related in the general concept of rapid access are the capabilities of large diameter hot-water drilling, described separately under Hot Water Rapid Access Drills, above.

Relevant to Science Section(s): I.3, I.4, I.5, I.6, I.7, II.1, II.2, II.3, II.4, II.5, III.1, III.3	
Current Status:	No mechanical rapid access drills capable of drilling to 1-4 km exist. Clow and Koci (*Memoirs National Institute Polar Research, Special Issue* **56**, 5-37, 2002) have suggested the use of coiled tubing technology, which has been used in the petroleum industry, to drill rapidly to these depths.
Technical Issues:	A drill fluid is needed to keep borehole from closing. Logistical burden for even small diameter holes is non-trivial and access for coring may be prohibitive. Minimum core diameter usable by interested scientists should be explored.
Plans:	1. Define science requirements for feasibility study – FFY 2012 2. Evaluation of feasibility and conceptual design of mechanical rapid access drills – FFY 2012 – FFY 2013 3. Design mechanical rapid access drills as appropriate – FFY 2014 – FFY 2015 4. Fabricate mechanical rapid access drill – FFY 2015 - 2016 5. Test mechanical rapid access drill – FFY 2017

Logging Winches

The IDPO-SAB recommended that IDDO purchase or develop two logging winches and make them available for use by the science community. The first, and higher priority, is a 1-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.

Relevant to Science Section(s): I.2, I.3, I.5, II.2, II.3, II.4, II.5	
Current Status:	The logging community has prepared a white paper that can be used for guidance in procuring the logging winches. IDDO personnel have also done preliminary searches for the availability of logging winches. 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.
Technical Issues:	Performance History – None; users such as Gary Clow and Ryan Bay should be contacted 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. Other – Experience of Gary Clow and IceCube indicates that off-the-shelf winches require a substantial amount of modification to be useful and reliable for logging ice boreholes. The suitability of the IceCube logging winch for deep boreholes needs to be determined; e.g., is the depth capability sufficient.
Plans:	1. Develop science requirements for logging winches – FFY 2011 2. Purchase and modify if necessary a 1-km winch – FFY 2011 3. Acquire and refurbish/modify, if necessary, IceCube logging winch – FFY 2011

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 or two 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 five year period are discussed.

WAIS Divide Ice Core Project

Relevant to Science Sections: I.3

IDDO will continue drilling with the DISC Drill system at WAIS Divide in Antarctica during the 2010-2011 season.

FFY 2010 – During the 2009-2010 field season (FFY 2010) drilling continued to a depth of 2564 meters. The thin kerf version of the lower sections of the drill allowed the drill to retrieve approximately 3.3 meters of core per run, a 0.6 m/run improvement over previous seasons. Two other methods for increasing core length were tried but were not successful – the installation of a two stage pump and the installation of a chip “distribution tube”; both of these were aimed at improving chip distribution and packing in the screen sections.

FFY 2011 – The 2010-11 field season may be especially challenging as the drilling enters "warm" ice. Full advantage will be taken of the accumulated experience of previous drilling in warm ice, including the important advice and aid of the IDDO Technical Advisory Board. Drilling will have the aim of reaching a depth of about 3330 meters. If that depth is attained, the drilling of the main hole will be complete; if there is time remaining in the season, borehole logging can commence if desired. If the target depth is not reached the situation will have to be re-evaluated; IDDO currently expects 2010-2011 to be the last season of drilling in the main hole.

FFY 2012 – IDDO will support the logging activities in the WAIS Divide hole during the 2011-2012 field season. If the core drilling goes as scheduled, borehole logging will commence at the start of the field season. IDDO expects to be asked by some logging PIs to help with their activities and stands ready to do so as requested and approved by OPP and IDPO. Depending on time available, preparations for replicate coring and initial replicate coring operations could be undertaken.

FFY 2013 – During the 2012-2013 field season, IDDO expects to complete replicate coring in the WAIS Divide hole. Preliminary plans called for replicating approximately 12.5% of the core (~415 meters). Inasmuch as the replicate coring system has not yet been fabricated, the details of the replicate coring objectives – whether, for example, sampling is to be done at selected intervals down the entire length of the hole, or only in the deepest part of the hole -- are not yet decided. IDDO will also assist with additional borehole logging if requested and approved.

Shallow Coring and Drilling Projects

Relevant to Science Sections: I.1 and other PI-generated objectives

Support of NSF shallow coring and drilling (400m 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 FFY10. The involvement of IDDO with a project will begin in the proposal phase, in which IDDO and IDPO will work with the PI to understand the objectives of the project and to determine how best to support it. Once NSF has notified IDPO that it will support a project, IDDO and IDPO will decide on the appropriate means of funding of IDDO's participation. 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 PI in planning for IDDO support and in the special preparation of equipment, if necessary. At the end of each project, the PI will be asked to provide feedback on the successes attained and difficulties encountered in the course of the work.

FFY 2010 – IDDO supported five shallow coring and drilling projects in the field during the 2009-2010 Antarctic field season and will support several others in Greenland. In addition, IDDO provides support to investigators by issuing hand augers to them directly or through the logistics contractors.

FFY 2011 – IDDO will continue to support science projects approved by OPP.

FFY 2012 – IDDO will continue to support science projects approved by OPP.

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

Preserving Ice Core Boreholes for Logging Science

Relevant to Science Sections: I.2, I.3, I.4, II.2, II.3, II.4

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 bore holes 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 2011 .--. IDDO will undertake evaluation of the situation in the GISP2 borehole and, as staff time permits, begin to develop a plan for the restoration of unimpeded access to it

FFY 2012 -- IDDO will complete the plan for the GISP2 borehole, and implement it during the summer field season at Summit

FFY 2013 -- 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

Relevant to Science Sections: II.1, II.5, II.6, II.7, III.1, III.2, III.3, III.4

As mentioned in the section Hot Water Rapid Access Drills, IDDO (under the rubric of ICDS) is supporting the WISSARD project, which requires clean access into a subglacial lake on Whillans Ice Stream in Antarctica and also large-diameter access to the grounding zone. SEE FOOTNOTE PAGE 19

FFY 2011 -- Design and fabrication of the hot water access drill will proceed**.**

FFY 2012 – IDDO and the science team plan to test the hot water drill, the drill water/downhole instrument cleaning system, and the science instruments at a location near McMurdo Station during the 2011-2012 field season.

FFY 2013 – During the 2012-2013 Antarctic field season, IDDO plans to support the access into the subglacial lake by providing the drill equipment and the core of the drill crew.

FFY 2014 – IDDO plans to support the access to the grounding zone in several locations during the 2013-2014 field season. It would provide the hot water rapid access drill and related equipment as well as the core of the drill crew.

FUNDING

The target budget levels provided by NSF of IDDO under the cooperative agreement are

FFY 2009	$2,505,919
FFY 2010	2,600,916
FFY 2011	2,696,840
FFY 2012	2,799,545
FFY 2013	2,900,124

Total	**$13,503,346**

In addition, the development of the Blue Ice Drill is being funded by a University of California – San Diego science project supported by OPP via the American Recovery and Reinvestment Act (ARRA). Total funding for the development of the drill is expected to be $348,800 with the bulk of it being spent in FFY 2010.

Funding of the development of the Hot Water Rapid Access Drill for the WISSARD project and the related field support for the science projects described above is expected through grants to a consortium of several universities receiving ARRA funds through OPP. The total amount of funding to IDDO through subcontracts with the consortium universities is expected to be in the neighborhood of $3,400,000. Most of that amount would be spent in FFY 2010 and FFY 2011 for development of the drill system.

Concepts for equipment development such as the intermediate depth drill, the mechanical rapid access drill, etc. have not been developed and, consequently, their costs have not been defined. As the concepts and cost estimates are finalized the target budgets for IDDO will be quantified and the means of funding developed in collaboration with IDPO.

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	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 concept development	Mechanical rapid access drill drilling	Intermediate drill development	Intermediate drill drilling	RAM Drill modifications	RAM Drill drilling	Drill fluid development
SCIENCE	**Climate**																					
	200 yr arrays								x	x												
	2 k 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 yrs			x	x	x	x	x						x	x	x	x					x
	Pre-Quaternary													x	x	x	x					
	Climate transitions			x	x	x	x							x	x	x	x					x
	Ice Flow																					
	Bed conditions											x	x			x	x					
	Geothermal flux							x			x					x	x			x	x	
	Flow properties							x			x					x	x					
	Internal layering							x			x					x	x					
	Paleo-elevations							x				x	x			x	x					
	Sub-ice shelf mass balance											x	x									
	Grounding zone processes											x	x									
	Sub-Ice Environment																					
	Subglacial lake sediments											x	x			x	x					
	Sub-ice ecosystem											x	x			x	x					
	Geologic history											x	x			x	x					
	Subglacial hydrology											x	x			x	x					

Appendix 2
Long Range Project Schedule

X - Planned ; Y – Available for Use			PROJECTS																				
CALENDAR YEAR	**QUARTER**	**Number of 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**	**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 concept development**	**Mechanical rapid access drill drilling**	**Intermediate drill development**	**Intermediate drill drilling**	**RAM Drill modifications**	**RAM Drill drilling**	**Drill fluid development**
2010	2	7	x		x					x	x		x		x				x				
	3	7	x		x					x	x		x		x				x				
	4	8		x	x					x	x		x			x			x				x
2011	1	9		x	x					x	x	x	x			x			x				x
	2	9	x		x				x	x	x	x	x						x				x
	3	9	x		x				x	x	x	x	x						x				x
	4	9				x			x	x	x	x	x			x			x				x
2012	1	9				x			x	x	x	x	x			x			x				x
	2	9			x		x			x	x	x	x				x		x				x
	3	**9**			x		x			x	x	x	x				x		x				x
	4	8				x			x	x	x	x		x			x		x				
2013	1	8				x			x	x	x	x		x			x		x				
	2	9					x			x	x	x	x				x		x		x		
	3	9					x			x	x	x	x				x		x		x		
	4	8					x			x	x	y		x			x			x		y	
2014	1	8					x			x	x	y		x			x			x		y	
	2	5					x			x	x							x	x				
	3	**5**					x			x	x							x	x				
	4	5					x			x	x							x		x			
2015	1	5					x			x	x							x		x			
	2	4					x			x	x							x					
	3	4					x			x	x							x					
	4	5						y		x	x							x		x			
2016	1	5						y		x	x							x		x			
	2	3								x	x							x					
	3	3								x	x							x					
	4	4								x	x							x		x			
2017	1	4								x	x							x		x			
	2	3								x	x							x					
	3	3								x	x							x					
	4	3								x	x									x			
2018	1	3								x	x									x			

ACRONYMS

ARA: Askaryan Radio Array

ARRA: American Recovery and Reinvestment Act

BFC: Berg Field Center

BTU: British Thermal Unit

DISC: Deep Ice Sheet Coring

DRI: Desert Research Institute

DVD: Digital Video Disk

EPICA: European Project for Ice Coring in Antarctica

FFY: Federal Fiscal Year

GBASE: Geomicrobiology of Antarctic Subglacial Environments

HCFC: Hydrochlorofluorocarbon

ICD: Ice-coring Drill

ICDS: Ice Coring and Drilling Services

IDDO: Ice Drilling Design and Operations

IDPO: Ice Drilling Program Office

ITASE: International Trans-Antarctic Scientific Expedition

KE: Kamb-Engelhardt

LISSARD: Lake and Ice Stream Subglacial Access Research Drilling

NSF: National Science Foundation

OPP: Office of Polar Programs

PI: Principal Investigator

PICO: Polar Ice Coring Office

RPSC: Raytheon Polar Services Company

RAGES. Robotic Access to Grounding-zones for Exploration and Science

RAM: Rapid Air Movement

SAB: Science 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

WDICP: WAIS Divide Ice Core Project

WISSARD- Whillans Ice Stream Subglacial Access Research Drilling