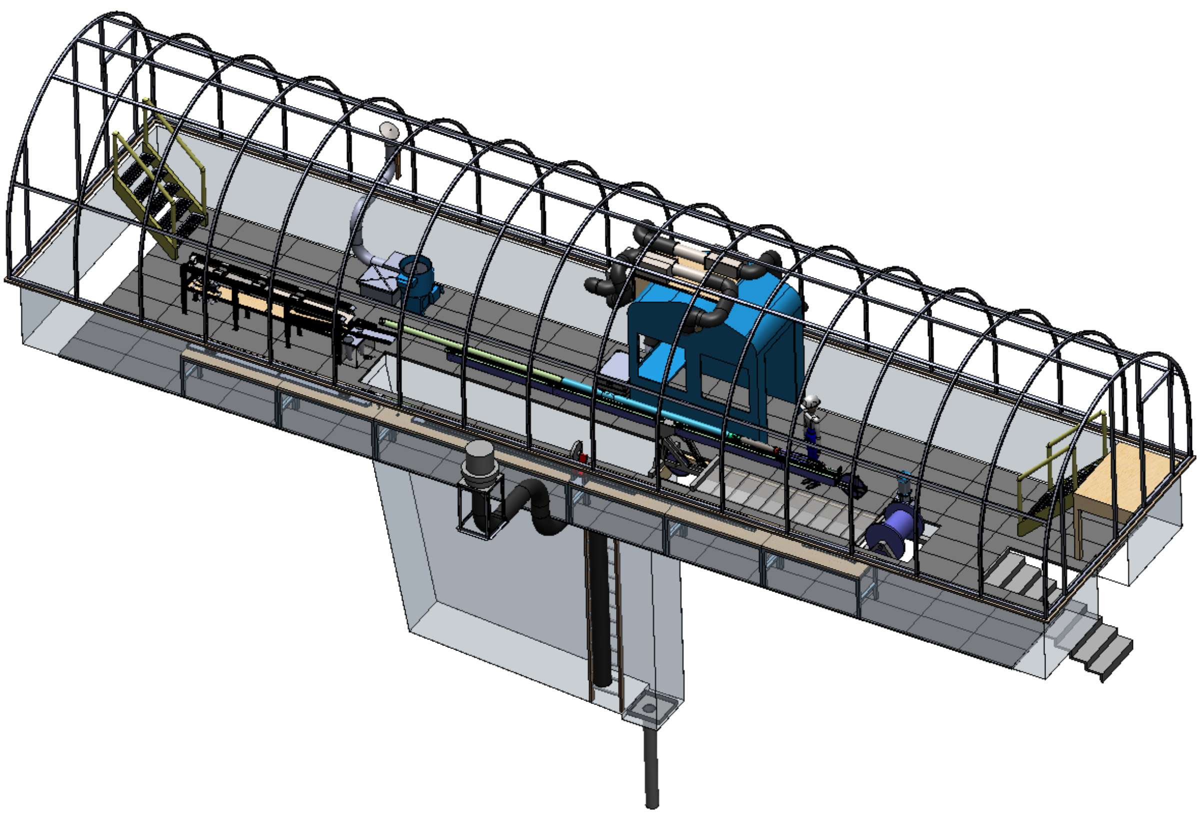
IDDO Foro 3000 Drill

Concept Overview

Revision 5/17/17



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INTRODUCTION and REQUIREMENTS

The following excerpt is one of the recommended science goals from the U.S. Ice Drilling Program Long Range Science Plan 2016-2026.

A climate record from the last interglacial period (the Eemian, ~130k to 110k years ago) is key to predicting the response of glaciers and ice sheets to future warming. The search for sites from which to extract Eemian ice in Greenland, both by coring and through horizontal sampling of blue ice ablation zones, should continue. Eemian ice was recovered from the Camp Century core in the 1960's, and an effort to retrieve an intermediate depth ice core from this region is in the planning stages. In Antarctica, extracting a record from Eemian ice is especially important for helping constrain climate and glacial histories of the West Antarctic Ice Sheet during the last interglacial, and is the primary motivation for planned deep drilling at Hercules Dome. Hercules Dome is the highest-priority next deep ice core for the US community. Understanding evidence from Antarctica, where the climate record may have evidence of changes in the WAIS during the last interglacial period are important, since WAIS history for this time is poorly known and because large sea level rise due to current climate warming may occur if the WAIS becomes destabilized.

To support the recommended science goals, the Long Range Science Plan 2016-2026 prioritizes a number of recommended technology investments. One of the priority 1 (needed this year) recommendations, in preparation for a future deep ice drilling project at Hercules Dome, is to develop a Conceptual Design for adapting the existing Intermediate Depth Drill (IDD) system, which was designed to reach 1,500 m depth, for drilling to 2,800 m. This document outlines that adaptation. The extended depth IDD will here forward be called the Foro 3000 Drill. The following science requirements for the Foro 3000 Drill were established in April 2017 through an iterative process between the science community, IDPO, and IDDO.

Science Requirements

1. Target depths: from the surface to 3,000 m depth
2. Ice core diameter: 98 mm +/- 3mm
3. Minimum core length: Core length per run should be designed to facilitate drilling to 3,000 m in three field seasons (assuming 40 drilling days each season with 24-hour operations).
4. The drill should be operable in ice temperatures down to -53°C.
5. The surface equipment should be operable in ambient temperatures from -40° to +5°C.
6. Transport type: prefer Hercules LC130 or ground traverse
7. Drill should be compatible with existing fluids Isopar K and Estisol 140; compatibility of other fluids would be vetted by the science community prior to use.
8. Core quality requirements:
    a. Core recovery over the entire borehole, as close as possible
    b. Ice pieces to fit together snugly without any gaps
    c. In non-brittle ice, the packed core should have no more than 12 pieces of ice per 10 m section of core
    d. In brittle ice, there may be a lot of pieces in a single core segment, but the pieces must fit together, retaining stratigraphic order; more than 80% of the ice volume must be in pieces that each have a volume > 2 liters
9. Absolute borehole depth measurement accuracy: 0.4% of depth

10. Borehole inclination should be less than 6 degrees
11. The drill will be a complete system which includes a drilling structure and ice-core processing equipment. The drill structure will be appropriate for moderate accumulation rate sites (<15 cm per year), recognizing that specific sites may require additional specifications. Additional logistical equipment is permissible for drill site set-up and tear-down, for example a tractor with 3,000 lb. fork capacity for moving equipment and bucket or snow blower for drill trench excavation and site maintenance.

Safety

Safety of personnel using this drill is paramount due to the hazardous nature of the operations, severe environmental conditions at the drilling locations and the extremely long travel time to advanced medical and life support facilities. Even small mishaps may have severe consequences in this environment. In addition to the safety of personnel, preventing damage to the equipment is important, because of the difficulty and cost of repairing the equipment in the field. The failure of a single piece of equipment that cannot be field-repaired could potentially cause the loss of an entire drilling season. The following are safety requirements for the drill system.

1) Create a safety plan that defines how key issues for the project will be identified, managed, assessed and addressed during the system development.
2) Conduct a Failure Modes and Effects Analysis (FMEA) to identify and manage mechanical/physical/chemical and personnel hazards for the system.
3) Provide operational and safety trainings, as identified by the FMEA, to address safety hazards.
4) Provide operational and safety trainings, as identified by the FMEA, to address quality issues.
5) Provide hardware and/or software protection devices to prevent damage to the equipment due to overloads in the system, such as torque limiters, over-current protection, and limit switches.
6) Provide appropriate Personal Protective Equipment (PPE) for operating the drill system and handling drilling fluids, as identified in the FMEA.
7) Minimize environmental impact of the drilling operations through mitigations identified in the FMEA.
8) Provide identification of and protection from dangerous voltages.
9) Provide safety interlocks (Lock-Outs) to prevent the in-advertent operation of the equipment that would endanger personnel.
10) Provide emergency stop and emergency power-off systems to respectively halt and power-off the equipment in the case of an emergency. The emergency power-off systems in some cases must have fail-safe brakes such that the removal of the power will engage the brakes. (Examples include the winch or tower mechanisms, which must engage the brakes and hold their last position in case of a loss of power.)
11) Create an operations plan and procedures for normal drilling and surface operations of the system.
12) Create safety and maintenance check lists that will be completed at defined intervals to verify safety equipment is in place and the drill system is in proper working order.

BACKGROUND and DESIGN DECISIONS

The likelihood of having an intermediate depth and deep drilling project in the field at the same time is very low. This brought about the idea of adapting the existing IDD system to extend the depth capacity to 3,000 m rather than building a completely new drill system. Both cost and lead time benefits could be realized by utilizing as many components as possible from the existing system. However, any changes made must be reverse compatible so the system can be reconfigured as a 1,500 m drill.

Increasing the amount of core recovered per drill run will have the single largest impact on how long it will take to complete a project and therefore should be maximized. However, a longer drill also has a direct impact on the size of the tower, core processing line, drill tent, and other support systems. Extending the drill's core capacity per run from 2 m to 3 m, which increases the overall drill length by 2 m, is a good balance to meet both the science requirements and design goals. Increasing the core capacity by 1 m per run will reduce the drilling time by approximately one season while requiring minimum changes to the support systems and still allowing the entire system to fit within the existing drill tent.

SYSTEM DESCRIPTION

Sonde

New longer core barrels and chips chambers will be fabricated to accommodate a 3 m core. Core diameter will remain unchanged at 98 mm. The length of the chips chamber and core barrel will increase 1 m from the existing IDD design to accommodate the additional core length and cuttings volume. Only one style of core barrels, with full height flights, are proposed to be made, as this style of barrel proved to work well for both dry and wet drilling with the IDD on the SPICE Core project. A 126 mm diameter borehole was drilled for the SPICE core project; however, it is proposed to drill future projects with the larger 129.6 mm diameter cutters already included with the system. This will reduce winching loads while ascending and permit higher descent speeds. Two chips chambers and two core barrels will be fabricated to provide one spare of each. This cost is included in the project cost outlined below. No changes are required to the motor sections, as they were previously designed to operate to 4,000 m. The electronics package is currently being upgraded to provide borehole temperature, pressure, and inclination data. The anti-torque design will largely remain the same with the only change being to the cable termination section. The new cable will be larger in diameter and therefore require the termination components to be modified. All changes made to the sonde will be reversible so the downhole components can be used with either the IDD or Foro 3000 systems.

Winch and Tower

A longer tower is required to accommodate the increased length of the 3 m core drill. In order to fit the vertical tower in the drill tent without deepening the trench (floor level in the drill tent), only the lower portion of the tower will be extended. The upper portion of the IDD tower will be reused without modification. The lower portion will be extended by only 1 m and therefore the drill will extend beyond the end of the tower by approximately 1 m. The cable diameter has been increased from 5.7 mm to 7.2 mm to provide a higher breaking strength and to accommodate the increased weight of the longer cable and a maximum core break force of 12 kN at 3,000 m. Similar to the current IDD cables, this cable will have four internal electrical conductors, making it possible to deploy logging tools with this winch and cable. The IDD crown sheave assembly will be fitted with a new sheave grooved for the larger cable, but will otherwise remain unchanged. The new winch will be sized to hold 3,100 m of 7.2 mm diameter cable and will include the proven IDDO self-tracking level wind system. A standalone winch design has been chosen over integrating it with the tower base, as was done with the IDD. This was selected for a couple of reasons. The wider winch drum increases the cable fleet angle, which will put increased side loading on the crown sheave and level wind. The pivoting components of the tower also become much larger and more bulky than with the IDD, in order to work with the larger winch drum, restricting the walking space between the winch and core processing area. Separating the winch from the tower base makes for a much smaller and simpler tower base design and also permits the existing tower actuator, used to tilt the tower, to be reused. The new winch will be located just past the tower crown sheave and will be partially recessed into the floor so the cable running between it and the reaction sheave on the tower base can be below floor level, thus eliminating a potentially dangerous trip hazard. The winch design also makes it possible to reuse the IDD winch motors and still achieve max line speeds of 1 - 1.5 m/s. The other significant benefit of reusing the IDD tower actuator and winch motor, aside from not having to purchase new and expensive components, is the IDD control system can be reused without any modification. The conceptual design for the winch and tower assembly is shown below in Figure 1. The cost for a spare winch drum has been included in the project cost along with a spare cable. The spare cable will be deployed with the system already spooled and tensioned on the spare drum. In the event the spare cable is needed, the winch drums can be swapped instead of having to unspool the old cable and spool on the new one. This will save about a day of production time if a cable swap is required.

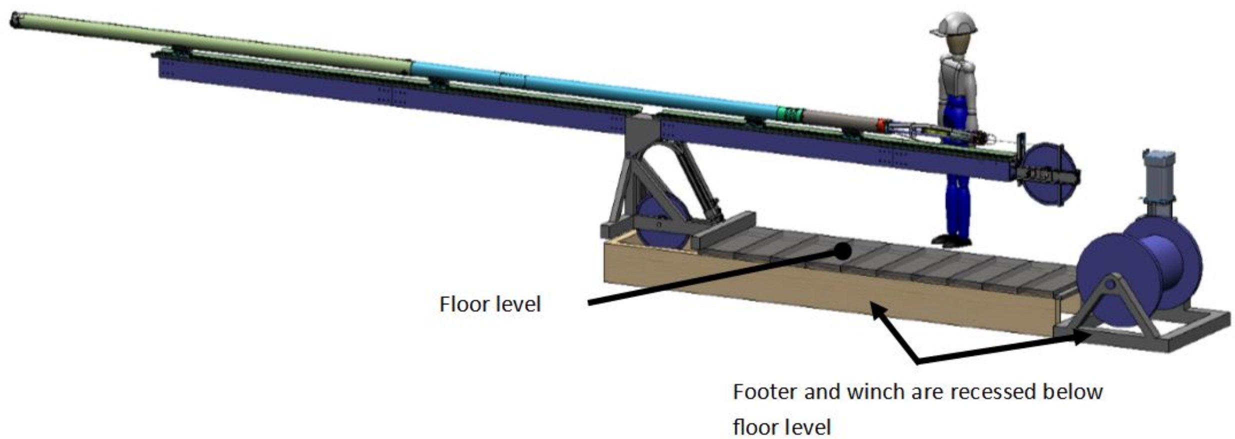

Figure 1: Foro 3000 winch, tower and footer concept with 3m core drill

Drill Slot and Core Barrel Pull-Out Table

Since all of the tower extension will be added below the pivot point, the drill slot will need to be 5.3 m deep or approximately 1.5 m deeper than is required for IDD. The length of the slot, and therefore hand rails, will also be increased by about 1.8 m. The overall length of the existing core barrel pull-out table is already 3 m, so it will not require any modifications to work with a 3 m core barrel or 3 m hollow shaft.

Core processing line

The core processing line will require reconfiguration to work with 3 m cores, Figure 2. However, the overall length of the system will remain the same as it is for the IDD by utilizing unused space on the far left end of the line. The core barrel station with drip tray, at the right end of table in Figure 2, will be made longer by about 1 m to work with the 3 m core barrel. The Fluid Evacuation Device (FED), used for removing excess drilling fluid from the ice core surface, will be fitted with a longer netting sleeve, increasing the brittle ice netting capacity to 3 m. The distance between the FED and the core saw is currently 3 m, so this section will already accommodate 3 m cores. However, this section currently utilizes a 2 m long core tray that slides back and forth so the netting can be loaded on the FED, which will be replaced with a longer 3 m sliding tray. No modifications are required after the saw for normal core processing, since the cores are cut into 1 m lengths by this point. However, depending on what type of tubes or trays are used for storing the 3 m brittle ice sections, additional modifications may be required.

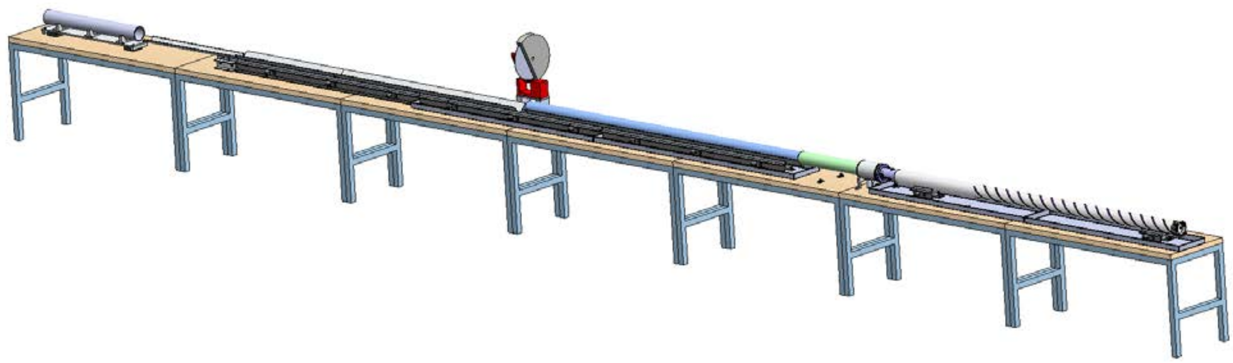

Figure 2: Core processing line

Chip and Fluid Handling

The size of the chip slurry collection pan, located between the core barrel pull-out table and slot, will be increased to accommodate the larger volume of chips slurry from the longer chips chamber. The existing centrifuge will be reused, but will need to be run twice for each drill run to process the increased volume of cuttings. Recovered drilling fluid will be filtered and delivered right back to the borehole, as was done for the SPICE Core project. Additional drilling fluid will be added to the borehole by pumping fluid directly from drums, located outside the drill tent, to the borehole using an electric barrel transfer pump.

In an effort to improve drill fluid recovery, which was about 85% for the SPICE Core project, a chip melter system has been included in the concept design and costs. This is a worthwhile pursuit because, for a 3,000 m borehole, every 5% improvement in drill fluid recovery will save 10 drums of fluid. Initial calculations show a 30-40 gallon tank with a 4-5 kW heating system will provide enough capacity to keep up with production. Two different methods for heating the chips slurry were investigated. The first method made use of waste heat from the generator, circulated through a glycol loop, to warm the chips slurry, Figure 3. The second method uses electric heating coils submerged in the slurry tank to do the heating. The electric version was chosen for its simplicity (it doesn't require the generators to be modified) and due to the low power requirements of the melting system. This system includes a smart controller in the design, permitting operation only when other electrical loads are below a predetermined set point. While this system would have some impact on fuel usage, it would not require the generator size to be increased, as it would run at off-peak demand times and would actually help keep the generator load more constant. The melting tank would be located outside the drill tent to mitigate any potential ventilation issues associated with warming the drilling fluid to above freezing. As the chips slurry is removed from the drill, it will go right into filter bags to drain off the bulk of the drilling fluid before being transferred by hand, in buckets, to the melter tank. Once the ice cuttings have melted, the two liquids will separate due to their different densities and then be drained off through valves on the side of the tank. The clean waste water will be dumped and the drilling fluid will be transferred into drums to cool before being reintroduced into the borehole.

Figure 3: 8kW, 50 gallon capacity chip melter system (white tank) using waste heat from one of the Agile Sub-Ice Geological (ASIG) Drill diesel engines (under blue cover) to melt and separate cuttings from the drilling fluid

Drill Tent Layout

The drill tent layout, shown in Figure 4, will look very similar to that of the IDD, shown in Figure 5 for reference. The borehole location will remain in approximately the same relative location along with the control room and power distribution system. The Foro 3000 winch will be recessed into the floor about 0.3 m, so the lower flange of the winch drum is just below floor level. A raceway in the floor, with removable floor panels, will run between the winch and tower base to house the winch cable and power cables for the winch to keep the floor space open and free of trip hazards. The entry door landing and stairs on the winch end of the tent will be located as they were for SPICE Core project. The stairs to the core storage trench will also remain in the same location, but could be laid out differently so they protrude about 0.5 m less into the drill area. This will provide ample room for walking around the winch and for moving core and core boxes into the storage trench. As described above, the slot will be 1.5 m deeper than with the IDD, requiring longer fluid hoses going to the casing, a longer slot liner, and a longer slot ladder. The slot will be lengthened about 1.8 m. This will shift the core barrel pull-out table towards the opposite end wall by the same amount. To make room for the additional length, the landing inside this end of the tent, which was approximately 1.2 m long for SPICE Core and ran the entire width of the tent, will be removed, extending the trench all the way to the end wall.

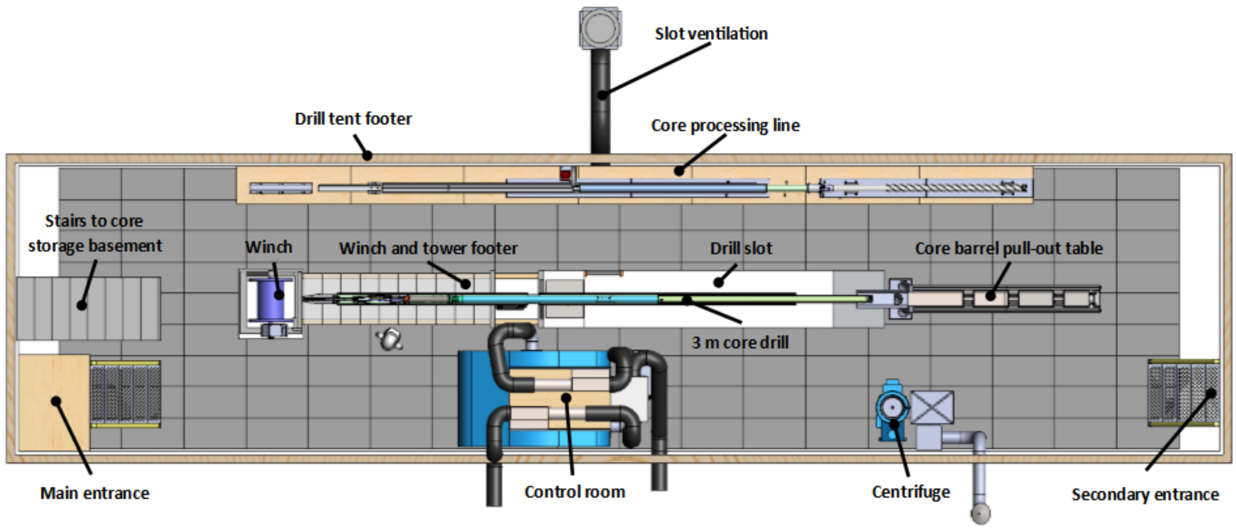

Figure 4: Foro 3000 System Plan View

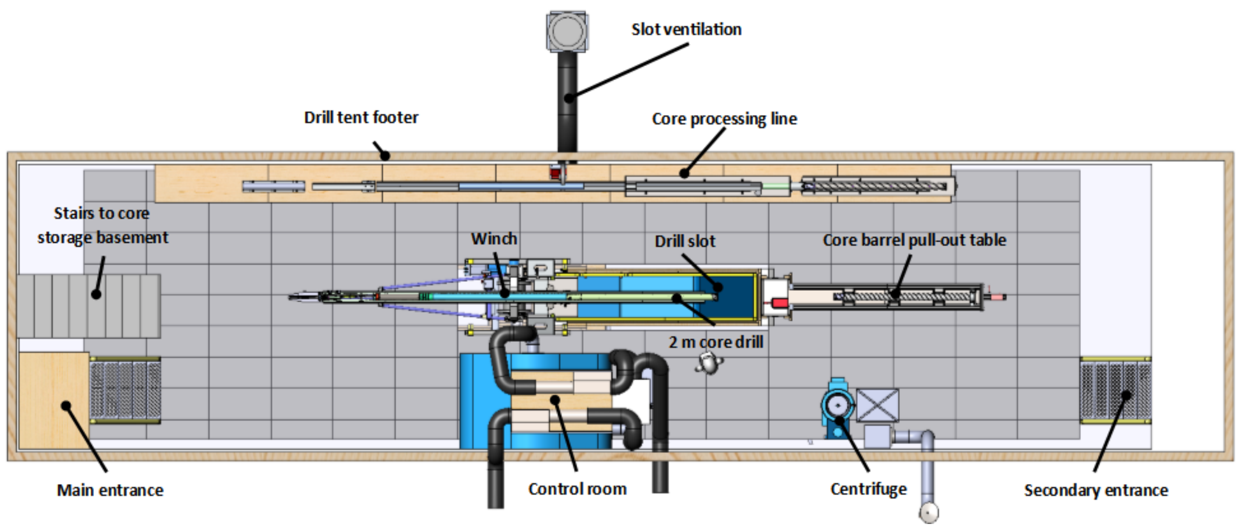

Figure 5: IDD System Plan View

Maintenance Shop

Having the proper tools and equipment on-site to service and repair the drilling equipment is a vital part of maintaining the project timeline by minimizing down time in the event of a breakdown. For the WAIS Divide project, the MECC Shop supported the DISC Drill operations. For the SPICE Core project at the South Pole, the MAPO Machine Shop supported the IDD. If components have to be sent off-site for service or repair, the down time could range in days to weeks depending on weather, flight availability, and off-site shop scheduling. With the short duration of the field seasons, not having shop facilities on-site could have a large impact on the success of a project. Three maintenance shop options have been explored to support the Foro 3000 system. The first is to use the MECC shop currently in IDDO inventory, Figure 6 - A. It is a very well-equipped shop with mechanical (machining and welding) and electrical repair capabilities. The shop is housed in a 20' shipping container with two opening sides that fold out, effectively tripling the usable interior floor space. All equipment, tools, and furniture are stored in the MECC for shipment. The benefit of this option is the MECC is currently in good working order and would require little effort to be ready for deployment. The down side to deploying this shop is its size and weight. The container is 20’ long x 8’ wide x 8’ high and weighs over 19,000 lbs., limiting deployment to LC-130 aircraft or ground traverse. The second option is to purchase a similar expanding container that is half the length of the MECC, commonly referred to as an Expandable Bicon (10’ long x 8’ wide, x 8’ high), Figure 6 - B. This shop would be outfitted with similar, but smaller and lighter, equipment as the MECC. Smaller equipment, primarily the milling machine and lathe, is adequate for servicing the Foro 3000 system due to the smaller size of the drill. The main benefit of this shop option is the logistics burden would be less than half what is required to deploy the MECC. All equipment would also pack into the container for shipping, and setup and take down would only take a few hours, as with the MECC. The downside to this option is the upfront cost to purchase and outfit the container and the size and weight would still limit deployment to LC-130 aircraft or ground traverse. A third option is to send the equipment, the same equipment as would be purchased for the Bicon shop, in several small crates and assemble the shop on-site in an insulated Weatherport type tent, with a minimum usable floor space of 150 ft^2, that would be provided by ASC, Figure 6 - C. The benefits of this option are the lower shipping weight and volume, making it possible to deploy with aircraft smaller than a LC-130, and the lower initial cost realized by replacing the expandable container with a tent. The downside to this option is it will take longer and require more people to setup and takedown than a containerized shop. A comparison of the three different shop options is shown in Table 1.

Figure 6: Mobile shop options. A – 20’ expandable container (MECC), B – 10' expandable container (Bicon), C – tent

Table 1: Comparison of the maintenance shop options

	MECC Shop	Bicon Shop	Tent Shop
Transport size	20’ L x 8’ W x 8’ H	9’ 10” L x 8’ W x 8’ H	6’ 7” L x 4’ 2” W x 4’ H
Weight	19,140 lbs.	7,000 lbs.	2,200 lbs. (w/o tent)
Cubes	1280 ft^3	635 ft^3	110 ft^3 (w/o tent)
Floor space (expanded)	393 ft^2	154 ft^2	150 ft^2 minimum
Heat	Electric, 6000 W	Electric, 3000 W	Kuma Stove – JP8 fuel
Power feeds	208V 3ph and 460V 3ph	208V 3ph	220V 1ph
Materials Cost	$0	$77,980	$11,480 (w/o tent)

If IDDO is directed to develop the Foro 3000 system, a joint decision will need to be made on which shop option will be implemented. Both purchase costs and logistics of getting the shop to the site should be considered.

Power Requirements

By utilizing the existing winch motor and tower actuator, along with the other support equipment from the IDD system, the power requirements have remained the same for the Foro 3000 system as they are for the IDD. A dedicated 55 amp 460V 3ph (35 kW) power feed to the drill tent will be required. The Foro 3000 system will utilize the IDD power distribution system, which includes a 460V 3ph panel, step down transformer, and 230V/120V 3ph/1ph panel. The power requirements for either the Bicon or tent shop are included in this number and the shop power would be fed from the drill's power distribution system. Based on this power requirement, about 10,000 gallons of fuel will be required for a 3,000 m project.

Operations

Operation of the Foro 3000 Drill system is expected to be accomplished by a team of 10 people per season. This consists of two IDDO drill operators and one member from the science team, per 8 hour shift, plus one IDDO lead driller, to maintain 24 hour drilling operations. The logistics provider is expected to provide the necessary camp facilities and the staff required to run them. Table 2 outlines the estimated days required to complete a 3,000 m drilling project.

Table 2: Estimated project duration

	Days
Drill system setup: excavate trench, drill system setup (one 10 hr. shift)	12
Pilot hole: drilling, reaming, and casing to 100 m (two 10 hr. shifts)	5
Drilling to 3,000 m (three 8 hr. shifts, not including days off)	120
Unpacking and packing for interim seasons	5
Drill system pack up (two 10 hr. shifts)	4

The following sections detail the expected major areas of operation.

Drill System Setup

Prior to installation of the tent and drill system, the drill and core storage trenches must be excavated. While this could be done by hand with chainsaws, it would be done much more efficiently and safely using a tractor equipped with a bucket or snow blower. A tractor with a minimum fork capacity of 3,000 lbs. to assist with moving and positioning cargo is ideal; however, it could be done with lesser equipment at a slower pace. The setup time listed in Table 2 assumes the use of heavy equipment for both the slot excavation and moving of cargo. The core storage trench design is not included in this concept, as its design and excavation is expected to be the responsibility of the logistics provider. IDDO recommends considering creation of a balloon trench, as pioneered by the Danes in Greenland for the East GRIP project, for the core storage area as opposed to excavating a trench and covering it with a fabricated wood roof, as was done for the SPICE Core project. The drill system will be shipped in reusable crates and cases. Once the equipment has been setup, the containers will remain on-site for storage space for spare parts and for re-packing the system at the end of the project. It is recommended the crates winter-over on a snow berm or elevated on drums to minimize retrieval efforts at the start of the following season.

Pilot Hole

To provide long term borehole access, a casing will be set down to the firn-ice transition. Polyethylene pipe, like that used for the SPICE Core project, will be used. However, the pipe joints will be fusion welded, as opposed to using threaded connections as has been done in the past. This will ensure the casing is leak tight down to the shoe. The pilot hole will be dry drilled, and then reamed to a larger diameter to receive the casing, using the Foro 3000 Drill.

Drilling Operations

Project drilling duration is based on operations running 24 hours per day and six days per week, as has been common with past intermediate and deep drilling projects. A field camp, with necessary support staff, will be required to support the drilling team and operations in order to meet the schedule laid out in Table 2. An additional 2-3 days will be required at the end of the first and second seasons and start of the second and third season for winterization and start up. For the drilling system, only equipment needing maintenance or repair and a small amount of do not freeze cargo will need to be shipped from the drill site between seasons. All other equipment will remain on-site for the duration of the project. Provided a 2.5 month long field season, it should be possible to complete a 3,000 m drilling project in three seasons given minimal drilling issues near the bed, fair weather, and good logistics support. However, it is recommended to budget for a fourth season in case drilling problems are encountered and for camp close-out.

Drilling fluid will be introduced into the borehole once operations reach 200-300 m, or at the first sign of degrading core quality. The fluid level will then be maintained between 100-150 m below the surface for the reminder of the drilling. Depending on how closely the selected drilling fluid and ice density match, the fluid level could be brought up higher between seasons to help manage borehole closure. Drilling to 3,000 m will require approximately 232 drums of drilling fluid.

The current IDD system has been designed for compatibility with Estisol 140 drilling fluid and will also work with Isopar K. IDDO recommends using Isopar K, with a yet to be determined densifier, or selecting an entirely different drilling fluid for future projects. From a drilling stand point, this is due to the side effects experienced by the drill operators from using Estisol 140 on the SPICE Core project, which included headaches, lightheadedness, throat/eye irritation, change in appetite, loss of smell, and loss of balance. Ventilation and other design modifications have been implemented to lessen the severity of these side-effects. Continued use of Estisol 140; however, has and will continue to have an impact on IDDO's ability to find and retain qualified personnel for future projects due to the experienced side effects and unknown possibilities of long term health effects. IDDO, along with personnel from the UW-Madison Space Science & Engineering Center (SSEC), the UW-Madison Chemistry Department and a UW-Madison Chemical Hygiene Officer, performed extensive testing on Estisol 140 following presentation of the side effects listed above. IDDO and SSEC also worked with the Estisol 140 manufacturer, Esti Chem A/S, throughout the investigation. Testing showed that Estisol-140 is composed of 99% 2-Ethylhexyl Acetate with a few trace components. Identity of the trace components is unknown, so the possibility remains that they could be toxic; however, with the quantities in which they are present, it is unlikely they would change the overall fluid toxicity. 2-Ethylhexyl Acetate does not have any known long term health effects.

Drill System Pack Up

At the end of the project, the drill system will be packed into the original cases and crates in which it was shipped to the site. The casing will be extended to above the snow surface and capped for future use. All drill equipment will be removed from the site.

Transport Logistics

The current IDD system is packaged for transport by LC-130 aircraft or ground traverse. The system could be further broken down and packaged in smaller crates for transport by smaller aircraft; however, this will result in some increase to the shipping weight due to the additional number of crates required. The tent version of the maintenance shop is the only one of the three shop options that could be packaged to fit into an aircraft smaller than a LC-130. The shipping weights and cubes for the current IDD system, with 100 m of casing are 28,808 lbs. and 2,132 cubes respectively. Extending the depth to 3,000 m and core length from 2 m to 3m, is estimated to increase the weight by 4,707 lbs. and the volume by 66 cubic feet for the Foro 3000 Drill, Table 3 and Table 4.

Table 3: Foro 3000 system estimated shipping weight

Current IDD system	Foro 3000 additions	Shop Option	Total Shipping Weight
28,800 lbs.	4,700 lbs.	MECC Shop = 19,140 lbs.	52,640 lbs.
		Bicon Shop = 7,000 lbs.	40,500 lbs.
		Tent Shop = 2,200 lbs.	35,700 lbs.

Table 4: Foro 3000 system estimated shipping volume

Current IDD system	Foro 3000 additions	Shop Option	Total Shipping Volume
2,130 ft^3	70 ft^3	MECC Shop = 1,280 ft^3	3,480 ft^3
		Bicon Shop = 635 ft^3	2,835 ft^3
		Tent Shop = 110 ft^3	2,310 ft^3

These numbers are for the drilling system and maintenance shop only and do not include the projected 232 drums of necessary drilling fluid, core storage trench materials, core boxes, generators, fuel, or the supporting field camp.

High-Level Equipment List

A summary of the major modifications and equipment necessary to extend the depth range of the existing IDD system to 3,000 m and increase the core length from 2 m to 3 m per drill run is shown in Table 5. The material costs for each of the three shop options are summarized in Table 6. Only one of the three options will be included in the final project budget.

Table 5: Foro 3000 High-Level Equipment List; does not include design/development/fabrication labor or indirect costs

Winch and tower	
Winch with level wind and 3,100 m cable	$68,698
Second winch drum for spare cable	$21,000
Spare 3,100 m winch cable	$26,058
Tower base and tower modifications	$10,430
Sonde	
Extend IDD drill for 3 m long cores	$56,110
Anti-torque modifications for larger diameter cable	$5,150
Drill Recovery	
Glycol freezer and equipment	$5,094
Baler	
Extend baler 1 m and add weight stack	$4,388
Control System	
Longer cabling for winch	$500
Drill Slot	
Modifications for longer and deeper slot	$3,029
Casing Installation Tools	$550
Core Pull-Out Table	
Modifications to work with Foro 3000 layout	$1,127
Core Processing Line	
Modifications to work with 3 m cores	$2,455
Fluid Handling	
Longer hoses	$450
Chips Processing	
Chips Melter system	$4,284
Drill Tent	
Add vestibule to one entry door	$150
Shipping Cases/Crates	
Crates for new equipment	$3,765
Consumables	
Casing, 100 m of pipe	$2,672
Casing shoe	$575
Glycol for drill recovery	$222
Drill Equipment Total:	**$216,706**

Table 6: Material costs for the three maintenance shop options; does not include design/development/fabrication labor or indirect costs

Maintenance Shop Options	
MECC Shop	$0
Bicon Shop	$77,980
Tent Shop	$11,480

SCHEDULE and COST

Once funding is in place and assuming engineering labor availability, duration for the development of the Foro 3000 Drill is expected to be eleven months. This includes time to complete the detailed design, fabricate components, assemble the system, complete functionality testing, and package the system for shipping. At the start of the project, a detailed project schedule, which will be used in the management of the Foro 3000 Drill development, will be created for the execution of the project.

The cost for completion of the development of this system is expected to be $787,000 to $1,060,000. This includes all labor, equipment, materials and indirect costs. A portion of the cost range is due to the various options laid out for the maintenance shop in Table 6.

CONCLUSION

The design of the proposed Foro 3000 system was guided by and meets the science requirements identified by the research community. The design starts with the proven IDD system and makes minimal modifications to extend the depth range from 1,500 m to 3,000 m. The sonde length would be increased, extending the core capacity per run from 2 m to 3 m, making it possible to complete a 3,000 m drilling project in three seasons. Minimizing logistical burden and providing flexibility in transport options was also a focus of the design. Development of the Foro 3000 Drill will be performed with attention to detail and consideration of safety and ease of use for the operators. It is recommended that the development of this drill be approved and scheduled for execution based on this concept and the budget and schedule provided in this document.