DISC Drill vs. Foro 3000 Drill Analysis

October 2017

Jay Johnson
Engineering Project Manager
Ice Drilling Design and Operations
University of Wisconsin-Madison
jay.johnson@ssec.wisc.edu

Matthew Kippenhan
Project Manager
Science & Technical Project Services
Antarctic Support Contract
Matthew.Kippenhan.Contractor@usap.gov

Contents

Introduction

Motivated by science community priorities articulated in the U.S. Ice Drilling Program Long Range Science Plan, IDDO has undertaken a comparison of the existing Deep Ice Sheet Coring (DISC) Drill system and an extended depth version of the existing Intermediate Depth Drill (IDD) system. The technology investment priorities, as listed in the Long Range Science Plan, were stated as such:

- *Prepare a comparison of total cost estimates for drilling at Herc Dome with DISC versus IDD-Deep, by adding a 3-m or 4-m sonde to the IDD and for extending the IDD capability to 2,800 m.*
- *Develop a Conceptual Design for adapting the IDD for drilling to 2,800 m and for replicate coring with IDD using a whipstock.*

The following excerpt from the companion Ice Drilling Design and Operations Long Range Drilling Technology Plan, June 30, 2016, echoes the pursuit of this analysis.

Per discussions between IDPO, IDDO and community scientists, the next deep U.S. drilling project is planned for Hercules Dome. IDDO is currently working with community representatives on a DISC Drill vs. Intermediate Depth Drill-Deep (IDD-Deep) analysis, to help determine which system should be used for drilling at Hercules Dome. Prior to this deployment, which is not anticipated before 2019-2020, the DISC Drill would need to undergo some level of modifications and repairs. The list of DISC Drill sub-systems that require repairs and maintenance includes, but is not limited to, the gantry cranes, centrifuge, screen cleaning and fluid handling systems, winch, tower, sonde and numerous surface control system electrical and software redesigns and upgrades. Should the next drilling assignment be in East Antarctica, several key components of the drill will require additional modification/redesign in order to operate at down-hole temperatures at least as cold as -50 °C and perhaps as cold as -58 °C. If the IDD-Deep is chosen, IDDO will need to design, fabricate and test modifications to extend that system's capability from the current depth of approximately 1900 m to depths expected at Hercules Dome (2,800 m).

Since the writing of the 2016 Ice Drilling Design and Operations Long Range Drilling Technology Plan, the Intermediate Depth Drill-Deep (IDD-Deep) system has been renamed the Foro 3000 and will be referred to as such from here on. A conceptual design has been completed for the Foro 3000, which extends the existing IDD depth range to 3,000 m and core length capacity from 2 m to 3 m per run. A conceptual design to add replicate coring functionality to the Foro 3000 Drill is also currently being investigated.

Background

Both the DISC Drill and IDD are proven systems capable of delivering high quality ice cores. The DISC Drill, producing 122 mm diameter ice cores, delivers 55% more ice per unit length than the Foro 3000 Drill does with its 98 mm diameter ice core. The larger core diameter, combined with the original science requirements for drill data to be recorded at 10 times per second, low winch cable stretch, and high winching speeds, resulted in the DISC Drill having a much larger logistics burden then the Foro 3000 system with its more modest requirements. The DISC Drill was designed to recover ice cores up to 4 m long and to depths of 4,000 m and also features steerable replicate coring capability. It was very successfully deployed for the West Antarctic Ice Sheet (WAIS) Divide Ice Core project and was in service from 2007 through 2013. The drill system is now back at IDDO and will require maintenance and upgrades to be ready for deployment. The system is currently only capable of recovering 3.2 m long cores, which is limited by the cuttings storage capacity in the drill, but is believed to be capable of recovering full 4 m cores with some modifications. The IDD was designed to recover ice cores up to 2 m long and to depths of 1,650 m, although the winch drum will hold up to 1,900 m of cable. The IDD has also been successfully deployed on one project to date, the South Pole Ice (SPICE) Core project from 2014 – 2016. This drill system is also back at IDDO and is currently undergoing maintenance and upgrades. The proposed Foro 3000 enhancements would be required for drilling to 2,800 m.

DISC Drill System

The DISC Drill, which was under development from 2003 - 2006 and then deployed to West Antarctica from 2007 - 2013 to drill the 3,405 m deep ice core for the WAIS Divide ice coring project, is a cable-suspended electromechanical drill that creates a 163 mm diameter borehole and recovers 122 mm diameter ice cores up to 3.2 m long (Slawny and others, 2014). With modifications to the chip collection and possibly the pump sections, the drill should be capable of recovering 4 m long cores without increasing the overall length of the drill, which is 15.5 m. The drill is suspended on a 15.2 mm diameter cable that provides two electrical conductors for power and six optical fibers for communications. An electrically driven winch, with a 112 kW main drive and 4,400 m cable capacity, is capable of hoisting the drill out of the hole at speeds over 2 m/s. The winch, cable level wind, and tower base structure sit below floor level in a 31’ L x 12’ W x 6’ D recess. The drill tower, which tilts horizontal for servicing the drill and vertical for drilling, requires a 34’ L x 4’ W x 36’ D slot below the floor. A 89’ L x 30’ W x 26’ H structure (Figure 1) is required to house the drill and support systems, which includes the control room, barrel handling gantry crane, core transfer table, screen cleaning system, chip processing centrifuge, and drill fluid handling system (Figure 2). While a steel structure was used at WAIS Divide, use of a lighter weight tent structure may be possible at certain sites, depending on site conditions and accumulation rate.

Figure 1. Core processing arch (left half) and drill arch (right half) at WAIS Divide.

Figure 2. Inside view of the drill arch looking towards the core processing side.

An additional attached structure, with core storage basement, is required for processing and storing the ice cores. For the WAIS Divide project, the core processing arch was 84’ L x 30’ W x 16’ H (Figure 1 and Figure 3) and the basement under the core processing arch was 60’ L x 12’ W x 12’ D (Souney and others, 2014) (Figure 4).

Figure 3. Inside view of the core processing arch looking towards the drill side.

Figure 4. Core storage basement at WAIS Divide.

A dedicated 135 kW power feed is required for operation of the drill system. Fuel requirements for a 2,800 m deep project are estimated to be 22,400 – 26,000 gallons depending on whether the drill is configured for 4.0 m or 3.2 m long cores. It is estimated that 20,400 gallons (385 drums) of drilling fluid will also be required to maintain a pressure balanced borehole. A portable shop, called the MECC (Mobile Expandable Container Configuration), is an integral part of the drill system. It is outfitted with hand tools, machine tools, and electronics tools required to service and make field adjustments the drill system. The shop comes self-contained in a 20’ long expandable shipping container (Figure 5).

Figure 5. MECC shop

To maintain 24-hour per day drilling and core processing operations, a team of 17 people is required. This includes 9 dedicated drillers, 6 core handlers, one lead driller, and one lead scientist. The total shipping weight for deployment of the drill, core processing system, drill and core processing structures, shop, casing, drill fluid and fuel is estimated to be 479,500 lbs. for the 4 m system.

Active replicate coring capability is a very unique feature of the DISC Drill (Shturmakov and others, 2014). The replicate coring system is capable of creating a branch hole at any depth and at a specific orientation in the parent borehole, including on the uphill side of the main (parent) borehole. The DISC Drill is transformed from a traditional coring drill to a replicate coring drill by adding actuator sections above and below the instrument section, which make it possible to tilt and steer the drill in the borehole, and by fitting the drill with smaller diameter core and screen barrels (Figure 6). The replicate drill creates a 148 mm diameter hole and recovers 108 mm diameter cores up to 2 m in length. Further information about the replicate coring system can be found at http://www.icedrill.org/equipment/replicate-coring-system.shtml.

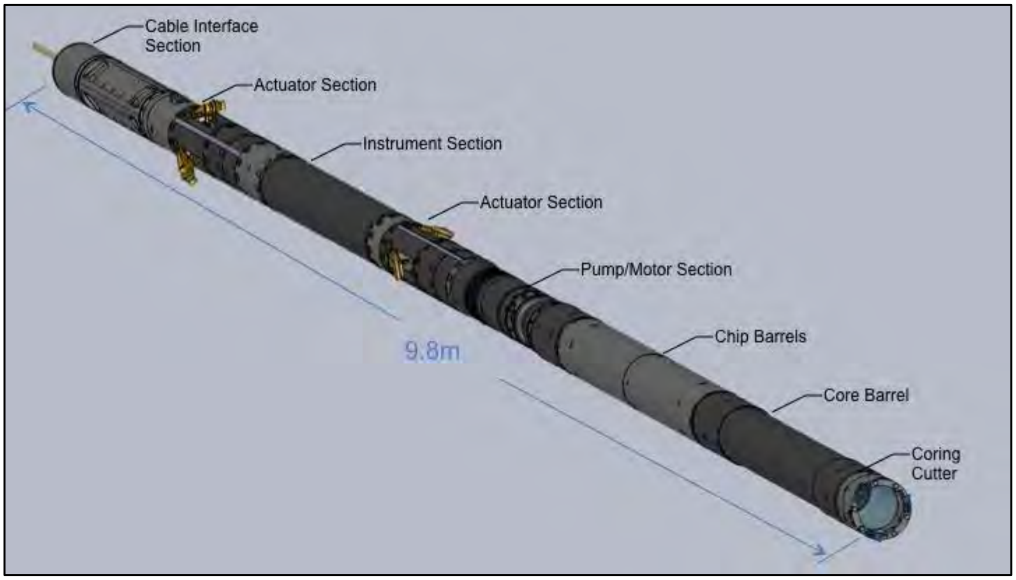

Figure 6. SOLIDWORKS rendering of the replicate coring sonde.

Foro 3000 System

The Foro 3000 system currently exists only in the concept phase. The base system, the IDD, is the next generation of the Danish Hans-Tausen Drill and Danish Deep Drill, which was under development at IDDO from 2012 – 2014. It was deployed to the South Pole for the SPICE Core project from 2014 – 2017 for the successful drilling of a 1,751 m deep ice core. The Foro 3000 concept outlines a series of reverse-compatible additions and modifications that would be made to the IDD system to extend the depth range to 3,000 m and core length to 3 m without enlarging the existing tent structure. The Foro 3000 Concept Overview document (Appendix A) describes the system in further detail. The main changes to the IDD system are a new larger winch with larger diameter cable, new tower base with longer tower, and longer core and chip barrels. The Foro 3000 drill is a cable suspended electromechanical drill that creates a 130 mm borehole and recovers 98 mm diameter ice cores up to 3 m long. The drill is suspended on a 7.2 mm diameter cable, which provides two electrical conductors for power and two conductors for communication. An electrically driven winch, with an 8.7 kW drive and 3,000 m cable capacity, is capable of line speeds up to 1.5 m/s. The drill tower, which tilts horizontal for servicing the drill and vertical for drilling, requires an 18’ L x 3’ W x 17’ D slot below the floor. The entire drilling and core processing system fits within the 64’ L x 16’ W x 11’ H tent structure (Figure 7). The floor space inside the tent is recessed 4.5’ below grade to minimize the tent height and reduce warming due to solar gain (Figure 8).

Figure 7. The IDD drill tent at SPICE Core, South Pole.

Figure 8. Inside the IDD drill tent. The core processing line is along the left-hand side.

For the SPICE Core project, a 15’ W x 24’ L underground trench, with wooden roof at grade level, was dug off one end of the drill tent for storage of brittle ice and packed ice core boxes waiting to be palletized (Figure 9). A larger trench will most likely be required for the Hercules Dome project to accommodate storage of the longer (3 m vs. 2 m) brittle ice cores. A simple electrically driven lift is used to hoist the full ice core boxes to the surface through a hatch in the core storage trench roof. Access to the trench was via a set of stairs inside the drill tent.

Figure 9. Core storage basement at SPICE Core, South Pole. Brittle ice is stored on the wood shelves. The ice core box lift is on the right.

A dedicated 35 kW power feed is required for operation of the Foro 3000 system. Fuel requirements for a 2,800 m deep project are estimated to be 7,500 gallons. It is estimated that 11,200 gallons of drilling fluid will also be required to maintain a pressure balanced borehole. A maintenance shop is also required to maintain the drill system. A dedicated shop does not currently exist since, for the SPICE core project, the machine shop in the South Pole Dark Sector was able to provide this support. The MECC shop built for use with the DISC drill could be used, as it already exists; however, due to the smaller size of the Foro 3000 Drill, a smaller and lighter shop is also an option to reduce the logistics burden. Three shop options are described in detail in the Foro 3000 Concept Overview (Appendix A). The smaller (half size) version of the MECC, the Bicon Shop, will be included for this analysis (Figure 10).

Figure 10. Bicon mobile shop container.

To maintain 24-hour per day drilling and core processing operations, a team of 11 people is required. This includes 6 dedicated drillers, 3 core processers, one lead driller and one lead scientist. The total shipping weight for deployment of the drill with tent, core processing system, shop, casing, drill fluid and fuel is estimated to be 182,800 lbs. for the 3 m system.

A replicate coring system does not currently exist for the Foro 3000 Drill. However, a conceptual design is in process for a passive system. The current thinking is to set a removable whipstock in the parent borehole, which will direct the drill out of the parent borehole at a shallow angle, to collect replicate cores as opposed to building an actively steerable drill (Figure 11). The whipstock would be set using installation tools fitted to the existing motor and anti-torque sections. Specialized tooling would be developed that works with the existing motor section to start the deviation. The drill would then be converted back to a standard coring drill to recover the replicate cores.

Figure 11. Whipstock operations used in the Oil and Gas Industry.

Drill System Comparison

The distinguishing features and major requirements for two configurations of both the DISC Drill and Foro 3000 Drill are summarized below in Table 1. The field camp size and number of camp support personnel required for either system would be very similar. The main differences are the DISC Drill requires larger generators and larger heavy equipment to handle the increased cargo size and weight. The DISC Drill system would also require additional traverse and LC-130 support due to the larger amount and weight of equipment, drilling fluid, fuel, and returning ice core volume. For the Hercules Dome site, a fabric tent structure is a suitable alternative to the metal building used for the WAIS Divide project and has been included in this analysis. The Foro 3000 system includes the tent used with the SPICE Core project, which weathered two South Pole winters and 2-1/2 summers without issue.

Drill System Parameter	DISC Drill		Foro 3000	
Core length (m)	3.2	4	2	3
Core diameter (mm)	122		98	
Replicate coring capability	Yes – active system		Passive system in development	
Time for setup/takedown (days)	71	71	28	24
Drilling days required to reach 2,800 m (days)	122	100	165	125
Number of seasons to reach 2,800 m [assuming 50 day field seasons]	3.9	3.4	3.9	3.1
Drill crew size (people)	10		7	
Core handlers/scientists (people)	7		4	
Drilling fluid required (drums) [53 gallons per drum]	385		210	
Power requirements at sea level (kW)	135		35	
Fuel requirements (gallons)	26,000	22,400	9,900	7,500
Core processing equipment (lbs.)	5,000		Included in cargo wt. & vol.	
Drill and core processing building	21,000lbs., 1,300 ft^3		Included in cargo wt. & vol.	
Core storage area (below -20° C)	Required		Required	
Drill volume (cubes) [Includes MECC for DISC and Bicon shop for Foro 3K]	8,600		2,900	
Drill weight (lbs.) [Includes MECC for DISC and Bicon shop for Foro 3K]	136,300		40,500	
Drill fluid weight (lbs.) [Assuming 423 lbs. per drum]	162,900		88,900	
Diesel fuel weight (lbs.)	184,900	159,300	70,400	53,400
Ice Core weight (lbs.) [Heavy only on the way out]	72,200		46,500	
Total weight (lbs.)	**582,300**	**556,700**	**246,300**	**229,300**

Table 1. Comparison of DISC Drill and Foro 3000 Drill system parameters for a 2,800 m deep project.

Field Camp

USAP Field Camp Planning Guidelines
Standard USAP guidelines and practices for field camps shall be applied to any drilling activities and, more specifically, the Hercules Dome field site for this analysis. A more detailed camp infrastructure and operations evaluation is required should the project continue to develop. At that time, the evaluation shall address the most current and best practices to better serve the project goals and field operations. This will also take into consideration the allocation and scheduling of key resources. In general, USAP guidelines and practices look to minimize the level of infrastructure necessary for safe, healthy working and living conditions. In addition, the camp will be designed for the efficient use of support labor, equipment operations and fuel usage to maximize the field season length and applied resources to minimize the annual costs.

An annual field camp would be required to support drilling activities at Hercules Dome. Due to the limited capacity of mobile support facilities at this time, it is recommended that a static field camp be established each season regardless the presence of mobile traverse facilities. Therefore, traverse facilities will only be used to support smaller field teams while traversing to and from locations and during transitional periods at camp.

The basis of design for a USAP field camp considers numerous factors during analysis. Specific to the Foro 3000/DISC Drill proposal, key areas include the following:

– Life / safety risks analysis

- Science activities and support requirements for drilling / core handling operations
- USAP field camp guidelines
- Geographical location and remoteness
- Expected field /weather conditions
- Elevation and altitude considerations
- Project duration
- Maximum and sustained camp populations
- 24 hour operations
- Fixed wing operations
- Traverse operations

Camp Population

One of the leading design factors is driven by the projected camp population, in particular, the number of science personnel, and any direct support teams. Camp population is calculated per person per day for the duration of main field science activities including the put-in and close-out periods each season. General USAP camp population thresholds are used to determine the appropriate staffing and medical care levels during final design phases.

Each drill system identifies dedicated drill and core handling staffing levels as listed below:
DISC – up to 17 people
Foro 3000 – up to 11 people

Camp and visiting trade support staffing levels vary depending on the complexity of annual activities and camp infrastructure levels including structures, equipment and environmental conditions. For this proposal, a key factor with staffing positions is supporting 24 hour operations for both drilling activities and aircraft operations, in particular, weather observations. The difference of 6 people per drill system may or may not factor much overall; however, significant spikes may and will be taken into consideration as seasonal plans are developed.

Projected camp staff for each drill system:
DISC – up to 6
Foro 3000 – up to 6

Projected total camp population (sustained level only):
DISC – 23 persons
Foro 3000 – 17 persons

Camp Structures

A minimalist approach shall be applied to the camp infrastructure design to achieve less cargo being moved and handled in the field, less setup/takedown time required, and overall field simplicity. However, for a moderate sized field population and duration on the plateau, basic amenities are needed to ensure safe and healthy living conditions. Basic laundry facilities will be included due to the use of drill fluids and extended field seasons. The following list of structures are recommended and a full examination of the camp design and layout would be conducted prior to obligating any resources:

- Galley / dining tent – approximately 12 sections
- Communications / medical tent – approximately 6 sections

- Berthing - individual tents
- Outhouses (an environmental review as to best practices for human waste releases to be conducted)
- Emergency shower shack / ablution facility
- Field mechanic / material storage container*
- Driller clothing changing / drying area
- Drill maintenance tent / container with DNF storage*
- Drill tent and core storage

* Identifies dedicated sled mounted structure if traverse supported, otherwise an alternative structure will be used

Structure Heat
Current USAP field camps utilize electric and diesel fuel heating systems. Both types offer benefits and conveniences at various times of camp operations (i.e. no electricity available). For Hercules Dome, the primary heating source in structures would likely be diesel fuel heaters with electric heating sources used as supplemental sources or located in key structures. The average diesel fuel consumption for a standard heating unit is approximately 6 - 10 gallons per day depending on structure size and weather conditions. Fuel burning stoves also provide additional snow melting capabilities with use of a stock pot. Since electric heaters place additional demand on power generation, the extent of use is calculated as the camp's total load and available output. At this time, heating structures with generator waste heat loops may be cost prohibitive, unavailable (typically with smaller generator systems) or too complex for the application. All heating options shall be addressed further as a detailed evaluation is conducted.

Snow Melter
With many variations between electric, waste heat, and direct fuel heated snow melters, the current USAP field system utilizes an electric heat coil system with stainless steel melt tub that is manually loaded with snow. This simple system is used in many USAP camps that have adequate generator power supply for 24 hour melting capabilities. The melt tub is often plumbed directly to a manually pressurized or electric motor pressurized water filter/storage system that is integrated into the galley tent or hard paneled structure. Daily consumption varies between camps mainly due to population levels and amenities. For general planning, a deep field, twenty person camp as described in this assessment, could expect consumption rates in excess of 150 gallons per day. Supplemental snow melting also occurs with the use of a metal stock pot mounted on fuel burning heat stoves. Total camp water consumption rates and snow melter options shall be addressed further as a detailed evaluation is conducted.

Power and Fuel Requirements
Generator power will be sized to accommodate the drill system, camp, and ancillary equipment requirements. It will consist of a primary and secondary generator and power distribution setup. Generator performance is subject to several input factors including operating elevation, temperature, distribution sizing and distances and fuel type. Generator performance is de-rated above 6,000 feet at 4% per 1,000 feet. Some efficiency is regained due to colder operating temperatures, however, significant fluctuations in barometric pressure and use of AN-8 fuel will also negatively affect generator performance.

A typical USAP field camp consumes between 15-60 kW of electricity for daily operations. Galley equipment, heavy equipment plug-in heaters, and electric heat/appliances are typically the higher power demands. A load assessment will be required to properly size the generators, cables, and power distribution system and to estimate fuel consumption.

Fuel Delivery and Storage

Bulk fuel delivered to the field site via LC-130 will be stored in standard USAP deep field 10,000 gallon bladders and secondary containment berms. A standard USAP fuel pumping system shall provide fueling capabilities to aircraft, equipment, and mobile tanks or drums. Fuel delivered in steel drums is typically used for fuel caching in other areas in support of aircraft operations.

If traverse resources are available, bulk fuel may be delivered by over-snow traverse in multiple 3,000 gallon fuel bladders without secondary containment. Traverse-provided fuel will be transferred to the same deep field 10,000 gallon bladders and secondary containment unless consumed during the operational period. Currently, there is no approved “over winter” fuel storage for the mobile traverse fuel bladders, therefore, any fuel to be staged over winter requires storage in an approved container (ie. steel drum) or a standard deep field stationary fuel bladder and secondary containment berm.

Annual resupply of fuel will be accomplished with LC-130 or science traverse support depending on resource availably. To facilitate the camp opening of the following season, adequate operational fuel supply should be conserved following camp closing.

Camp Equipment

Dedicated camp equipment will be assessed to support typical deep field camp operations such as aircraft, camp and drilling cargo handling, skiway grooming, snow maintenance, winter berming, and snow gathering.

Camp equipment will be standardized to meet all current USAP Fleet guidelines and field maintained for the duration of the project. Aircraft put-in equipment for skiway grooming (i.e. Tucker SnoCat) may be utilized based on the final project schedule. Skiway maintenance shall require a standard deep field grooming implement that is towed.

Camp equipment activities to be supported:

- Camp construction / deconstruction
- Snow maintenance and excavation
- Snow gathering for melters
- Cargo handling arrival and fork lift movements
- Skiway grooming
- Aircraft pallet staging and loading
- Cargo handling for return to McM

High Altitude Considerations

The Hercules Dome field site is located at an elevation of approximately 8,200 feet (2,500 meters), which borders the typical “high altitude” demarcation zone. With abrupt fluctuations in atmospheric pressure, personnel working in this plateau environment and elevation will be exposed to high altitude related physiological health risks, especially when first arriving. USAP camps at higher elevations are subject to standard USAP high altitude protocols. This includes high altitude medical procedures and individuals successfully completing an acclimatization period of several days under the observation of a qualified medical provider.

Several approaches have been successful at minimizing altitude-related illnesses, and a likely arrangement for this site would be to provide the initial put-in field team the opportunity to acclimatize at a designed altitude facility prior to arriving at Hercules Dome. Upon successfully showing acclimatization progress, the team would be moved on to the Hercules Dome site and begin the camp put-in process. Due to the proximity of Hercules Dome and logistic conveniences, South Pole Station would be the recommended acclimatization location.

Once basic shelter and heat is established by this initial put-in crew, the acclimatization protocol may shift to an on-site approach to expedite personnel transportation and minimize impacts to other stations. A full assessment of all medical risks would be conducted by the program's medical team as further camp planning develops.

Logistics

Science Traverse Overview

The current science traverse fleet was first commissioned in 2009 in support of a deep field subglacial lake project, and since then, has been dedicated annually in support of similar type field projects to areas around the Ross Ice Shelf. Due to the size and complexity of the projects, the science traverse required additional tractor support from the McMurdo based operations traverse (SPoT) to supplement the overall lack of capacity to operate autonomously. Additional required towing support was due in part to excessive weight of fuel and container loads including field camp structures, towing dynamics (tractor, sled and surface conditions) and driving distances. These field projects were further supplemented with aircraft support to move passengers, samples and critical cargo when needed. Upon completion of field operations, the camp was deconstructed and all sleds and cargo were returned to McMurdo Station and staged. Traverse tractors and mechanical equipment were inspected, serviced and winterized.

Traverse performance is greatly impacted by numerous challenges of operating in the changing polar plateau surface conditions, with colder temperatures and higher elevations than experienced in the Ross Ice Shelf region. Future endeavors to increase traverse efficiency across all aspects is being tested and applied where possible. Gains in efficiencies with new designs and materials may be available that may greatly enhance total capacity for this project. Similarities in previous traverse operations will apply to any future, deep field camp support.

For this analysis, an assumption is made that the project would be limited to the science traverse fleet assets only and no supplemental traverse support shall be available. To maximize the current science traverse capabilities, reducing the total weight of the drill system (DISC vs. Foro 3000) and minimizing the field structures and materials will yield the greatest benefits.

The science traverse fleet utilizes various sled systems to fit the varying requirements to tow large, heavy cargo loads, specialized ISO containers, and support structures with a small traverse team. Traverse fuel (AN-8) is calculated to support the outbound and return driving operations of the tractors and generators while in the field, and is deducted from the total load plan.

Recent traverse performance has shown tractors capable of towing up to eight fuel bladders on high-molecular-weight (HMW) polyethylene sheets or 3-5 cargo sleds / container sleds. Shuttling smaller loads is required when ascending the Leverett Glacier due to the terrain's incline or if adverse snow conditions are encountered. A detailed load plan based on projected fuel consumption and load carrying capacity is required.

The Science traverse fleet consists of the following major assets:
- Qty. 2: Caterpillar MT865C Challenger tractors with rear mounted FASSI 110 knuckle boom crane
- Qty. 1: Caterpillar MT865C Challenger tractor with rear mounted wire winch
- Qty. 2: Case Quadtrac tractor with front blade
- Qty. 1: Caterpillar 297C multi terrain tracked loader with various implements (48" forks, snow buckets, blade, backhoe)
- Qty. 5: 8' x 20' sleds
- Various 8' x 20'-40' ISO2 and ISO3 container sleds
- Qty. TBD: 3,000 gallon AN-8 fuel bladder on HMW sheet

Route

The likely route to Hercules Dome from McMurdo Station will utilize the existing SPoT trail across the Ross Ice Shelf, up the Leverett Glacier to a convenient point on the plateau approaching the South Pole Station. This entire section of traverse route is maintained and annually inspected by ground penetrating radar (GPR) prior to all traverse activities. At a selected junction, the science traverse will depart the SPoT route and begin a "safe" new route to the selected Hercules Dome field site. This new route would require a pre-season "route finding" analysis to determine a "safe" path. The traverse team will then GPR the entire trail to ground proof a safe passage as they proceed to the field site. Once at the drill site, the team will then GPR a "safe" area for the camp and aircraft support to operate within. GPR capabilities typically require an additional tractor to conduct the surveys ahead of the main traverse fleet.

Time Required

Based on historical traverse data, a conservative traverse duration is as follows:
- McM to the top of the Leverett Glacier: 20 days
- Top of the Leverett Glacier to plateau turn off point: 5 days
- Turn off point to Hercules Dome field site: 7 days
- Estimated total from McM to Hercules Dome: 32 days

Notes:
- An "empty" traverse return duration from Hercules Dome to McMurdo Station is typically 7+ days shorter, assuming fair conditions are encountered
- A "loaded" traverse return duration from Hercules Dome to McMurdo Station is typically the same as outbound, assuming fair conditions are encountered
- This analysis assumes traverse support would be utilized for the initial put-in and take out efforts only, with no resupply provided during the middle seasons.

Opening period:
- Site GPR, skiway grooming, camp structures, cargo handling – completed approx. 7 days after arrival
- Drill setup and operations to occur following camp start and grantee arrival

Closeout period:
- Drill system and facilities – 2-3 days (during camp closeout)
- Winter berms, take down of camp structures, winterization of equipment and materials – 7 days

Aircraft support
No historical or specific data for fixed wing operations to/from Hercules Dome were available for this analysis. The USAP has recently operated aircraft in areas near Hercules Dome, such as the Ohio Range, which is approximately 50 nautical miles away and roughly grid SSW. Some information related to the Ohio Range has been considered in this section, including previous input from flight crews and field planning for the general area. A more detailed analysis for flight operations is recommended.

Hercules Dome is approximately 750 nautical miles (NM) from McMurdo Station and is within direct range of a LC-130, Basler and twin otter. However, significant constraints to fuel capabilities, allowable cabin load (ACL) and refueling range apply to the Basler and twin otter. As skiway conditions improve, LC-130 landing weights increase, allowing more ACL to be used for cargo, fuel delivery and passengers. Further analysis for LC-130 operations is required to more accurately target maximum ACLs. Overall, twin otter and Basler are heavily constrained on operations out of McMurdo due primarily to the flying distance and flight time to Hercules Dome. These smaller airframes would likely be better utilized focusing on specialty missions, such as shuttling high priority cargo from other LC-130 landing sites or fuel caching, since they rely heavily on en route refueling support between locations.

LC-130 estimates:
- Flight time between MCM & Hercules Dome – approximately 2.8 hours (one way with no wind adjustment)
- Planning expectation is for significant increases in ACL once annual skiway conditions are established and improved
- Conservative ACL estimates are provided below based on minimal skiway conditions and general flight parameters used for calculations
- ACL “lower” end estimates (based on non-improved skiway conditions such as season opening/early missions):
    - ACL without refueling en route: ~1000-5000 lbs. (dependent on landing weight and landing surface)
    - ACL with refueling at another location en route (e.g. Camp 20 or SDM): ~8100 lbs.
- ACL “higher” end estimates (based on improved skiway conditions after grooming and hardening):
    - NYANG to provide projected ACL for an improved skiway operation
    - Expected to be up to 15,000 lbs.

Basler estimates:
- Flight time between MCM and Hercules Dome - approximately 5 hours (one way with no wind adjustment)
- Roundtrip capability between McM and Hercules Dome is extremely limited
  - ACL estimate for direct flight to Hercules Dome is approximately 340lbs.
  - ACL estimate for direct flight to Hercules Dome with refuel at site increases ACL only by several hundred pounds
  - ACL estimates with multiple refueling points en route increases ACL to ~5,000 lbs.
- 1500 miles is the maximum distance for a single crew day

Twin Otter estimates:

- Flight time between MCM and Hercules Dome - approximately 5.25 hours (one way with no wind adjustment)
- Return flights cannot be direct if route originated at/returns to MCM. Twin Otter crews must Remain Over Night (RON) at Hercules Dome or at another camp en route.
- Two refueling spots are necessary between MCM & Hercules Dome
  - ACL estimate with multiple refueling points en route is between approximately 695 – 1025 lbs.

Based on the above calculations, utilizing airlift for this project is best suited for passengers, high priority cargo, retro cargo and fuel resupply due to the performance limitations and range of Hercules Dome. A significant increase in aircraft support is required if an over-snow traverse is not available for the majority of transportation of camp and drill cargo to and from the field during the first and final seasons of the project (Figure 12). The effects an over-snow traverse would have on the required number of LC-130 flights is further detailed in Table 2 - 7.

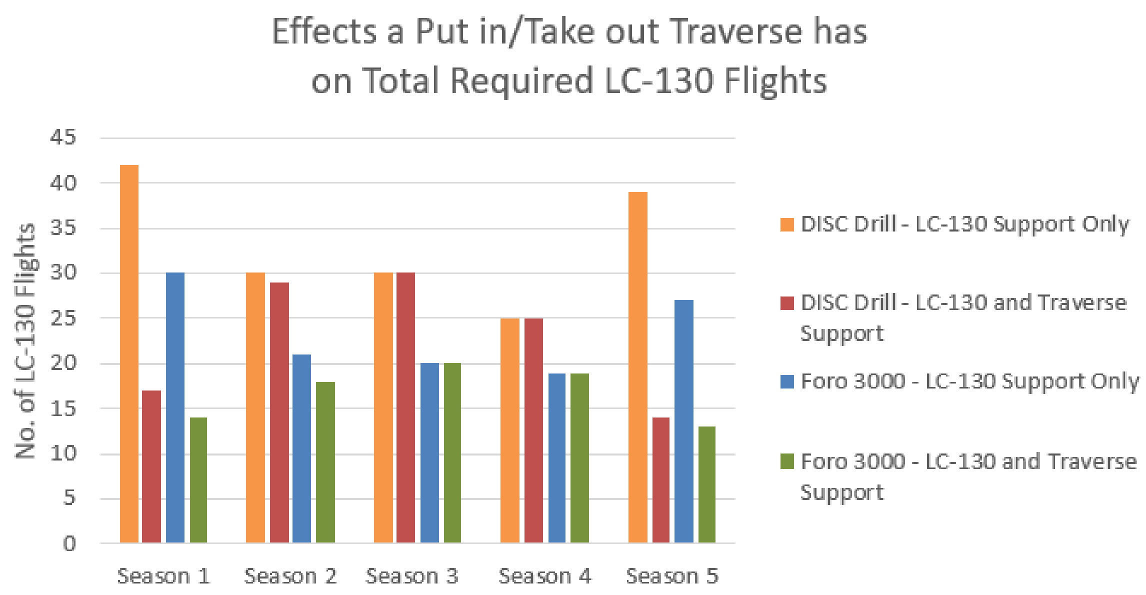

Figure 12. Summary by season of the number of LC-130 flights required with and without a put in/take out traverse.

	Estimated Total LC-130 Flights for Project Duration	
Drill system	**LC-130 support only**	**LC-130 support with Traverse**
DISC Drill – 4 m core*	166	115**
Foro 3000 Drill*	117	84**

*Does not include any KBA fixed wing support

**Total missions may change based on final traverse configuration and load plan

Table 2. Estimated total LC-130 missions for project duration

	Estimated Number of LC-130 Flights for Project Duration Camp infrastructure, pax and resupply ONLY	
Drill system	**LC-130 support only**	**LC-130 support with Traverse put in/take out**
DISC Drill – 4 m core	55	37
Foro 3000 Drill	55	37

Table 3. Estimated total LC-130 flights for camp support only

	Minimum Estimated Number of LC-130 Flights for Put-in & Takeout of Drill Systems	
Drill system	**LC – 130 support only**	**LC-130 support with Traverse put in/take out**
DISC Drill – 4 m core	14 in / 14 out	0
Foro 3000 Drill	5 in / 5 out	0

Table 4. Effect an over-snow traverse has on aircraft support

	Estimated Number of LC-130 Flights for Put-in of Drill Fluid	
Drill system	**LC – 130 support only**	**LC-130 support with Traverse put in**
DISC Drill – 4 m core	11*	8 or less pallets depending on traverse configuration**
Foro 3000 Drill	6*	3 or less pallets depending on traverse configuration**

*Based on 12 drums per AF pallet @ 15,000 lbs. ACL
**Based on 12 drums per AF pallet @ 15,000 lbs. ACL & available space/towing capacity after drill systems is loaded

Table 5. Estimated number of LC-130 pallets for put-in of drill fluid

	Estimated Number of LC-130 Flights for Put-in of Ice Core Boxes	
Drill system	**LC – 130 support only**	**LC-130 support with Traverse put in**
DISC Drill – 4 m core	6*	4*
Foro 3000 Drill	4*	2*

*Based on 32 core boxes per AF pallet and 4 AF pallets per flight

Table 6. Estimated number of LC-130 flights for put-in of ice core boxes

	Estimated LC-130 Flights for Fuel	
Drill system	**Annual flights**	**Total flights for project**
DISC Drill – 4 m core + CAMP*	Up to 14 per season	66
Foro 3000 Drill + CAMP*	Up to 8 per season	42

*Based on 15,000 lbs. ACL per fuel delivery

Table 7. Estimated number of LC-130 flights for fuel

Ice Core Storage and Handling

Assuming a total of 3,000 meters of ice are drilled over the duration of the project (2,800 m depth with 200 m of replicate core), the following number of ice core boxes and AF pallets will be generated (Table 8).

Drill System	Cores per Box	Total # of Boxes	Total # of AF Pallets
DISC Drill	4	750	24
Foro 3000	6	500	16

Table 8. Number of core boxes and AF pallets of ice generated for each drill system

Ice core storage in the field shall be accomplished by incorporating a storage trench or similar space with the drill system tent similar to the SPICE Core project at South Pole Station (Figure 9). The space will be designed to accommodate the required annual sample storage volume at the ambient firn temperature, thus reducing an active cooling requirement. In addition, storage design and access will integrate safe handling and ease of movement features for both inbound storage and outbound shipping phases. Mechanical assistance with moving ice core tubes, boxes or pallets into or out of the storage trench will be discussed as project plans develop further.

Adequate AF pallets and Tie Down Equipment (TDE) must be coordinated and staged at camp each season. TDE often reduces ACL by 10%+ due to its material weights. This includes insulated pallet blankets to minimize the impacts of air and ground transportation temperatures changes. The core handling crew will coordinate all ice core shipment requirements with camp management and McMurdo Fixed Wing management. Upon notification of an aircraft departure, the core handlers will work jointly with camp staff to pack and build up to 32 ISC type insulated boxes onto an AF pallet and secure them for shipment. The sample pallets will be loaded into the LC-130 using a forklift or the aircraft winch system, depending on available equipment at camp. All LC-130 return trips with ice core samples shall be designated a “cold deck” flight to McMurdo and may include a grantee escort.

Ice core samples arriving by LC-130 from the field will be moved to a refrigerated facility at McMurdo Station until the arrival of the annual resupply vessel. Samples will be loaded onto the resupply vessel in a dedicated SafeCore or similar type refrigerated container and maintained at a temperature of -20 C or colder during the return trip to Port Hueneme (PTH), California. After receiving the inbound refrigerated containers, PTH personnel will coordinate the delivery of the containers to the National Ice Core Laboratory (NICL) via over road trucks.

Drilling Fluid Transport and Storage

Significant quantities of drilling fluid are required for both proposed drill systems. As with previous drilling projects needing larger quantities of drilling fluid, individual drums, typically 10-12 per AF pallet, are shipped in multiple LC-130 Hercules missions to ensure adequate supply is on hand as drilling progresses. Camp operations provide drums to the drill team as needed throughout the field season. Empty drums are then returned to McMurdo as hazardous waste products. A winter over snow berm is established for any drums stored onsite between seasons.

Fluid suppliers also offer shipment of their products in an IBC tote, typically holding 275 gallons each. Shipment and storage using IBC totes is more efficient space-wise than drums and reduces the handling of multiple drums; however, some risks are present, inherent to plastic containers versus metal containers.

Another storage option that has not been utilized in the USAP is transporting bulk drilling fluid in 3,000 gallon traverse bladders. Although the bladder supplier has acknowledged Estisol 140 and ISOPAR K as compatible fluids, several issues remain with bulk shipment of fluid to McMurdo, which has not been investigated fully. There is also a need to transfer the fluid to stationary bladders for long-term storage at the field site. As with bulk fuel, traverse bladders are not used for over winter storage.

Key areas of the DISC Drill system that require an increased level of support over the Foro 3000 system:

- Cargo weight to move in/out of field – 3.4 x heavier
- Additional equipment and material handling on site
- Longer drill setup and takedown duration and trade support
- Winch weight – requires larger forklift
- Drilling fluid – 1.8 x more
- Power requirement - 3.8 x larger
- Fuel consumption - 3 x higher
- Core samples - 1.6 x more volume and weight
- Additional fixed wing annual missions – Fuel and drilling fluid resupply and cold deck missions

Key similarities or minor differences in level of support between drill systems:

- Camp staffing and structures
- Camp setup and closeout duration and trade support
- Camp power requirements
- Camp heavy equipment for general operations
- Camp fuel consumption

Project Duration

The first season of the project would focus on traversing all equipment from McMurdo Station to the site and setting up camp and the drill system. With the shorter setup time for the Foro 3000 system, drilling operations would also begin. Going with either the 4 m version of the DISC Drill or 3 m version of the Foro 3000 Drill makes it possible to drill to 2,800 m deep over the next 3 seasons. A fifth season would likely be required to conduct replicate coring of 200 m of high interest ice, packing the drill system and camp, and traversing the camp and drill equipment back to McMurdo Station. The proposed project timeline for the 4 m configuration of the DISC Drill and 3 m configuration of the Foro 3000 Drill are shown in Figure 13 and Figure 14 respectively.

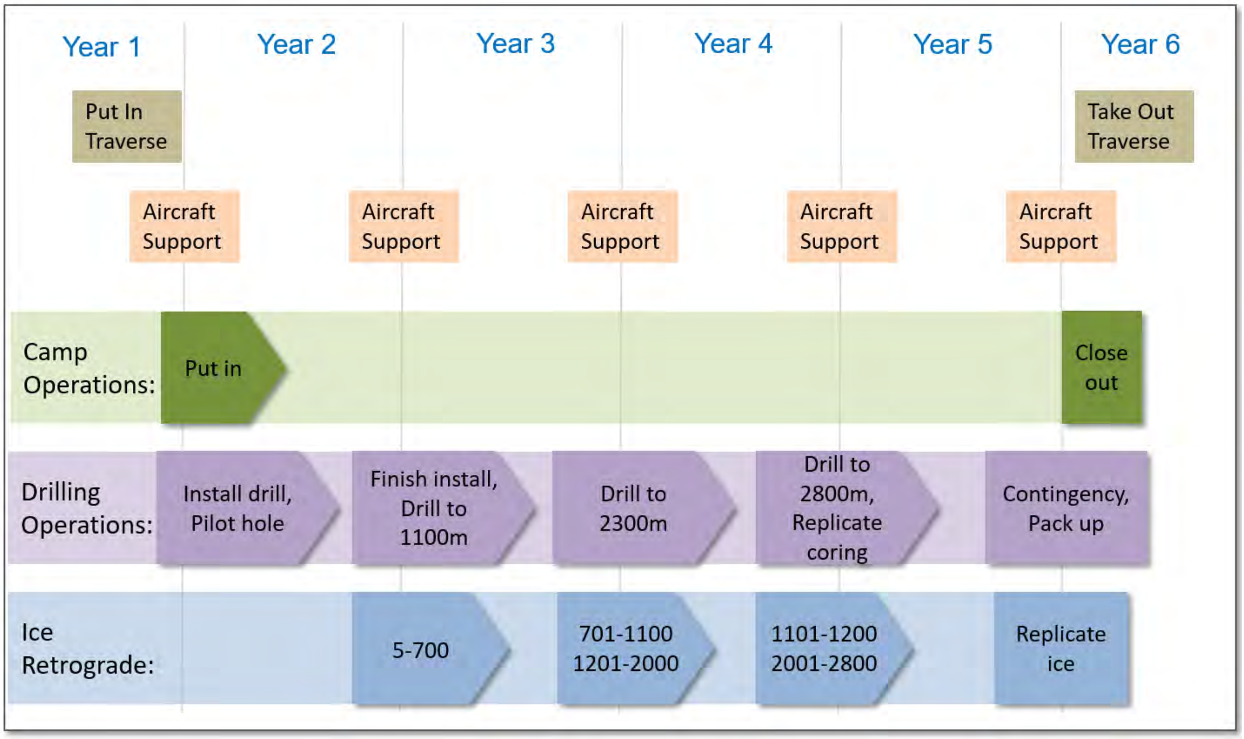

Figure 13. DISC Drill project timeline – 4 m core

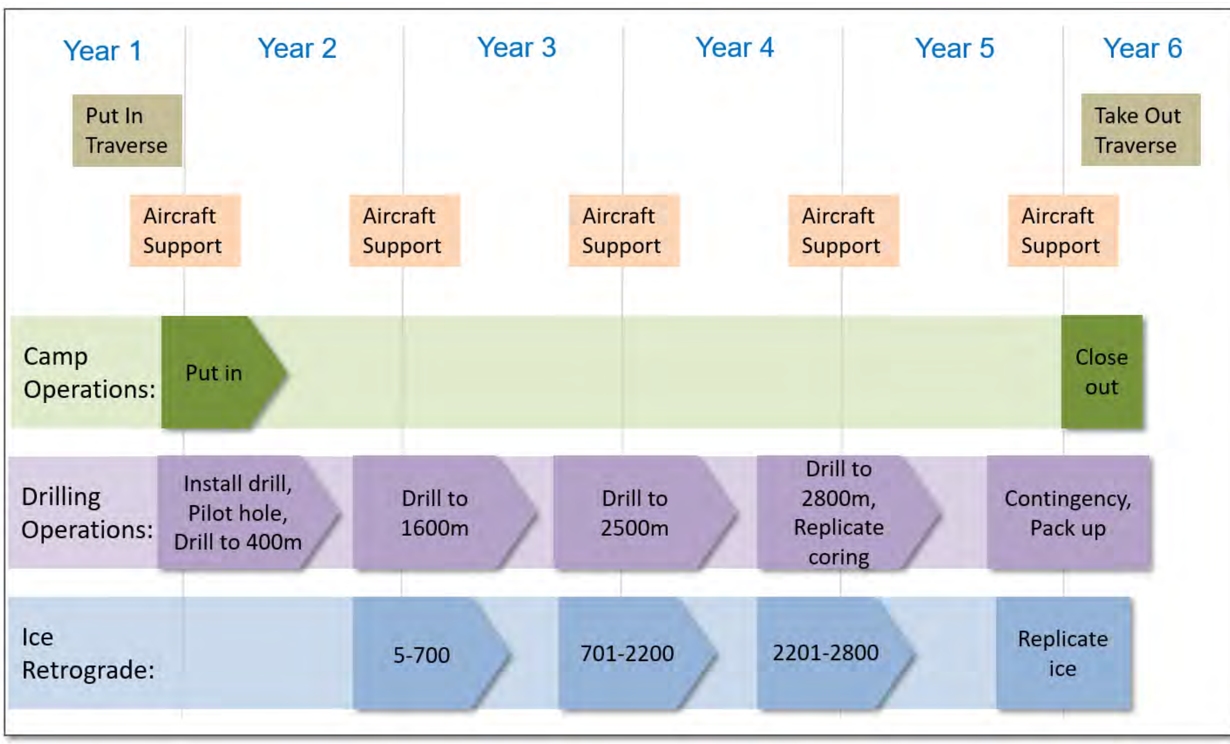

Figure 14. Foro 3000 project timeline – 3 m core

Cost Estimate

The cost for readying the 4 m DISC Drill system for deployment is expected to be approximately $835,000. This includes upgrading aging electronics and components, upgrades for recovering 4 m long cores, system maintenance, a core processing system and tent structure for the drill and core processing systems.

The cost to extend the depth and core capacity of the IDD (transforming it into the Foro 3000 system) and for the Bicon shop is expected to be approximately $1,040,000. Development of the replicate coring system would be in addition to this amount. Both cost estimates include all IDDO labor, equipment, materials and indirect costs.

The provided logistic assessments are based on previous field camps and support requirements. The assessment for resources is of Rough Order of Magnitude (ROM) level only. A more detailed resource loaded schedule and cost estimate would include a more comprehensive assessment of available inventories, traverse route and capabilities, traverse load plan, aircraft operations and general field logistics.

At this ROM level, the outlined DISC/Foro 3000 drill camp would be classified as a <u>MEDIUM</u> sized USAP field camp due to the number of field participants and complexity of supporting drilling and fixed wing operations. Recent USAP field camps such as the CReSIS, RAID AFT and Pirrit Hills traverse/drill camp were considered similar in scope and cost for this assessment, however project durations are not equivalent. Assuming a reasonable inventory level of infrastructure items were available, including all Science Traverse assets, the project costs would largely consist of annual labor, transportation and general materials costs. Investment in any additional camp equipment, generators, and structures was not considered and would require additional funding. Same as any specific science materials such as drill fluid and ice core boxes. Support by a Science Traverse put-in and take out would increase the direct labor costs to the project WBS due to the effort and team associated with traverse support. In addition, project costs would vary greatly for McMurdo sustainable labor costs (not included in direct project budgets) in support of additional LC-130 missions and associated cargo handling if no traverse support was provided.

Conclusion

IDPO, with direction from its Science Advisory Board and the Ice Core Working Group (ICWG), has identified Hercules Dome in West Antarctica as the likely next site for a U.S. deep ice coring project. Both the DISC Drill and Foro 3000 Drill systems are possible candidates and are capable of recovering high quality ice cores to the estimated depth of 2,800 m at this site. From a logistics and support view, the Foro 3000 Drill system has a more conservative demand on resources than the DISC Drill. However, the DISC Drill system offers 55% larger ice samples and a proven active replicate coring system. These benefits need to be considered and weighed against the additional logistic and funding requirements to determine which system is the right choice.

Under the current USAP operating climate, the drill system and camp would be most efficiently deployed to the site and retrograded back to McMurdo Station using an overland tractor traverse. Since the WAIS Divide project and through the SPot and other science traverses, traverse technology and expertise has developed greatly, making it an efficient and cost effective means to transport large amounts of equipment long distances. Fixed wing aircraft would be focused on seasonal demands of moving people, resupplying fuel, smaller cargo missions, and transporting ice core samples back to McMurdo Station.

A seasonal camp, comprised of mostly tent type structures and operated by a staff of 6 people, can support the 11 – 17 drillers and science personnel required to maintain 24-hour drilling and core processing operations. A diesel generator in the 150 – 200 kW range with the DISC Drill, or 50 – 100 kW range for the Foro 3000 Drill will provide the electrical needs for both the drill and camp. The drill tent will stay up for the duration of the project, while the camp structures will be taken down at the end of each season and stored on berms, along with the tractors.

The entire duration of the project is expected to be 5 seasons using either the DISC Drill with 4 m core or Foro 3000 Drill with 3 m core. During the first season, all equipment will be traversed to the site and the camp and drill system will be installed. Drilling the main borehole will take place the second through fourth seasons. Replicate coring, packing both the drill and camp, and traversing all equipment back to McMurdo Station will round out the fifth and final season.

IDDO and ASC look forward to continued collaboration, discussions, and planning with the science community for a potential drilling project at Hercules Dome. Through open sharing of ideas and discussions, we strive to identify the best logistic, drilling, and camp solutions that will result in a fundable project.

References

Slawny KR and seven others (2014) Production drilling at WAIS Divide. Ann Glaciol., 55(68), (doi: 10.3189/2014AoG68A018)

Shturmakov AJ and two others (2014) DISC drill and replicate coring system: a new era in deep ice drilling engineering. Ann Glaciol., 55(68), (doi: 10.3189/2014AoG68A017)

Souney JM and 15 others (2014) Core handling and processing for the WAIS Divide ice-core project. Ann. Glaciol., 55(68), (doi: 10.3189/2014AoG68A011)

Appendix A

IDDO Foro 3000 Drill Concept Overview.