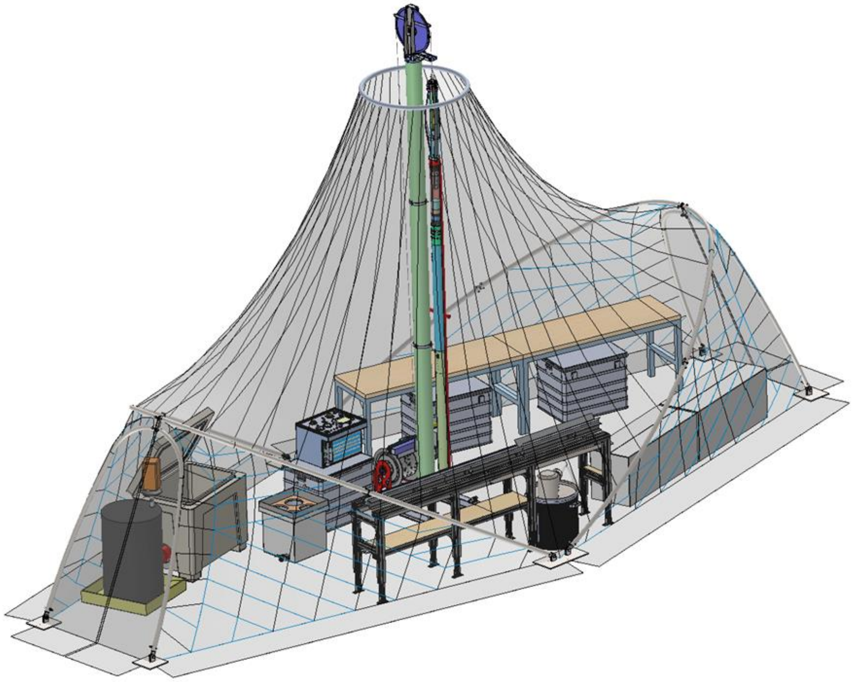
700 Drill

Conceptual Design Review

November 23, 2020



Science Requirements

Changes from the Foro 700 Science Requirements are shown in red

1. Target depths: from the surface to a potential maximum of 700 m depth
2. Ice core diameter: 64 mm
3. Core length: 1 m
4. The drill should be operable in ice temperatures down to -25 C.
5. The surface equipment should be operable in ambient temperatures from -20 to +5 C.
6. All electrical connections and control boxes should be sealed to function well in environments with high levels of humidity, e.g. in tropical sites.
7. Air transport type: Bell 212 or similar helicopter and/or Twin Otter
8. Drilling fluid: drill should be compatible with existing fluids, e.g. Isopar K, Estisol 140
9. Maximum field project duration: 2 months on-site with at least 40 days of production drilling. Target core recovery is 700 m within a single ~60-day field season.
10. 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 ~2 m 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
11. Absolute borehole depth measurement accuracy: 0.2% of depth
12. Field set-up time: the system should be able to be set up with no more than five persons with limited logistics (i.e. no heavy equipment), including surface infrastructure and any core handling/processing setup
13. Core processing equipment will be included with the drill system.
14. Core packaging materials (tubes, boxes, straps) and transportation materials (pallets, blankets) shall be provided by the logistics provider.
15. The core will be transported from the site in the same season it is drilled.
16. System should include the capability to bail fluid from the borehole.
17. Borehole should accommodate logging instruments after ice coring is complete.
18. Drill system should operate with either a generator or a renewable source, and a lightweight portable renewable source should be provided, e.g. flexible or folding solar panels.
19. Borehole temperature (±0.1 C or better)* and borehole inclination (±0.5 degrees or better) should be measured and recorded.

* The temperature sensor in the Foro drills has an accuracy of ±0.5 C

Safety

Safety of personnel using this drill is paramount:

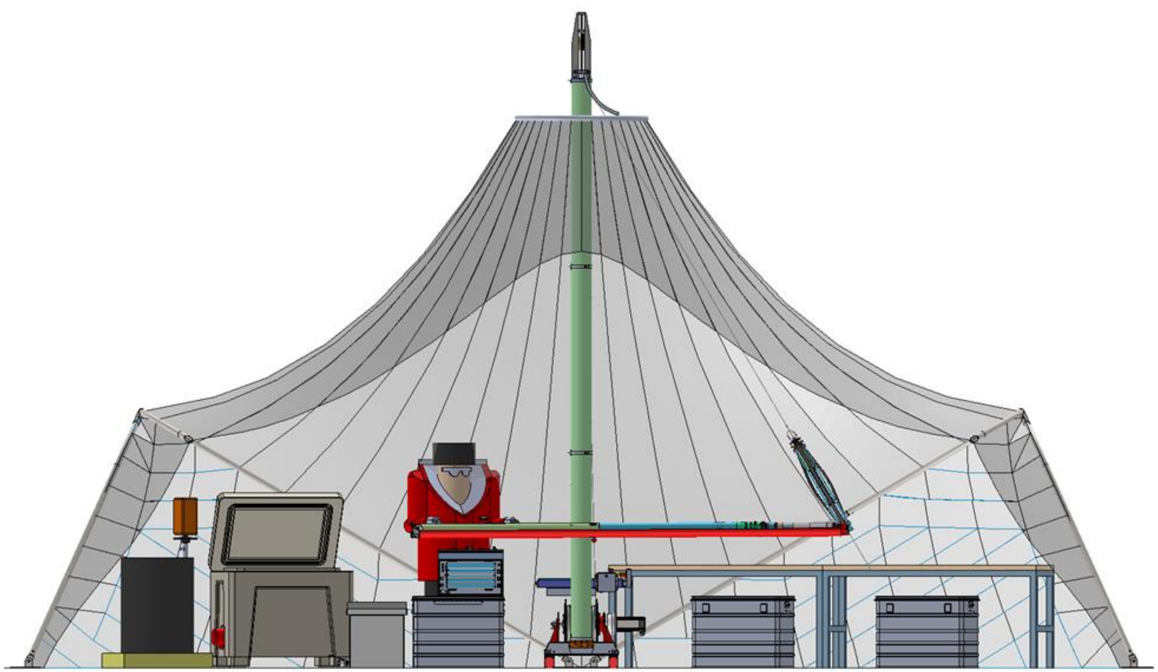
- Hazardous nature of the operations
- Severe environmental conditions at the field sites
- Extremely long travel times to advanced medical care and life support facilities
- Small mishaps may have severe consequences in this environment

Safety Requirements:

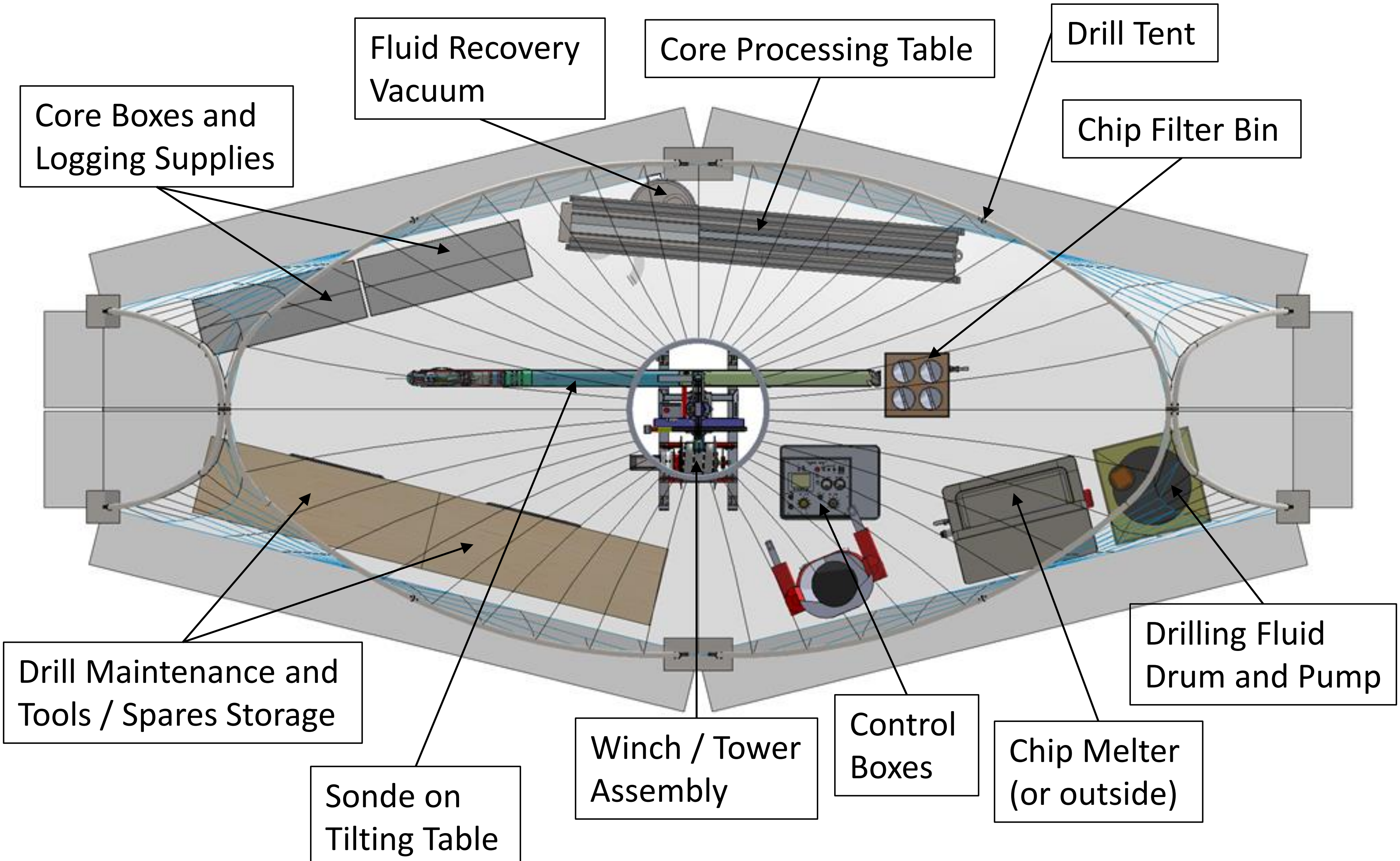
1. Create a safety plan that defines how key issues for the project will be identified, managed, assessed and addressed during the system development.
2. Conduct a Failure Modes and Effects Analysis (FMEA) to identify and manage mechanical/physical/chemical and personnel hazards for the system.
3. Provide 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 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.

System Description

- New drill system with smaller diameter sonde based on the existing Foro 1650 (IDD) for mid-range ice coring to 700 m depth.
- Incorporates designs from existing drill systems wherever possible.
- Primary focus on minimizing weight and logistics requirements to make it possible to access sites with limited logistics and seasons as short as two months in length.



Drill Tent Layout



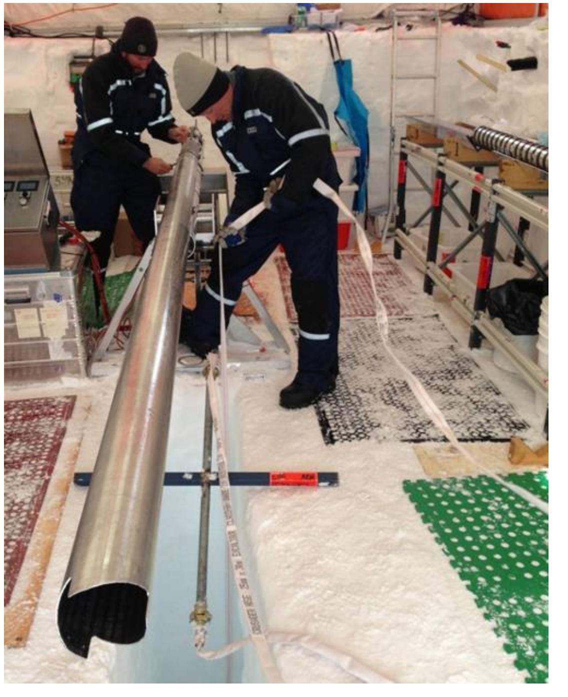
Foro 1650 (IDD)/ 700 Drill Comparison

	Foro 1650	700 Drill
Max. Depth (m)	1500+	700
Core Length (m)	2	1
Trench (L x W x D, m)	15 x 4.6 x 1.5	None
Slot (L x W x D, m)	3 x 0.9 x 3.5	None
Pilot Hole	2-stage Reamer	Main Borehole Diameter
Casing	Polyethylene Sewer Liner	None
Tower	Tilting	Fixed w/ Tilting Table
Fluid Recovery from Chips	Centrifuge	Chip Melter
Ventilation	Forced Air / ERV	Passive
Tent (lbs)	4000	400
Electrical Generator (kW)	30	5
System Weight (lbs)*	62,500 (estimate to 700m)	15,000 (estimate)

*Includes drill system, generators, drilling fluid, fuel, and empty core boxes

Firn Borehole

- Dry drilled with 700 Drill sonde
- No reaming
- No casing
- Layflat tubing to deploy drilling fluid below the firn-ice transition
- Drilling fluid level kept below the firn-ice transition
    - Hole is only partially pressure balanced unless a 2-part fluid is used

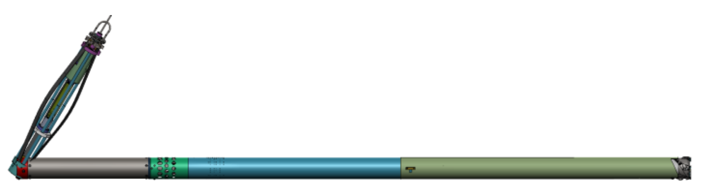


Adding fluid to an uncased hole at Aurora Basin

Sonde Overview

- 1 meter core capacity
- Estimate < 4.5 m overall length (compared to 6.4 m for Foro 1650)
- Hinge between AT and Motor Sections to facilitate rotation to horizontal on tilting table

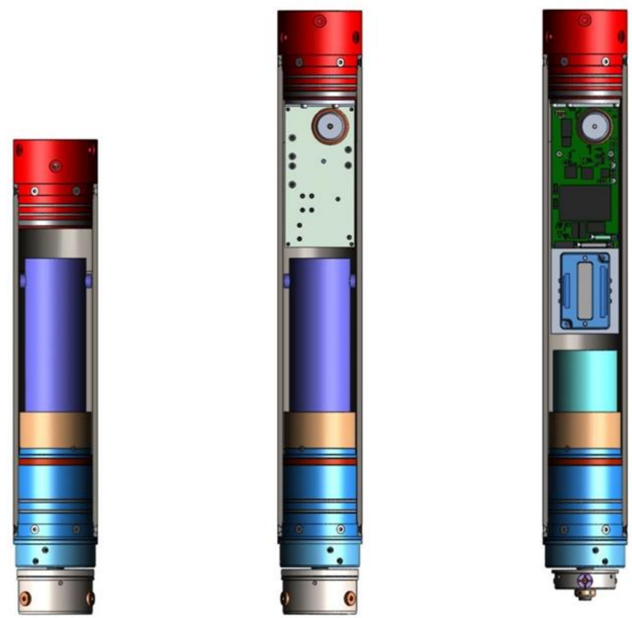
Foro 1650 Sonde



700 Drill Sonde Concept

Sonde Motor Section

- Comprised of similar components used in the Foro 400, Foro 1650, and Foro 3000 Drill systems
- Electronics package will likely be a reconfigured version of the Foro 3000 electronics.
- Driving design parameters are robustness, simplicity, and field-repairability

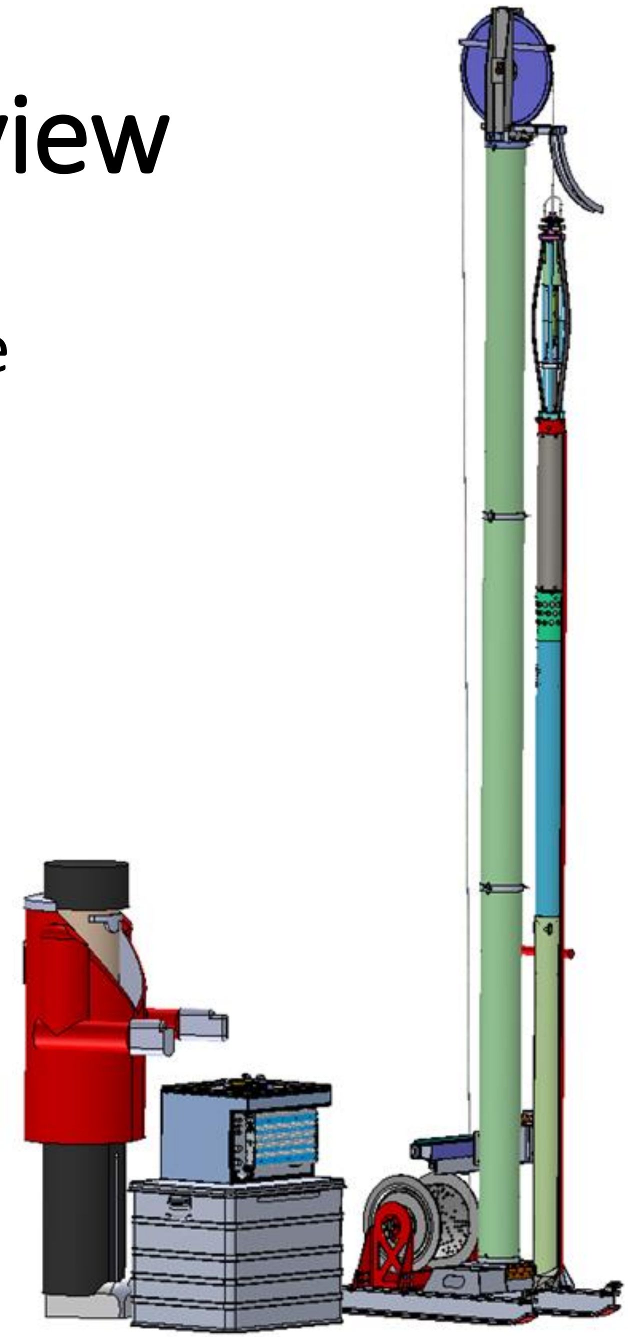


Sonde electronics options: Foro 400, original Foro 1650 (IDD), and Foro 3000 configurations from left to right

Sonde Motor Section Options	Foro 400 Type Electronics	Original Foro 1650 Type Electronics	Foro 3000 Type Electronics
Motor control method	Off-the-shelf pulse width modulated (PWM) controller on the surface	IDP designed motor power supply (MPS) in the sonde with DC power supply on the surface	IDP designed drill power supply (DPS) with off-the-shelf PWM motor controller and sonde interface electronics in the sonde; DC power supply on the surface
Motor type	Brushed DC, 500W	Brushed DC, 500W	Brushless DC, 500W
Motor functionality	Variable speed forward and reverse	Variable speed forward only without additional development	Variable speed forward and reverse
Other functionality	AT slip sensor	AT slip sensor	AT slip sensor, temperature and pressure sensors, inclination, motor speed
Positive aspects of design	No down hole electronics; possibly the lowest cost option	Leverages and reuses existing designs; better motor control than Foro 400 option	Leverages and reuses designs already in progress; added feedback from down hole sensors; better motor control than Foro 400 option
Negative aspects of design	Motor controllers are not designed for use over long cables; would require testing to vet option; may add electrical noise into the system; controller may be slow to respond to load changes due to the long cable length; **does not currently meet the 700 Drill science requirements**	Longer than Foro 400 option; no reverse function without further development; added down hole electronics; requires moderate additional development to downsize for smaller diameter sonde; **does not currently meet the 700 Drill science requirements**	Longer than Foro 400 option; added down hole electronics; **requires substantial additional development to downsize for smaller diameter sonde; may require computer for operation**

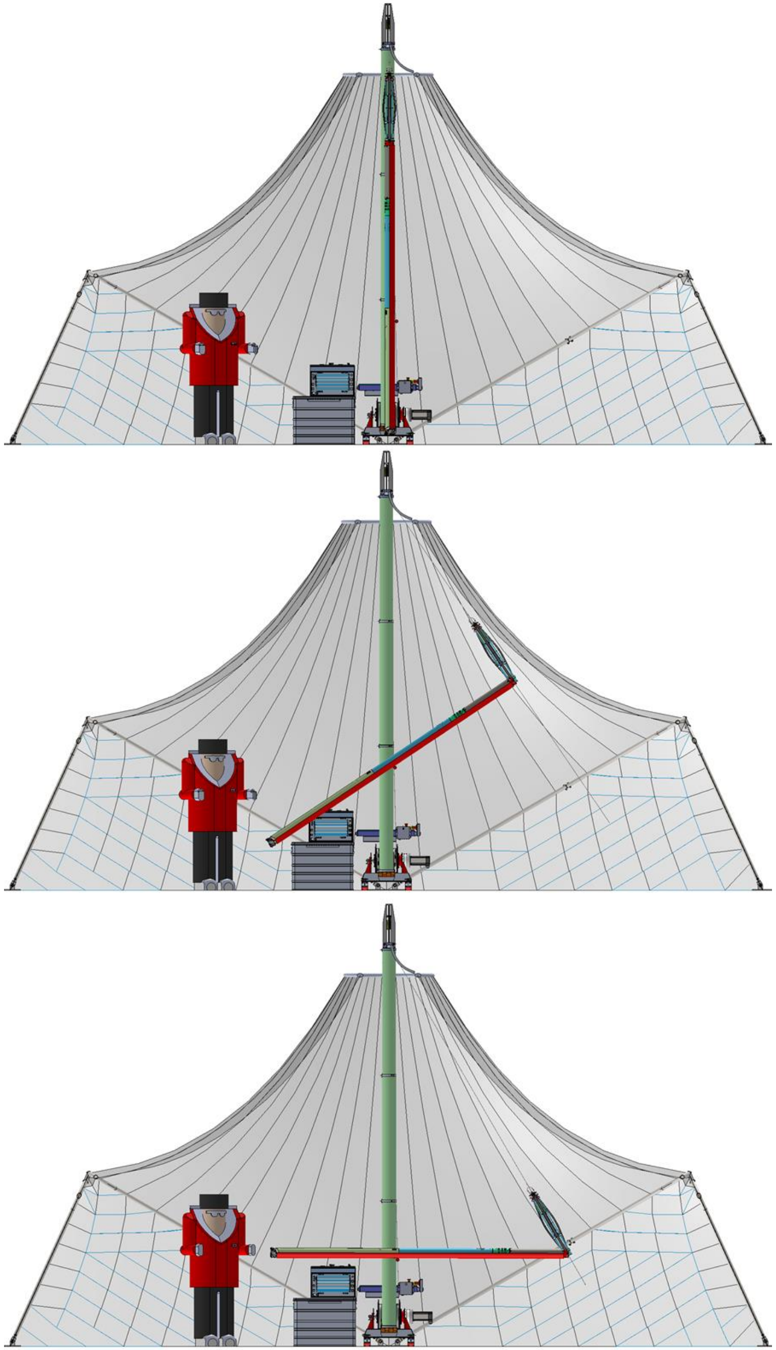
Winch and Tower Overview

- Based on existing Foro 400 design
- Larger winch drum for 700 m cable capacity
- Winch maintains 1 m/s ascent speed to meet production target
- Cable diameter has yet to be determined; will be ≤ the Foro 400 cable
- IDP self-tracking level-wind design
- Stationary tower allows use as a tent support member, minimizing tent weight
- Tilting table for sonde



Tilting Table

- Allows sonde to be rotated horizontal for core and chip removal
  - Tower remains vertical to support tent
  - No trench needed
  - Minimizes set-up time and system weight
- Weight counter-balanced, sliding design (with hinged AT section) allows drill system to fit within the existing BID/Foro 400 Drill tent design



Chip and Drill Fluid Processing

- Two-stage fluid recovery
    1. Gravity separation of the fluid through filter bags in a collection tub
    2. Melting of drained chips in a melter tank for near 100% fluid recovery
- Electric powered chip melter
    - Flame-proof immersion heater designed for flammable liquids
    - Commercial insulated fish-shipping tank
    - Load-shedding controller
        - Allows melter operation only when generator loads are below a pre-set level
        - Improves generator loading by keeping it more constant

Chip Filter Tub

+

Existing Melter Tank for Foro 3000

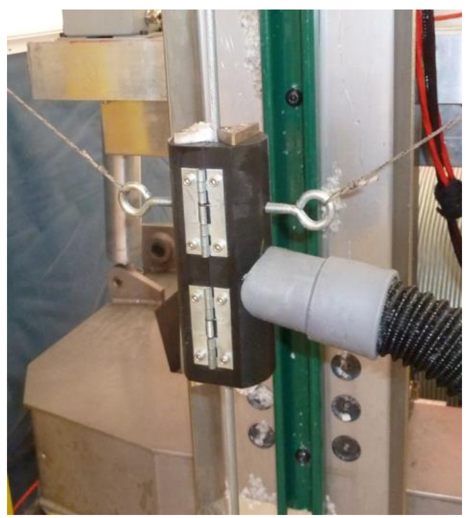
+

Load-shedding panel

Drill Fluid Recovery

- Cable vacuum to minimize fluid loss on drill ascent
- Vacuum used to recover fluid off of cores at the core processing table
- Drip trays under winch, around tower, under tilting-table, and on core processing table
- Bailer attachment to recover drilling fluid from completed borehole

Fluid Vacuum



Cable Vacuum Attachment

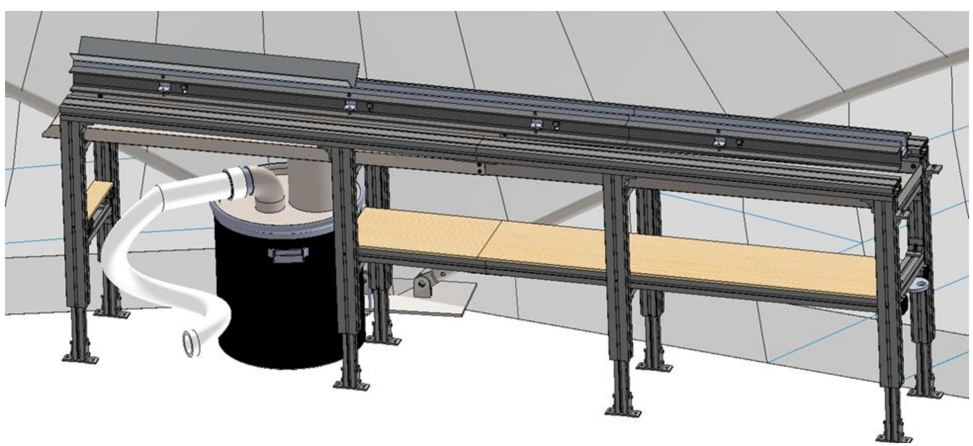
Fluid Bailer Check Valve from ASIG Drill

Drilling Fluid

- Drill system to be compatible with most drilling fluids, including Isopar K and Estisol 140
- Recommend using Isopar K, with or without a densifier
  - A densifier would be needed to fully pressure-balance the borehole (max fluid level at firn-ice transition)
- Fluid pumped to borehole directly from drums with an electric drum pump
  - Two-part fluids will require additional mixing/proportioning equipment

Core Processing

- Minimal core processing equipment to save system weight and size
- Core push-out table with logging tray
- No electric saw planned, but could be included as needed
- Core storage in a separate trench or freezer to avoid the elevated temperatures in the drill tent



Tent

- Drill system designed to fit within the existing tent used with the BID-Deep
- 400 lbs. vs 4000 lbs. for Foro 1650 tent
- Field tested in 50+ knot winds and high snow accumulation

Drill tent in use at Law Dome, Antarctica with BID-Deep

Tent

Tent setup with the Foro 400 Drill

Power requirements

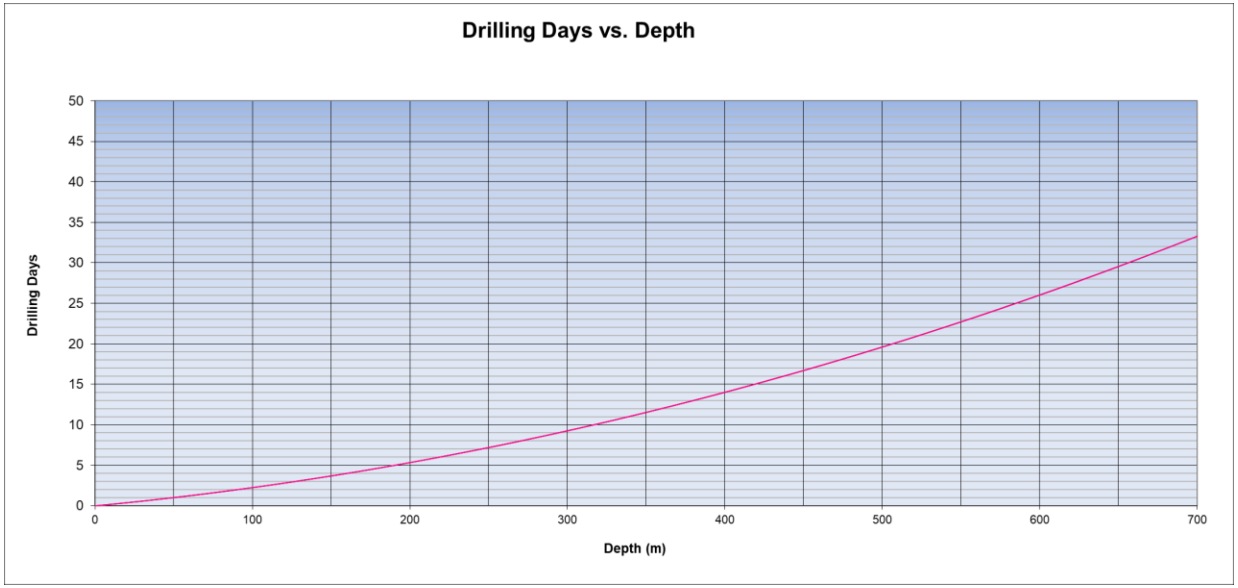
- The drill system is anticipated to require a 5.0 kW, 240-volt, 1-phase power feed
- Load-shedding circuitry will automatically cut-out chip melter, etc. when max. amperage is needed for core break and sonde ascent
  - Minimizes generator size and fuel usage
- Spare generator included in system concept

5.0 kW gasoline-powered generator

Operations

- Drilling and core processing operations will require a 3-person team
  - 10 hours per day, single-shift operation is anticipated
  - 3 people required for operation (2 IDP drillers and 1 science team member)
- Up to 5 people may be needed to safely assemble the drill system
- It is estimated to require less than 40 drilling days to reach 700 m

	Days
Drill system setup (one 10 hr. shift)	4
Drilling to 700 m (one 10 hr. shift, not including days off)	≤ 40
Drill system pack up (one 10 hr. shift)	3

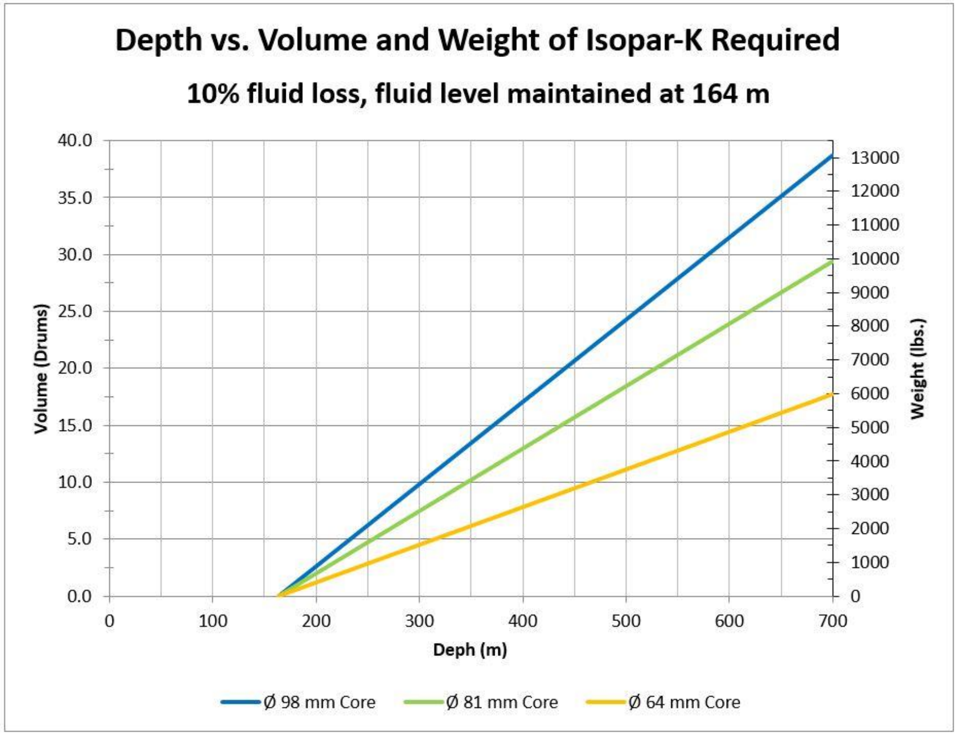


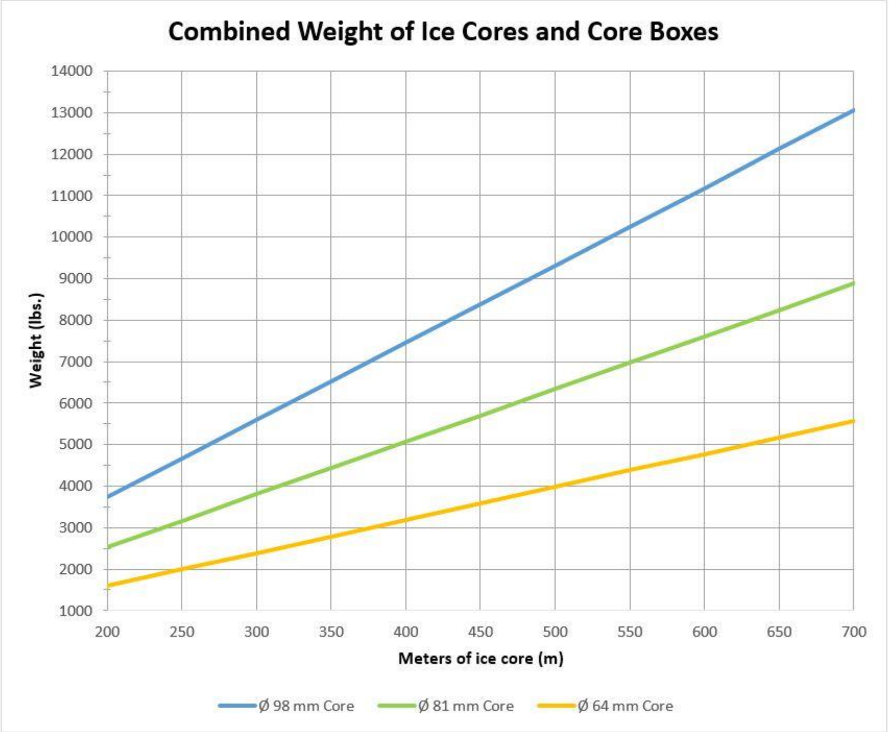
Logistics

700 Drill System Transport Estimates (one 700 meter hole)		
Component	**Weight**	**Cubes**
Winch/Tower assembly with tilting table	525	54
Spare winch drum with cable	225	5
Sonde with spares	525	25
Control system	200	14
Core processing table and equipment	350	20
Fluid handling equipment	250	15
Chips processing equipment	350	46
Tent	400	11
Tools, maintenance supplies, and PPE/safety equip.	490	25
Generator with spare and electrical distribution equip.	600	53
Sub-Totals	**3915**	**268**
Consumables		
Drilling Fluid (Isopar-k with 10% contingency = 950 gal)	6000	132
Gasoline (with 10% contingency = 380 gal)	3000	59
Ethanol (10 gal)	70	2
Core boxes (50 empty boxes)	1000	560
Sub-Totals	**10070**	**753**
Complete Drill System		
Totals	**13985**	**1021**
Flight Logistics	**# of Flights (one-way)**	
Twin Otter DHC-6 (1100 - 3200 lbs payload*)	5- 13	
Basler BT-67 (3000 - 8400 lbs payload*)	2 - 5	
LC-130 Hercules (5000 - 22000 lbs payload*)	1 - 3	
Bell 212 Helicopter (500 - 2000 lbs external load*)	7 - 28	

*Depending on distance, elevation, fuel availability, and skiway condition (fixed-wing)

Logistics Comparison





Volume Comparison for 700 m Core (cubic feet)			
	98 mm Core	**64 mm Core**	**Savings**
Drill fluid	290	135	155
Ice core and boxes	1,300	560	740
Totals	**1,590**	**695**	**895**

Weight Comparison for 700 m Core (lbs.)			
	98 mm Core	**64 mm Core**	**Savings**
Drill fluid	13,000	6,000	7,000
Ice core and boxes	13,100	5,600	7,500
Totals	**26,100**	**11,600**	**14,500**

Note: Going with Estisol 140 increases the shipping weight 2,000 lbs. for a 98 mm core and 1,000 lbs. for a 64 mm core.

High-Level Equipment List

- Total project cost of equipment and materials is estimated to be $881,000 to $920,000
  - IDP labor, contractor services and associated indirect costs are not included
- Completion is expected to take 18 months following approval and funding
  - Includes fabrication, assembly, testing, modification (as needed), and field packing

Winch and Tower	
Winch/sled assy. with level wind and 750 m cable	$51,500
Second winch drum for spare cable	$8,000
Spare 750 m winch cable w/ termination	$10,500
Tower and crown sheave assembly	$19,000
Sonde	
Foro 1650-style drill sonde with 1-meter core capacity	$141,000
Spare sonde	$141,000
Internal electronics	$40,000
Chips bailer assembly add-on to sonde	$7,000
Control System	
Control boxes, displays, and cables (with spares)	$25,000 - $50,000
Tilting Table	
Table, fluid tray, tilting mechanism with counterbalance	$6,000
Core Processing Line	
Core push-out and logging tray	$6,000
Misc. equipment	$1,000
Fluid Handling	
Drum pump (x2) and hoses	$3,500
Vacuum	$2,000
Cable cleaner	$2,000
Fluid trays and custom flexible liners	$3,000
Misc. equipment	$1,000
Fluid bailer	$2,000
Chips Processing	
Melter tank assy. with spares	$8,000
Collection tank with filter bags/screens	$700
Misc. equipment	$500
Drill Tent	
Custom drill shelter based on BID-Deep tent by Fabricon	$25,000
Pickets, guylines, and misc. for shelter set-up	$5,000
PPE and Safety Equipment	
Driller suits, gloves, safety glasses, etc.	$4,000
Maintenance Tools and Supplies	
Tools, common maintenance supplies, tool cases, etc.	$8,000
Electrical Power and Distribution	
Generator (x2), 240-volt, single-phase, gasoline	$6,000
Load sharing controller	$700
Distribution equipment and cables	$2,000
Renewable energy power system	$15,000
Shipping Cases and Crates	
Complete system	$20,000

Discussion