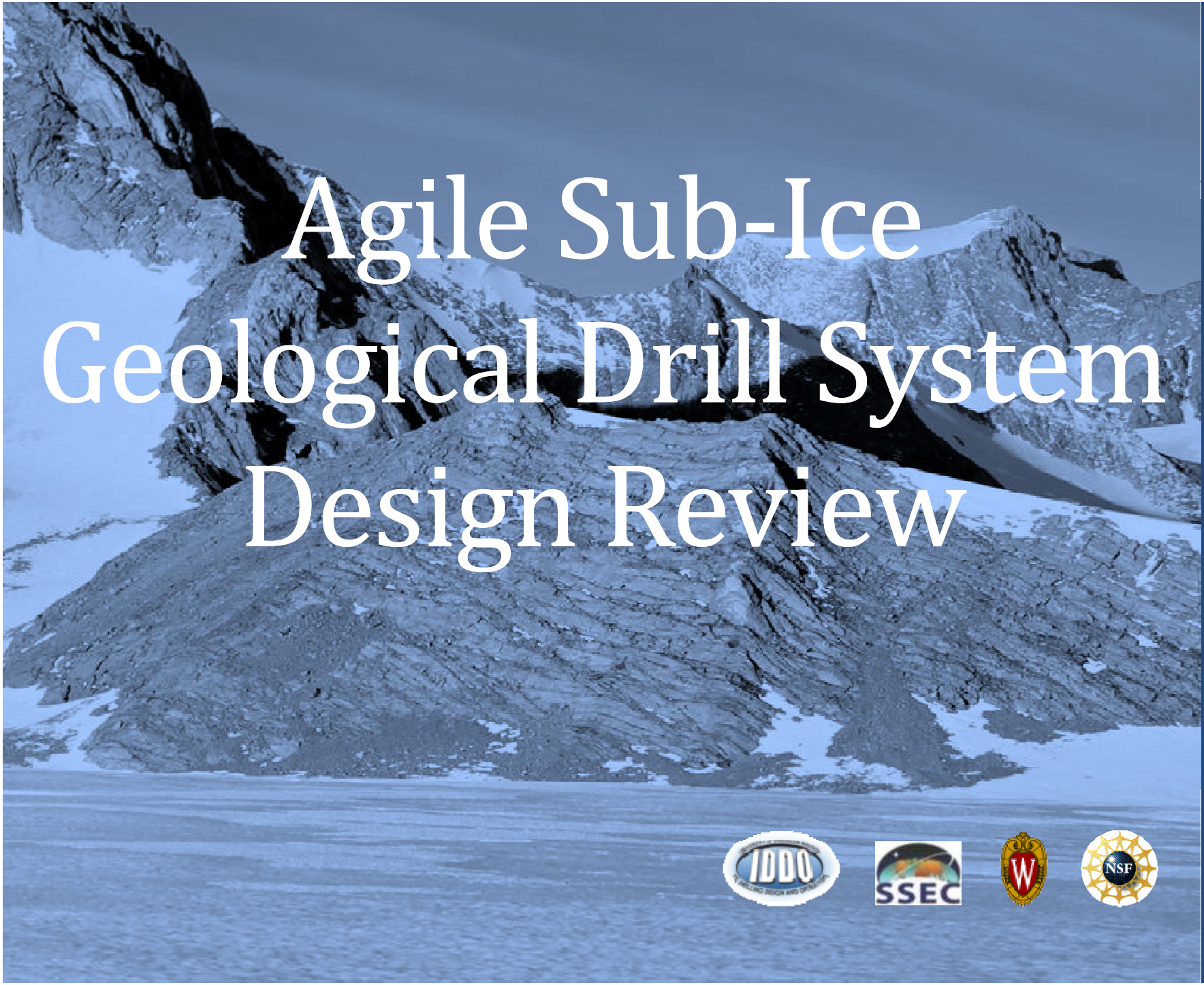
Agile Sub-Ice Geological Drill System Design Review



Science Requirements

- *Scientific Requirements*
- Produce a 700 m borehole to base of ice with drilling and retrieval of 10 m of bedrock core and / or unconsolidated frozen sediment core.
- Ice drilling will include the possibility that the ice is entrained with rocks.
- Ice drilling will be to dry, frozen-bed conditions, and will not be done in areas where there is sub-glacial water.
- Retrieve several short ice cores (~50 cm long) at up to 700 m depth.
- Ice drilling may be in ice that is within 2.0 C of the pressure melting point.
- Required ability to drill at ice borehole temperatures as low as -40 C, and surface temperatures as low as -30 C.
- Retrieve 10 m of bedrock cores of maximum 33 mm (1.3”) diameter beneath the ice sheet.
- Maximum site altitude for the design should be 2,500 m.
- Maximum time at a site, including set up and core retrieval, should be 6 days.
- Stand-alone capability is needed for operation in small field camps at remote sites.
- Minimal staff (4) for drilling operations in the field; other field camp staff in support of drilling operations to be provided separately.
- Drilling fluid or a fluid “system” (to be determined) will be immiscible with water.
- Drilling fluid should not be a boron-rich fluid.
- Drill system must be transportable by Twin Otter, or helicopter with sling load.
- Drilling depth of each core collected should be determined and recorded.
- Drilling and core handling history should be recorded.

Safety

- Safety of personnel using this drill is paramount:
  - Hazardous nature of the operations
  - Severe environmental conditions at the drilling locations
  - Extremely long travel time to medical and life-support facilities
  - Small mishaps may have severe consequences in this environment
- FMEA
  - Initial assessment completed
- PPE
  - Gloves, aprons for working with drill fluid
  - Eye protection
  - Hard hats
  - Insulated steel-toe Boots
- Safety Plan
- Pre-season Training with Consultant
- Operations, Maintenance, Assembly Procedures
- E-stop System

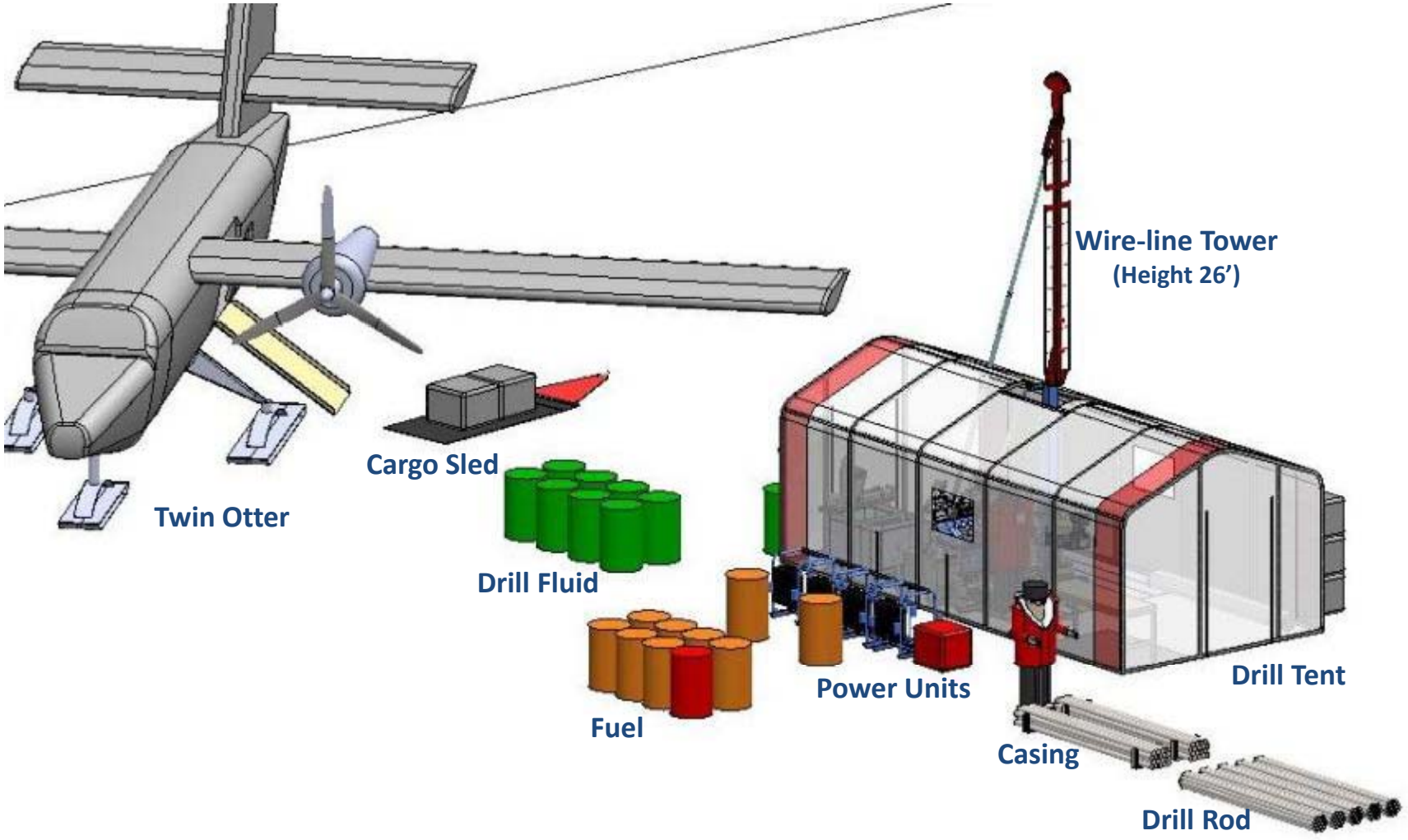
Background and Design Decisions

- Traditional tethered ice-coring drills have been modified for sub-glacial till and bedrock sampling with limited success.
  - Theoretically possible to obtain 5 meters of sub-glacial material (Talalay).
  - Previous attempts have recovered a maximum of 1 meter of true bedrock.

- Rapid access to bedrock through overlying ice was explored by Gerasimoff in support of the development of the Rapid Access Ice Drill (RAID), currently being designed by DOSECC Exploration Services.
  - RAID is based upon a modified commercial minerals exploration coring rig.
  - Ice is drilled in a continuous manner with only intermittent core recovery.
  - Traditional rock coring equipment and techniques are used for sub-glacial sampling.

- A simplified and down-sized version of the RAID concept would meet the science requirements developed for an agile sub-glacial sampling drill.

System Overview



Typical Drill Site

Operations Overview

- ASIG drill system designed to be operated by 2 experienced drillers and 1-2 core handlers per shift for maximum efficiency.
  - 4 people necessary for system transport and assembly

- Casing Setting
  - Porous upper layers pre-drilled with an auger (testing 2015-16 MCM) or traditional firn coring barrel assembly driven by the drill rig.
  - Rig utilized to insert casing.
  - Casing terminated with a inflatable packer to tightly seal to non-porous ice.

- Ice Borehole
  - Drilled in continuous manner with non-coring bit.
  - Ice cuttings transported to surface inside drill rods by reverse-circulating drilling fluid.
  - Intermittent ice coring possible by replacing non-coring bit with core barrel assembly (requires pulling and re-running drill string).

Operations Overview (cont.)

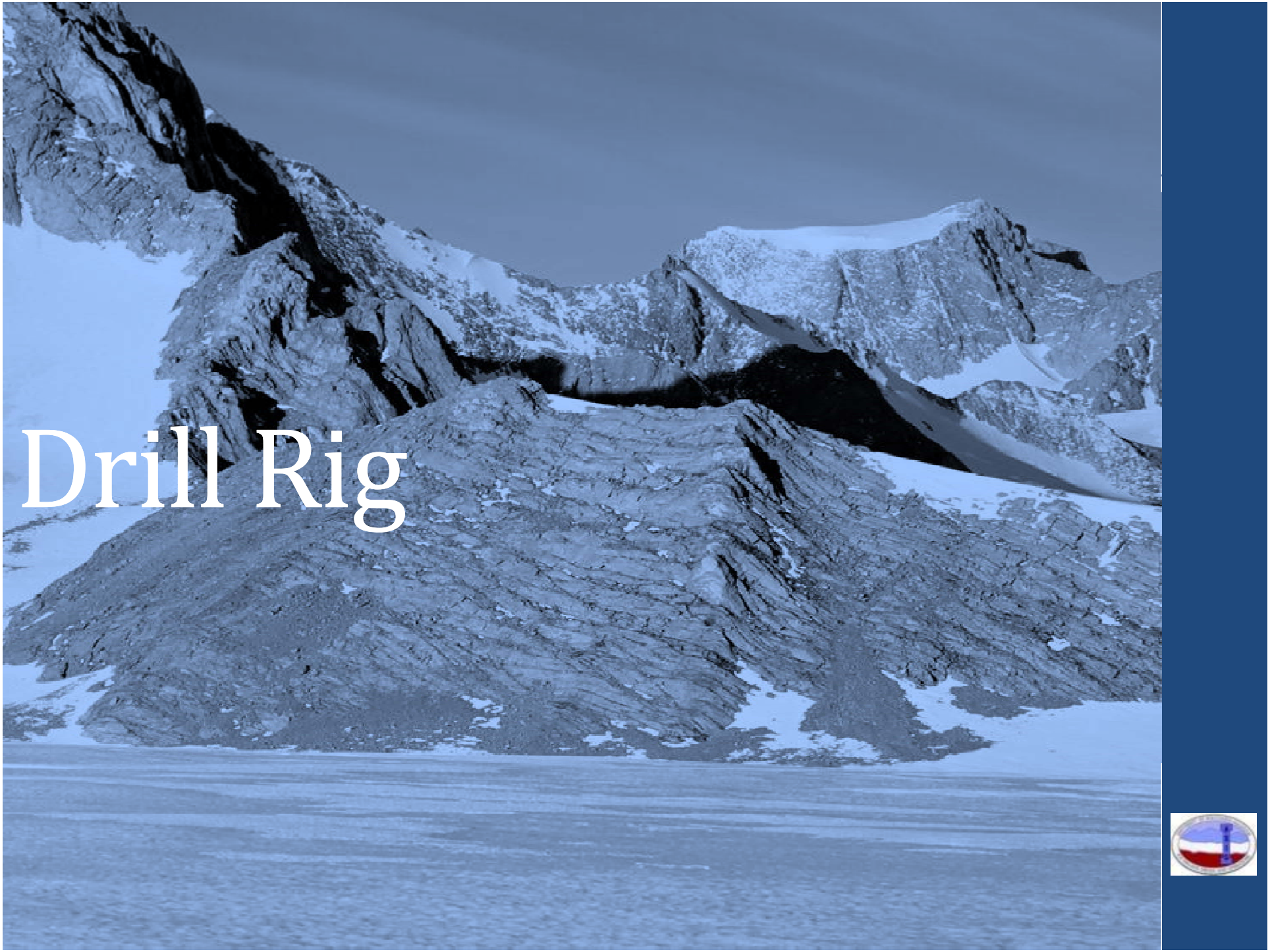
- **Rock Coring**
  - **Traditional rock coring bits used for sub-glacial sampling beginning several meters above the bed.**
  - **Conventional or wire-line core recovery depending on hole depth.**
  - **3 meter long cores in a single run.**
  - **Normal circulation used for coring operations.**

- **Filtration**
  - **Continuous filtration of drilling fluid using a custom de-watering screw-press.**

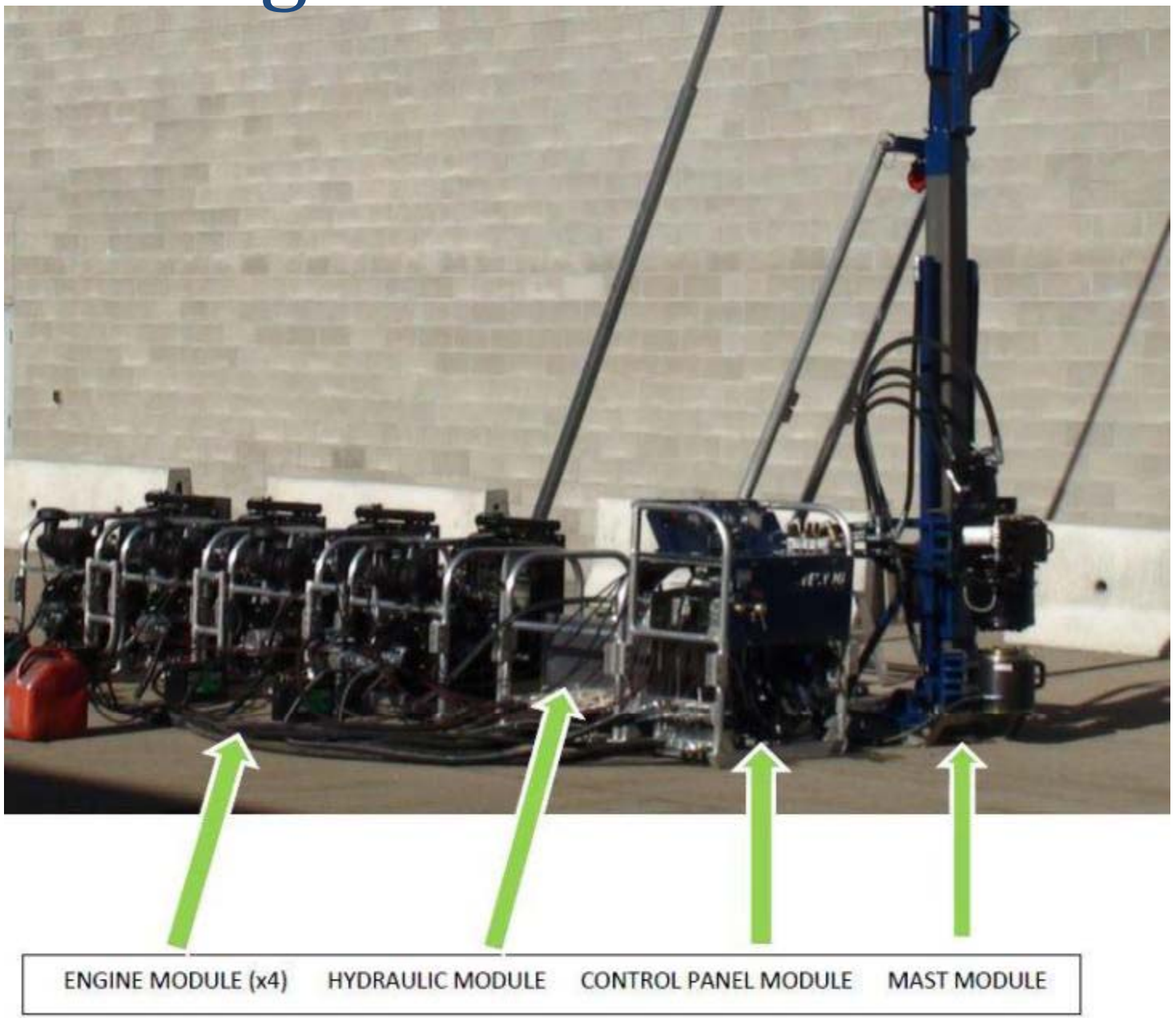
ASIG Project Timeline

Agile Sub-Ice Glaciological Drill Project Milestones	
Requirements Defined	3/15/14
Conceptual Design Complete	8/31/14
Drill Rig Ordered	11/1/14
Drill Rig Received *	4/1/15
Detail Design Complete-Design Review	5/31/15
Ready to Ship Antarctic Traverse Materials [i.e. Fluid, Casing]	8/15/15
System Components Received	10/31/15
Complete Assembly, Integration-Testing	3/15/16
Field Test of Drill System Complete	6/15/16
Ready to Ship Drill System to Antarctica	8/31/16

*Final acceptance pending.


Drill Rig

Drill Rig Overview



Drill Rig Components

Drill Rig Specifications

Multi Power Products Discovery MP1000 Man Portable Diamond Drill:
Depth Capacity:
B/WL – 1220 meters
N/WL - 945 meters
Equipment Specifications:
Kubota D1105T 32HP diesel x4
Hydraulic capacity – 60 GPM @ 3000 PSI
HWL MPP MP1000 lightweight rotation unit
Chuck maximum rod/casing diameter 3-1/2” (BWL – HWL)
HWL MPP MP1000 clamp assembly
Clamp maximum rod/casing diameter 3-1/2” (BWL – HWL)
Clamp & chuck clamping range ½”
(1) Jaw set provided with a clamping range accomodating BWL drill rod
(consists of 1 complete jaw set for the head and 1 complete jaw set for the foot clamp)
(1) Jaw set provided with a clamping range of 3” – 3-1/2”
(consists of 1 complete jaw set for the head and 1 complete jaw set for the foot clamp)
Fully synchronized head & foot clamp chucks hydraulic circuit w/ an additional chuck control
Rexroth AA6VM160HD2 variable speed/torque hydraulic drill motor
Rotation RPM - Infinitely variable between 0 and 1200
Max rotation torque – 1360 ft-lbs.
Rotation unit gear ratio 3:1
Quality Sauer Danfoss and Valvoil hydraulic components
Flush-face quick couplers
Controls: Rotation fwd and back, rotary torque, rotary speed/torque, chuck and clamp open/close, fine feed
up/down, fine feed speed, feed pressure, winch spool in/spool out
Wireline winch w/ swaged cable (3000 ft.) x 3/16 in diameter capacity
Winch line pull (bare drum) – 3623 lbs.
Winch line pull (Full drum) – 1267 lbs.
Winch pull speed (bare drum) – 619 ft. / min.
Winch pull speed (full drum) – 1771 ft. / min.
2500 ft. x 3/16” swaged wireline cable included
Steel Wire line tower w/ 3m core barrel pull capability
Dual cylinder mast module
17,524 lbs. feed force
28,000 lbs. pullback
1.82m (6 ft.) Stroke
Capacity for both 10ft and 3m rods and core barrels
Drilling angle 45 – 90 degree
Sandblasted, primed, & painted
Cold Weather Package:
120V Engine heaters and hydraulic oil pan heaters
Battery blankets
Low temp engine and hydraulic oil
Low temp rating hydraulic hose and fittings (Parker 301LT) rated for -67 degrees F

Drill Rig Components (continued)

Control Module

Width: 43”
Depth: 26”
Height: 48”
Weight: 565 lbs*

*Anticipated weight after weight-reduction work currently in process.

Drill Rig Components (continued)

Mast Module

Feed: 17,525 lb
Pull Back: 28,000lb
Stroke: 6 ft

Top Drive:
- **Clamp Range: Ø2” to Ø3.5”**
- **Speed: 0-1200 RPM**
- **Torque: 1360 ft-lb**

Overall Dimensions:
- **Height: 122”**
- **Length: 110”**
- **Width: 37”**

Weight:
- **1335 lb**
- **Multiple shippable units**
- **Excludes top drive, foot clamp, winch**

Drill Rig Components (continued)

Hydraulic Tank Module

Width: 29-15/16 in. / 760 mm
Length: 42-1/4 in. / 1073 mm
Height: 35-7/8 in. / 911 mm
Weight: 440 lb. / 200 Kg (wet)

Drill Rig Components (continued)

Power Modules

32 HP Kubota Turbo Diesel
Width: 25”
Length: 38”
Height: 39”
Weight: 395 lbs

Drill Rig Components (continued)

Wire-Line Winch

Length: 30”
Width: 28”
Height: 24”
Weight: 405 lb
(c/w 2500’, Ø3/16” Cable)

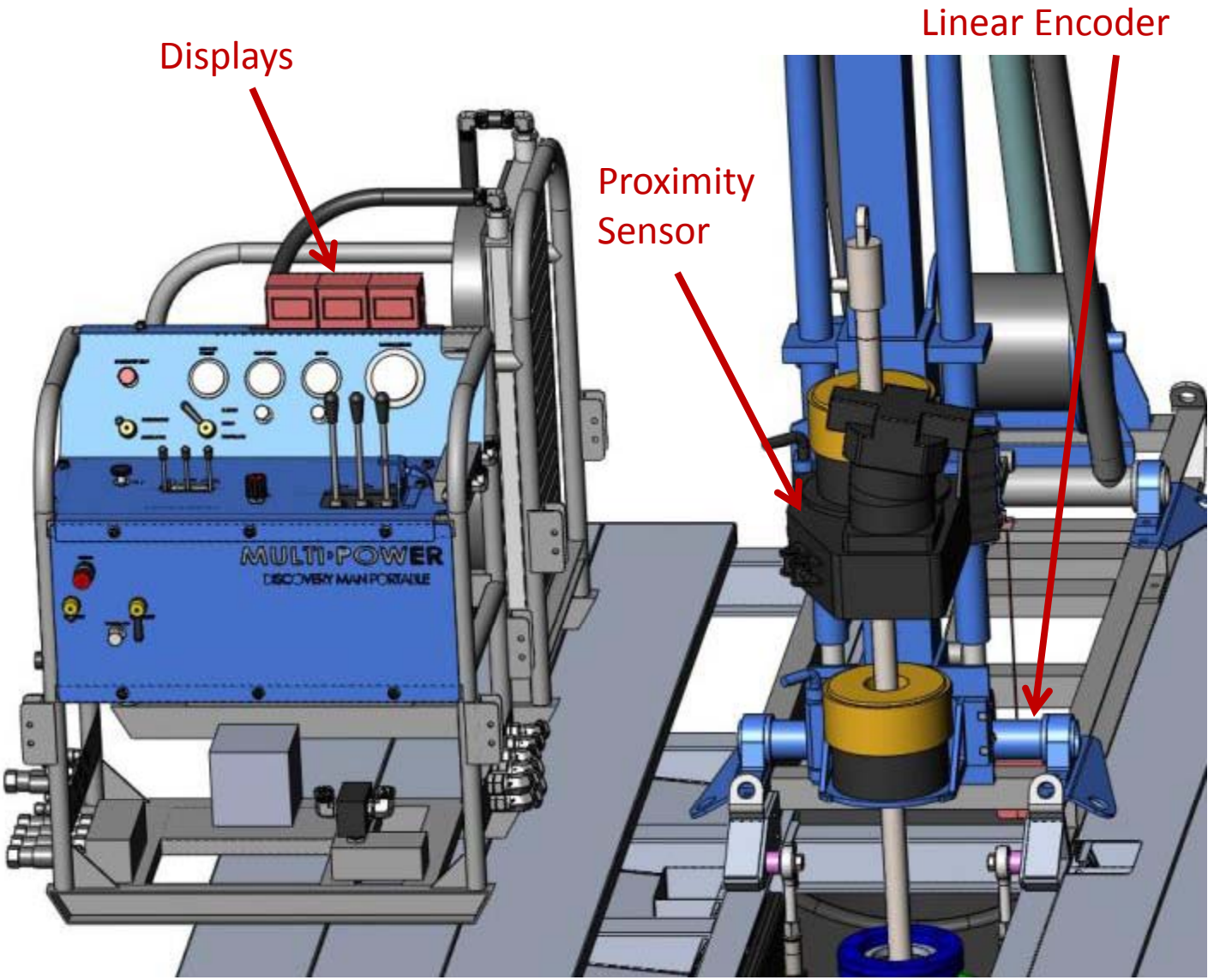
Speed: 619 ft/min (bare drum)
Line Pull: 1267 lb (full drum)

Drill Rig-Readout System

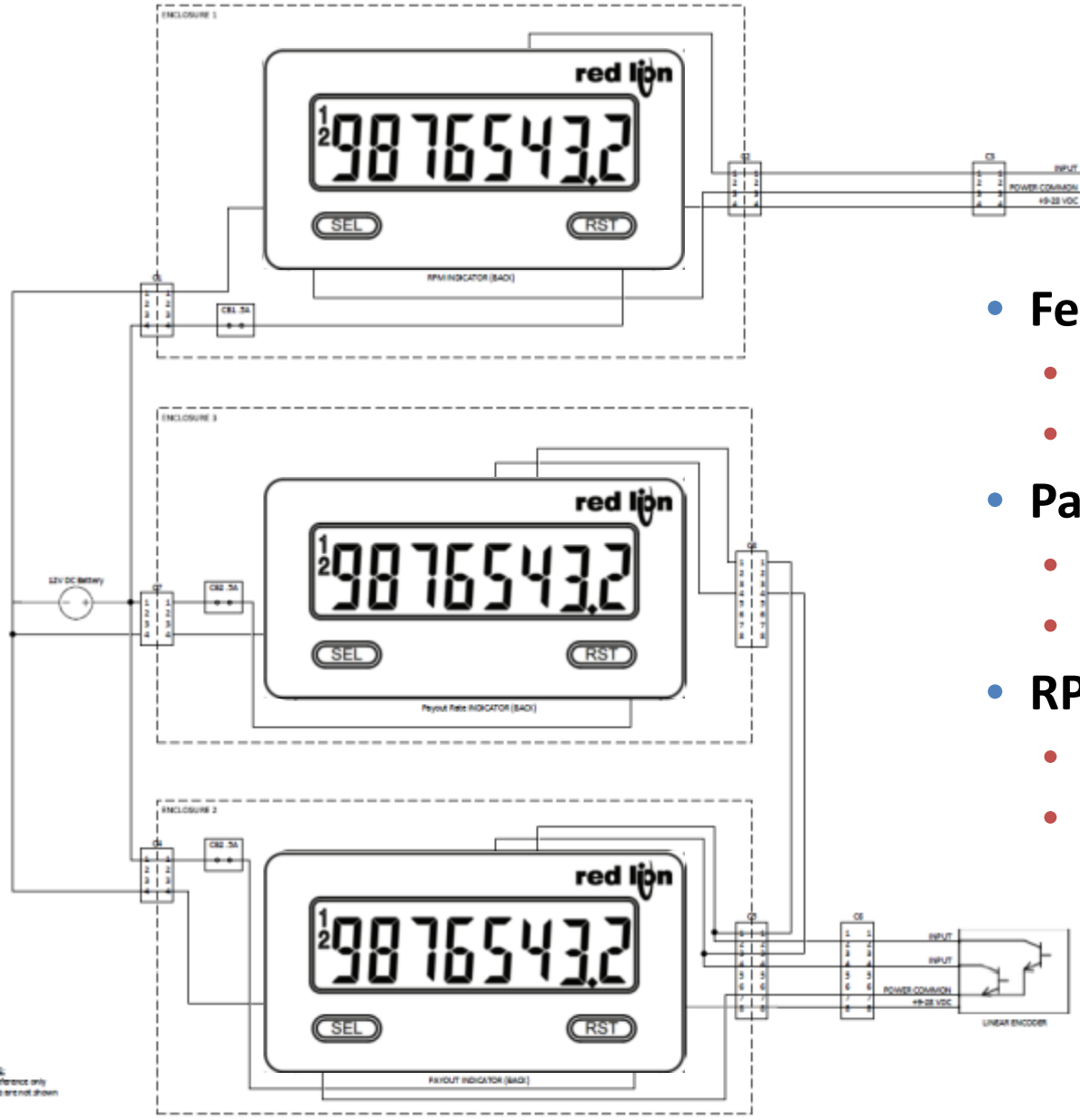
- **Improved feedback for ice coring and process development**

- **3 Displays**
  - Feed-rate
  - Payout
  - RPM

- **2 Sensors**
  - Linear Encoder
  - Proximity Sensor



Readout System Overview



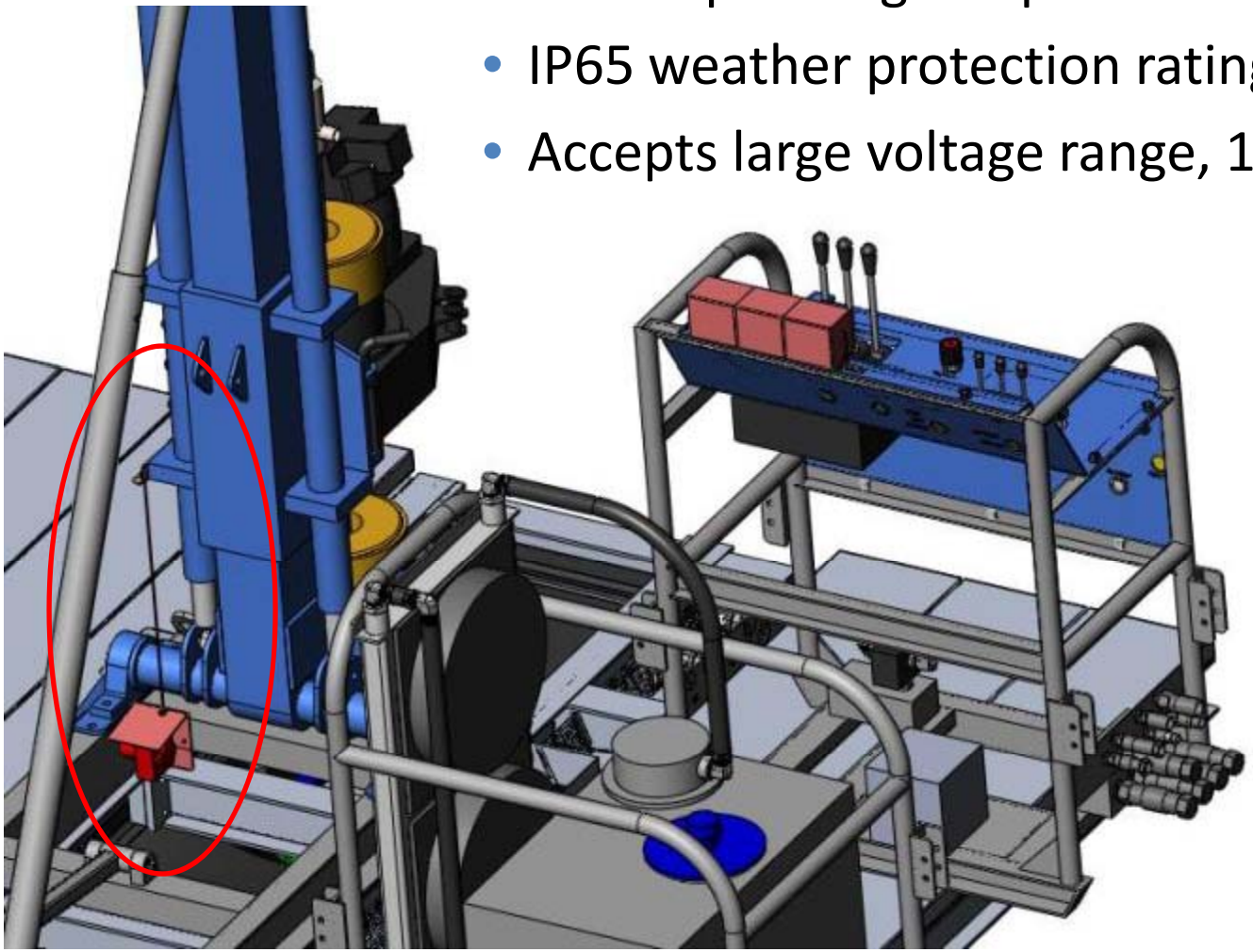
- **Feed-rate:**
  - 1 to 0.2m/sec
  - +/- 0.001m/sec
- **Payout:**
  - 0 to 2m
  - +/- .005m
- **RPM:**
  - 0 to 1500
  - +/- 10% reading

Display Unit

- Red Lion CUB5 8-digit rate indicator
- -35°C operating temperature
- IP65 and NEMA 4x enclosure rating
- Accepts large voltage range, 9-28 VDC
- Maximum count-rate 20kHz

Linear Encoder

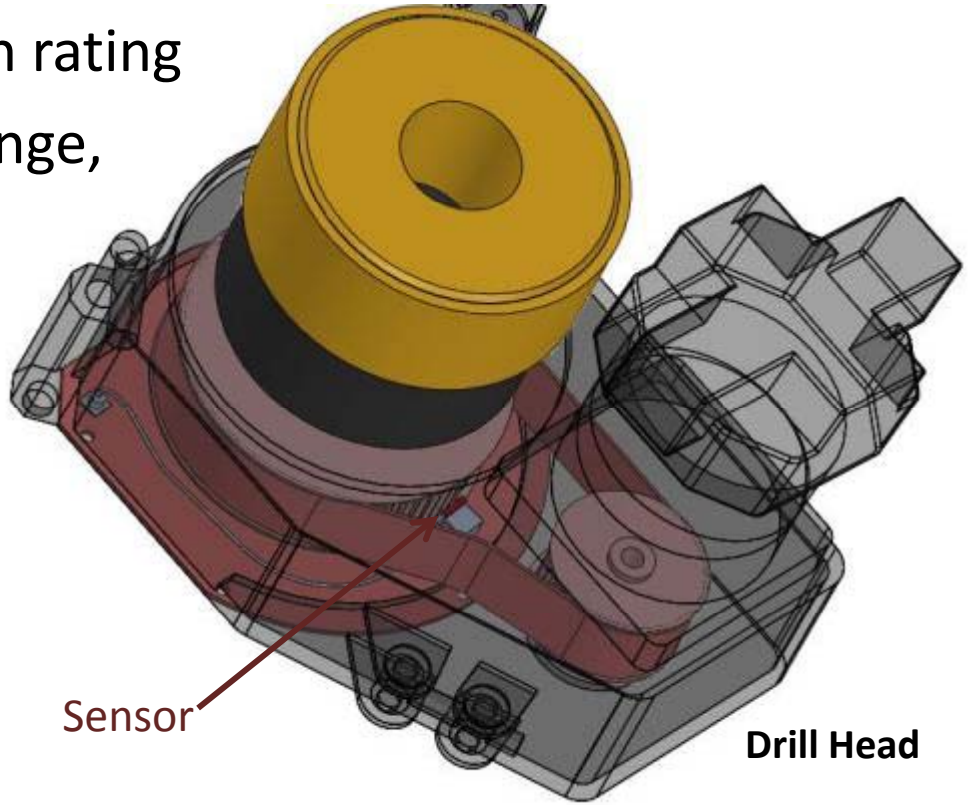
- Lika SF-1 draw-wire incremental encoder
- Generates feed-rate and payout
- -40°C operating temperature
- IP65 weather protection rating
- Accepts large voltage range, 10-30 VDC



Proximity Sensor

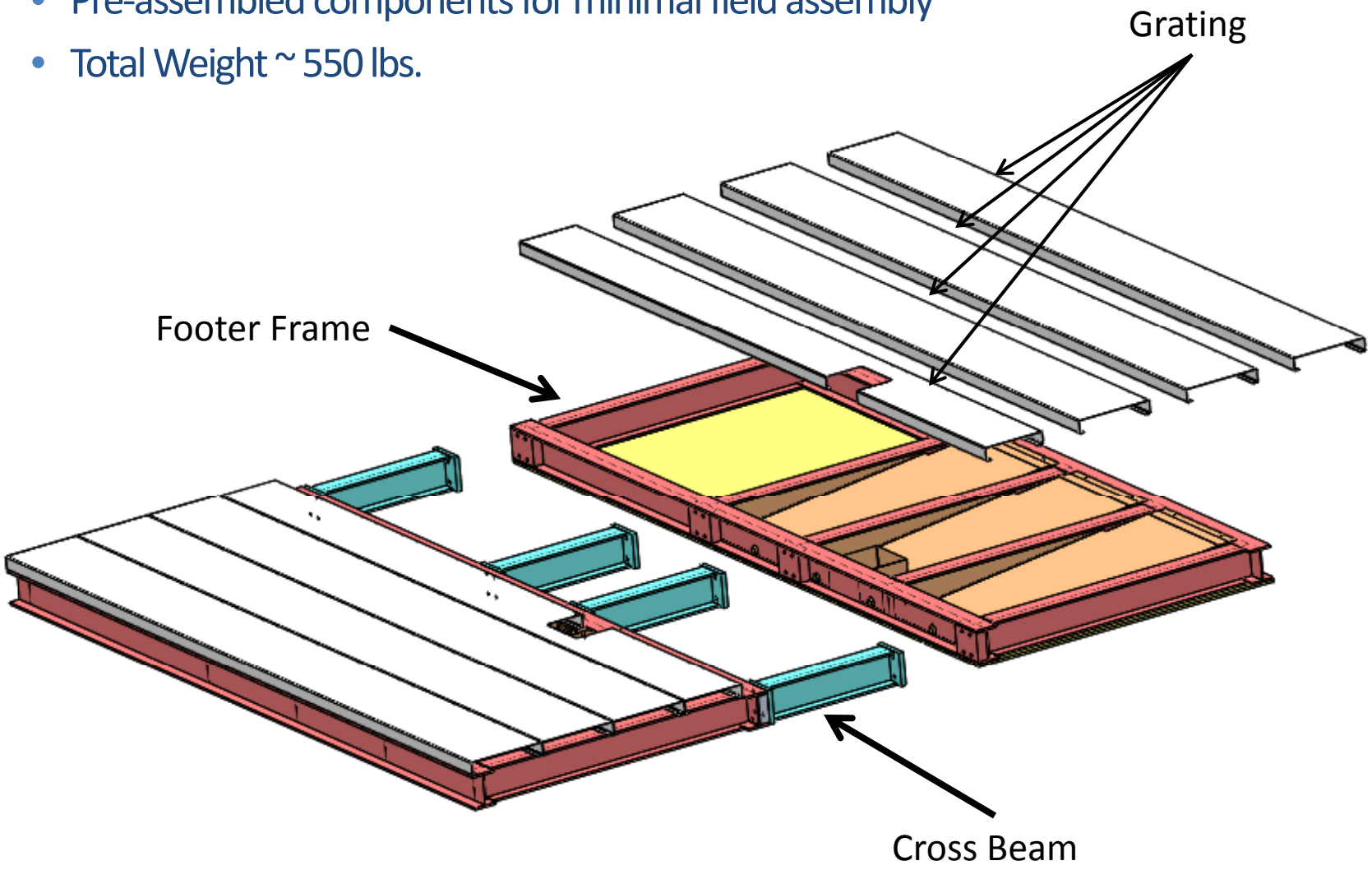
- Automation Direct CR5 Inductive Proximity Sensor
- Generates RPM signal
- Compact 5mm x 5mm x 25 mm
- -25°C Rated operation
  - Tested by IDDO to -40°C
- IP67 Weather protection rating
- Accepts large voltage range,

  10-30 VDC



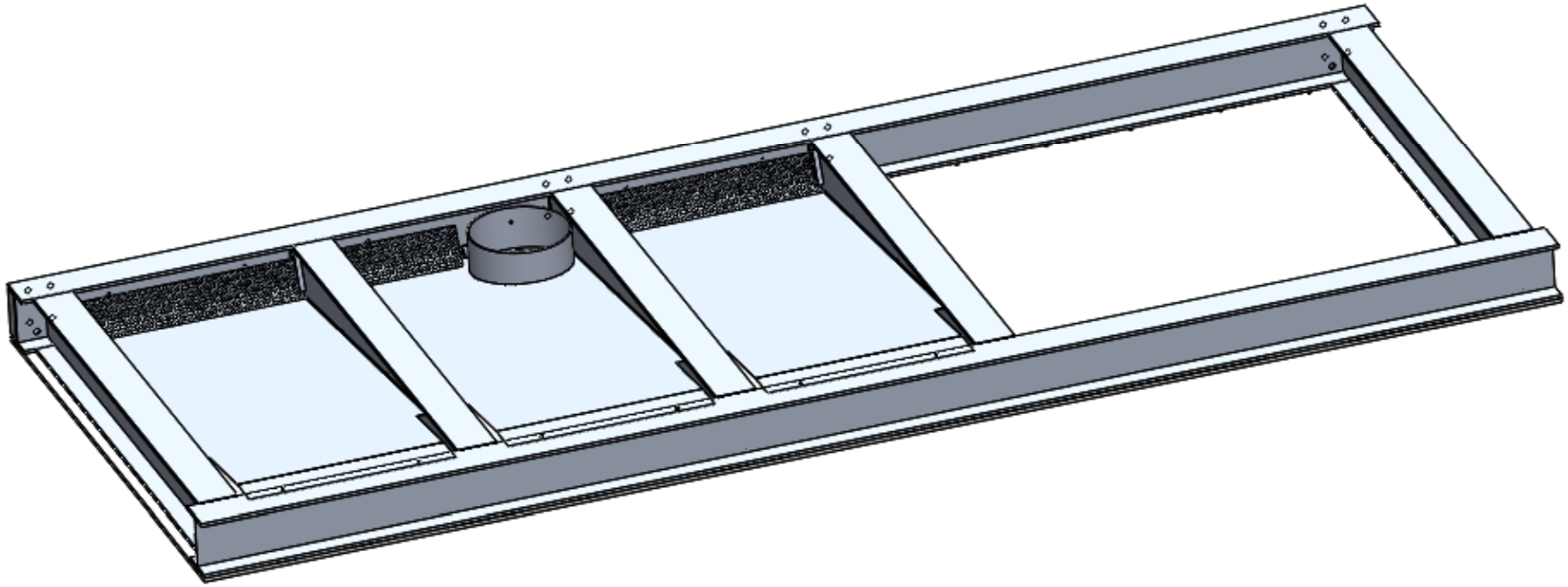
Rig Footer - Overview

- Pre-assembled components for minimal field assembly
- Total Weight ~ 550 lbs.



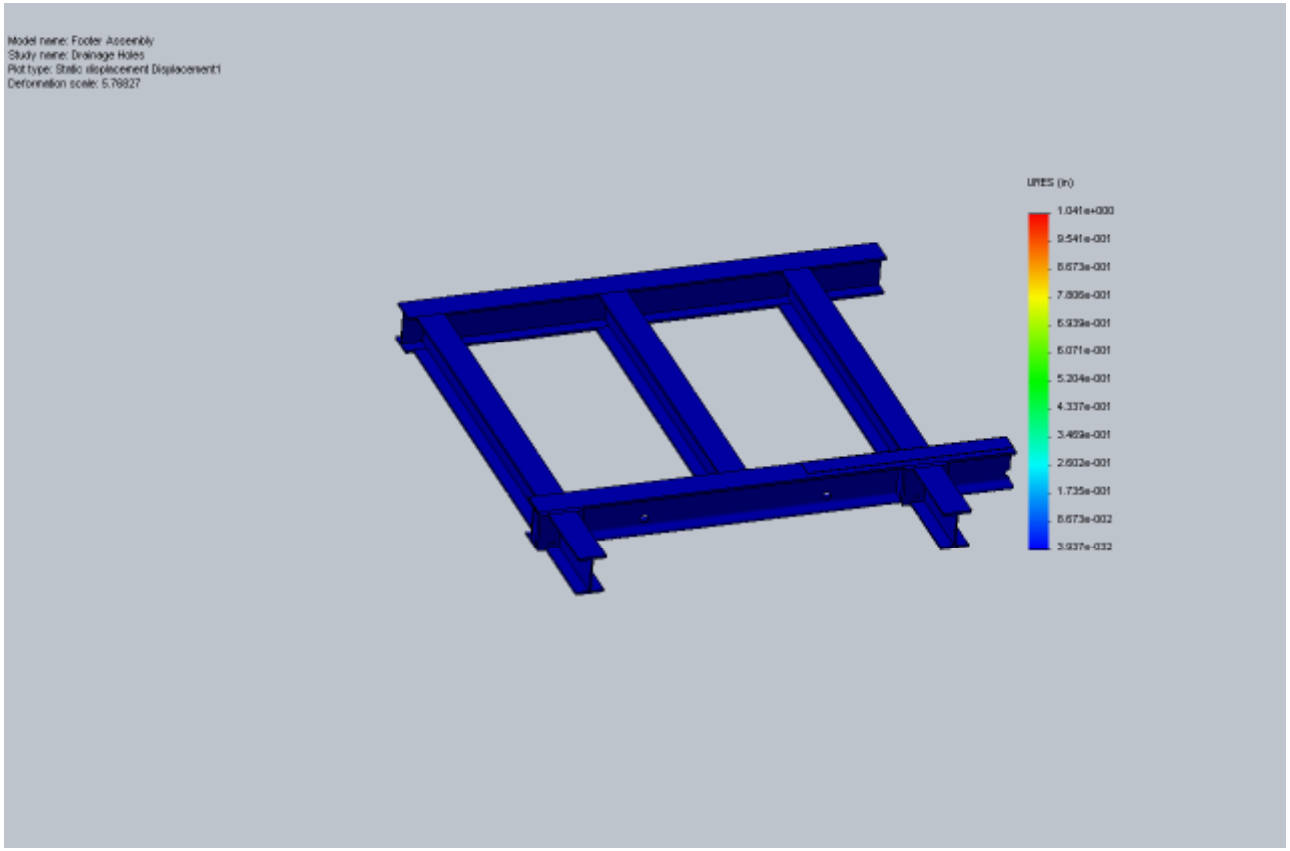
Rig Footer - Frame

- Assembly includes:
  - Aluminum weldment
  - Drip tray assemblies
  - HDPE sheet for weight distribution
- Dimensions: 120.00” x 48.75” x 5.38”
- Assembled weight = 180 lbs.
- Maximum Snow Pressure = 2.80 psi



Rig Footer – Frame Analysis

- **Maximum Load is the sum of the pull up force and weight of the rig***
- **Maximum load = 30,757 lbs.**
  - **Deflection = 1.04”**
  - **Safety Factor = 1.7**

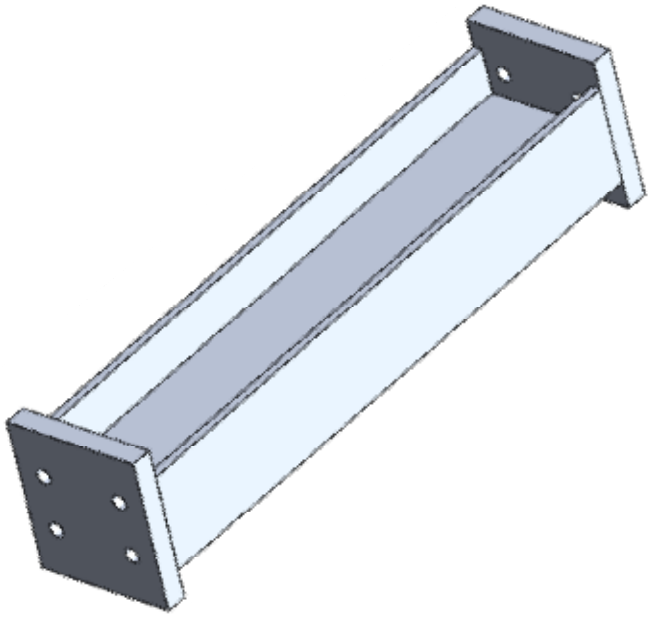


*Core break force is expected to be significantly less than rig capacity. Load will be transferred to casing as frame deflects, this scenario was neglected during study.

Rig Footer – Grating/Cross Beam

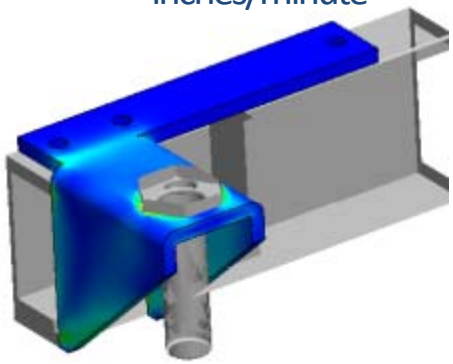
- **Grating**
  - 120.00" x 11.75" GRIP STRUT® Plank Grating (6x) = 16.0 lbs.
  - 120.00" x 9.50" GRIP STRUT® Plank Grating (2x) = 14.00 lbs.
  - Load Capacity – 631.00 lbs./ft.
    - Heaviest component resting on grating is control module (565 lbs.) but spans I-beams below grating.

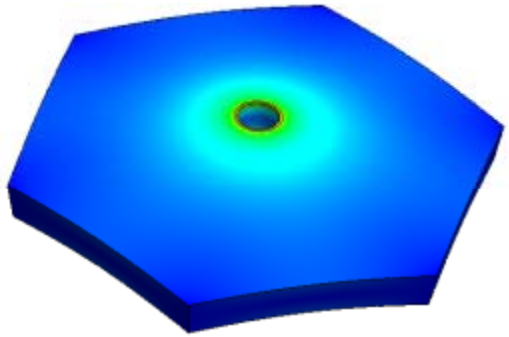
- **Cross Beams**
  - Weight = 10.2 lbs.
  - Assembled with ½-13 x 2.5, grade 8 bolts
  - Clearance for use of torque wrench during assembly

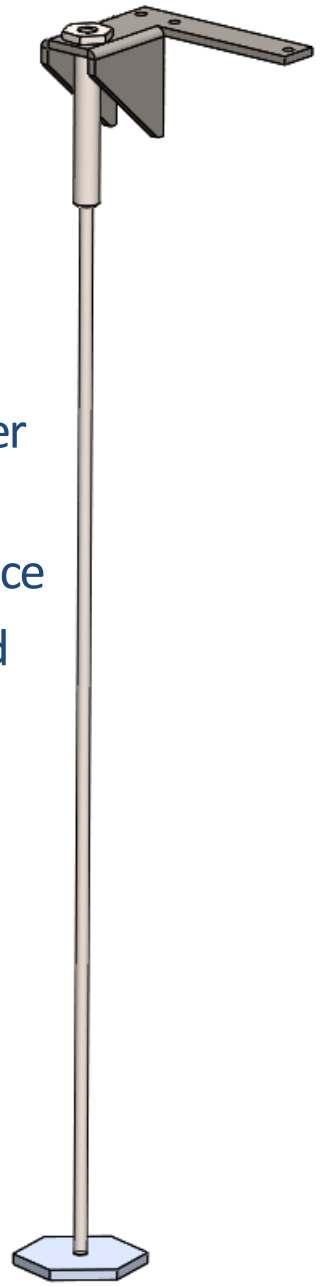


Rig Footer - Anchor

- 8” auger used to create 50” deep hole; snow is tamped during backfilling
  - 8” x 36” auger weight = 10 lbs.
- Drip tray is used as a template for location of hole
- Threaded rod does not protrude from snow – rig can slid onto footer without interference
- Disposable anchor plates; threaded rod can be removed from surface
- Failure modes – Based on Results from “Anchoring in Snow, Ice, and Permafrost” M.C. Hironaka
  - Compression limits ultimate load capacity,
  - Shear dictates depth of Anchor Plate
  - Maximum at each anchor is 7005lbm, at that load expected creep is <.007 inches/minute








Casing System

Casing System Overview

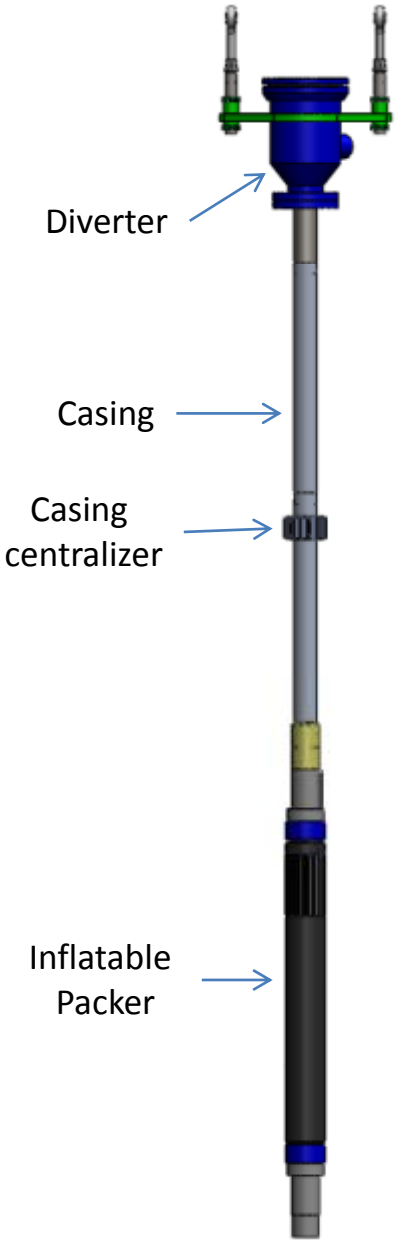
Diverter – Provides a sealed feed through for the drill rods while maintaining control of pressurized drilling fluid in the well. Required for operating in reverse circulation.

Casing – Fluid tight conduit between the diverter and the packer.

Casing Centralizers – Keeps the casing centered in the ice borehole and prevents buckling under compression.

Inflatable Packer – Seals the casing system to the surrounding ice my means of an inflatable rubber element. It also prevents axial movement of the casing system.

Estimated system weight of 600 lbs. for a 50 m casing



Casing System Components

Pilot Hole

- 476 mm Ø (5.75”) x 50 m max design depth
- Planning on drilling the hole with an auger
  - Drill rig will be used to drive the auger
  - 3’ long auger sections
  - Full fights to the surface
  - Modified off-the-shelf cutter head
- A Kwik Klamp 1 rod clamp with custom jaws will be used to support the auger string during pull back
- Auger system needs to be tested prior to the field project
  - Determine if a hole can be augered to 50 m depth
  - Establish speed and time requirements
- The back up plan is to use the IDDO Prairie Dog drill
  - Drill rig will be used to drive the core drill
  - Drills a 145 mm Ø (5.7”) hole
  - Will take ~ 10 hours to drill to 50 m depth

Auger head

Lake ice auger test

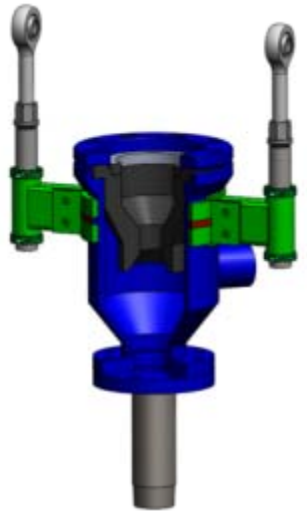
Prairie Dog drill

Kwik Klamp

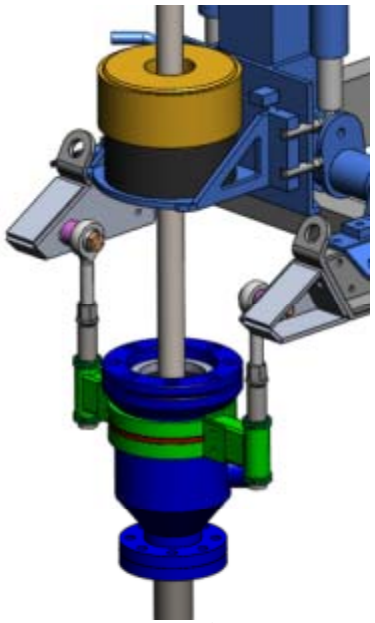
Casing System Components

Diverter

- 11.0” Ø x 16.5” long, 120 lbs.
- Flange mounted natural rubber stripper element
- Casing sub welded to bottom flange
- Mount assembly provides vertical and rotational adjustment
  - Vertical adjustment is made by turning the strut assemblies
  - Prevents the casing from pushing out of the well if the packer slips
  - 10,000 lb. axial load capacity
- 11.0” – 15.0” of clearance to the foot clamp
  - Provides clearance for removing the stripper and installing the drill pipe protectors (DPP)
- A sub-plate goes in place of the rubber stripper when using the drill rod clamp



Section view



Stripper element installed

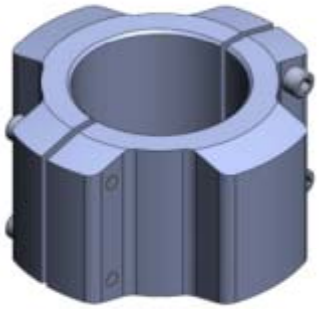
Removing/installing Stripper element

Casing System Components

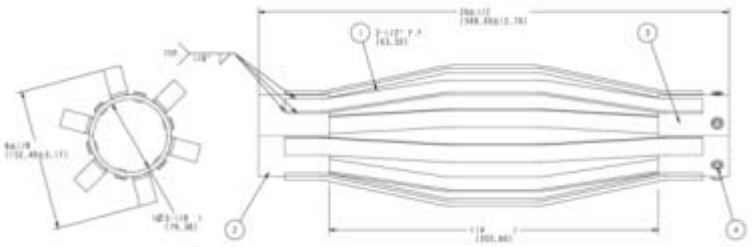
Casing

- 76.2 mm (3.00”) OD x 66.7 mm (2.63” ID)
- 6061-T6 Aluminum
- 3.0 m and 0.75 m long sections
- QD Tech design with shallow tapper threaded ends
- 6.5 lbs. per meter
  - 325 lbs. for 50 m length
- Will fit through the head and foot clamps
  - A Kwik Klamp 1 with custom jaws for an ancillary clamp
- Evaluating rigid and spring type casing centralizers
  - Clamp-on type preferred so rig head and foot clamps can be used for installing the casing
  - Placing 2.3 m apart will provide a 10,000 lb. axial load capacity with 2 x safety factor

Casing sections



Rigid clamp-on centralizer

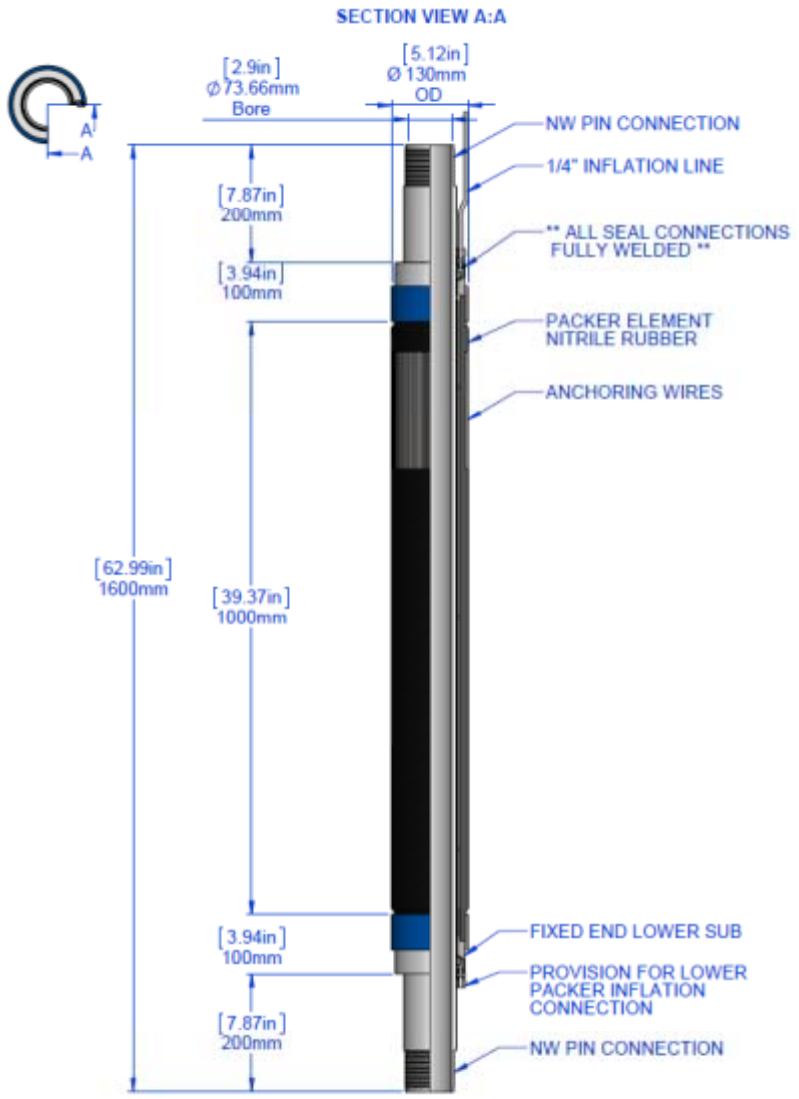


Spring type centralizer

Casing System Components

Packer

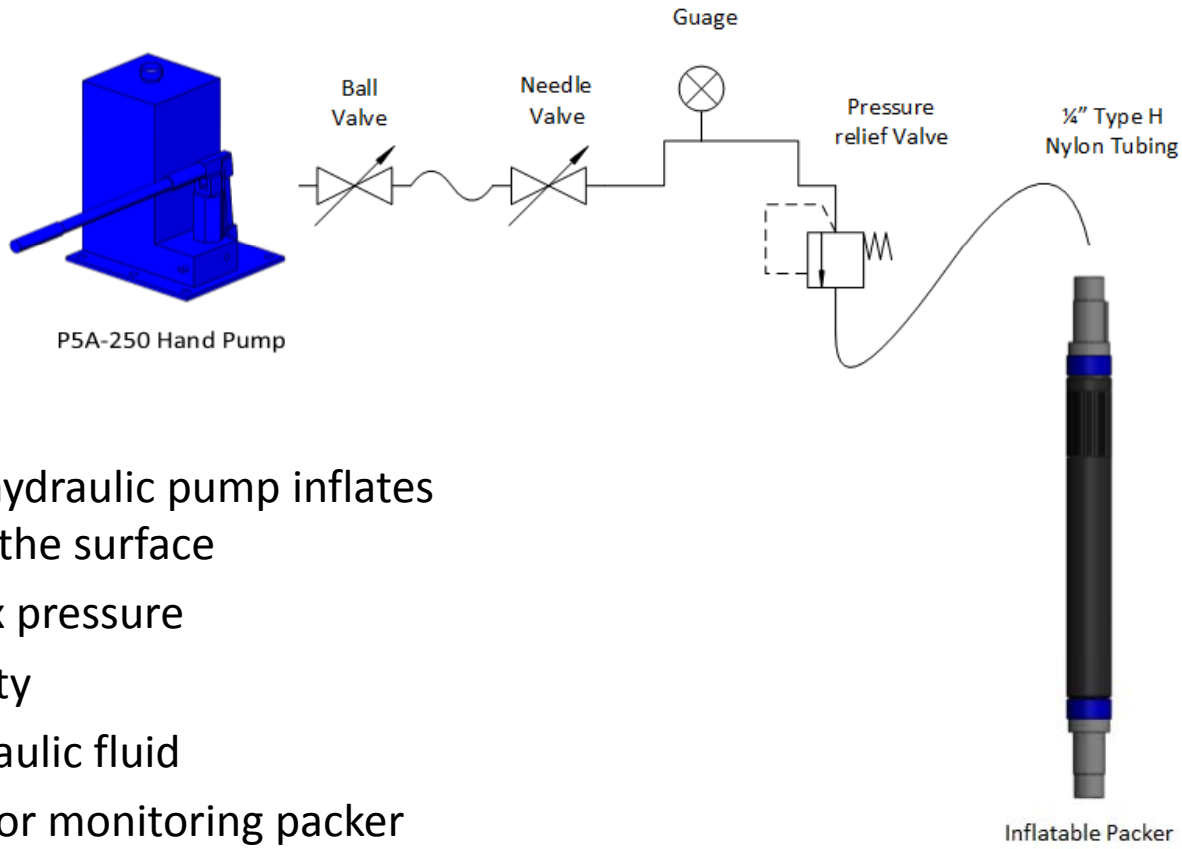
- Inflatable design by Inflatable Packers International LLC
  - Nitrile rubber element
  - Imbedded anchoring wires
- 1.6 m overall length
- 73.66 mm (2.9”) bore
- 130 mm (5.12”) OD when deflated
  - Expandable to ~ 190.5 mm (7.5”)
- The packer will need to provide 7,888 lbs. of axial holding force with drilling fluid at max design pressure of 350 psi
  - Requires a bladder pressure of 74 psi
    - Assuming a conservative friction coefficient of 0.2 for the ice/rubber interface
    - Negating any gain from the imbedded anchoring wires



Packer drawing

Casing System Components

Packer Inflation



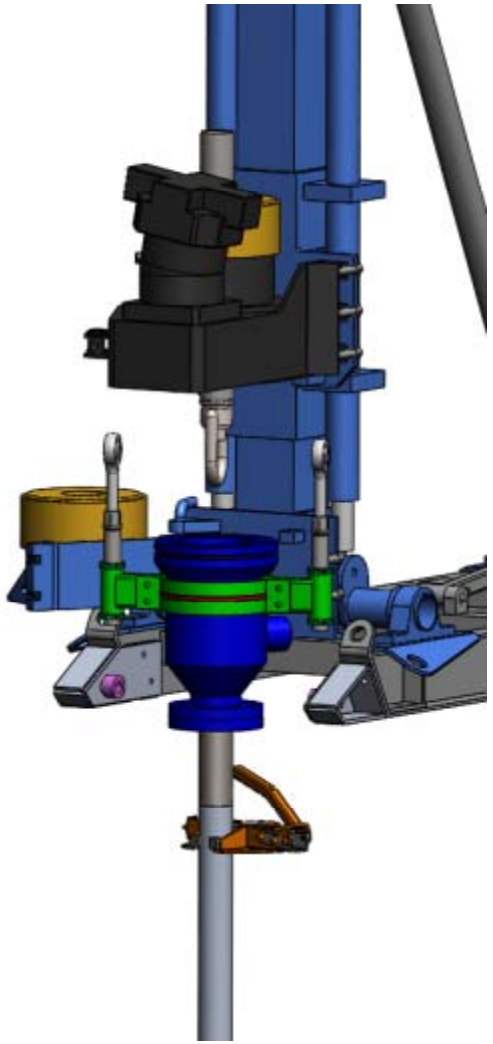
Packer Inflation Components

- Hand operated hydraulic pump inflates the packer from the surface
  - 1,000 psi max pressure
  - 4 Liter capacity
  - Isopar K hydraulic fluid
- Pressure gauge for monitoring packer pressure
- Needle valve isolates the gauge and packer from the pump
- ¼" Ø type H Nylon tubing runs between the pump and packer

Casing System Components

Casing Installation

- Casing sections will be installed using the head and foot clamps
- An ancillary clamp holds the casing string once it is near the desired depth
- The diverter assembly with sump liner will be installed next on the casing
- A hoist ring assembly will be inserted in the head clamp and rigged to the diverter with a chain or strap
- The head will be raised to lift the casing so the ancillary clamp can be removed
- The head will be used to lower the casing into place
- The diverter struts will be bolted into place and then the packer can be inflated



Lowering the casing system with the rig head


Down-hole Tooling

Down-hole Tooling Overview

Drill Rod

- **Sandvik WL56 thin-kerf; 53.2mm OD; 46.0mm ID**
- **11.3 kg per 3m rod (B rod = 18.0 kg/3.0m)**
- **3.0m and 0.75m long drill rod**

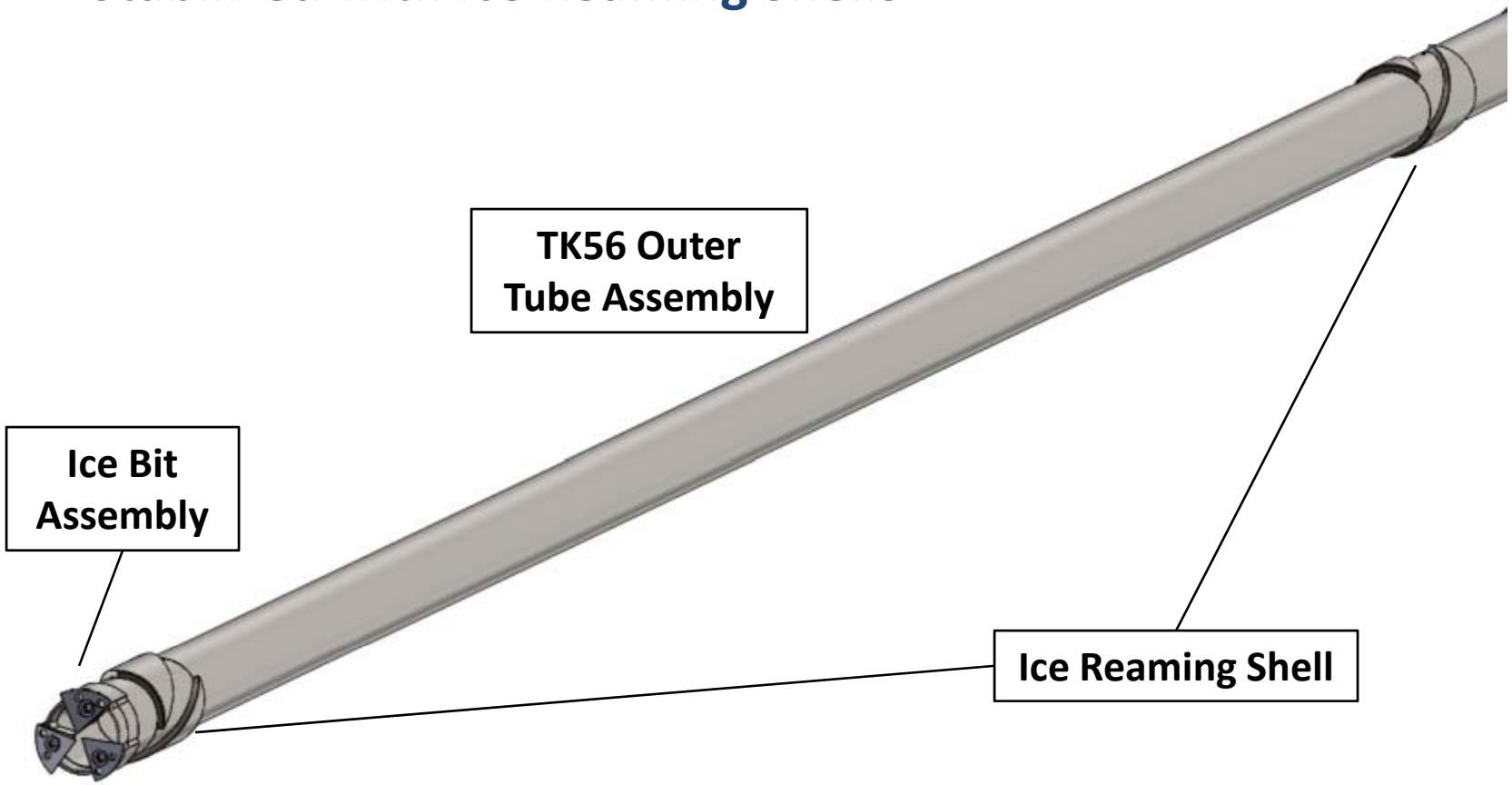
Stabilizer/Protector (as needed)

- **Centralizes drill rod in oversized casing**
- **Clamp-on style**

Down-hole Tooling Components

Ice Access Bottom-hole Assembly

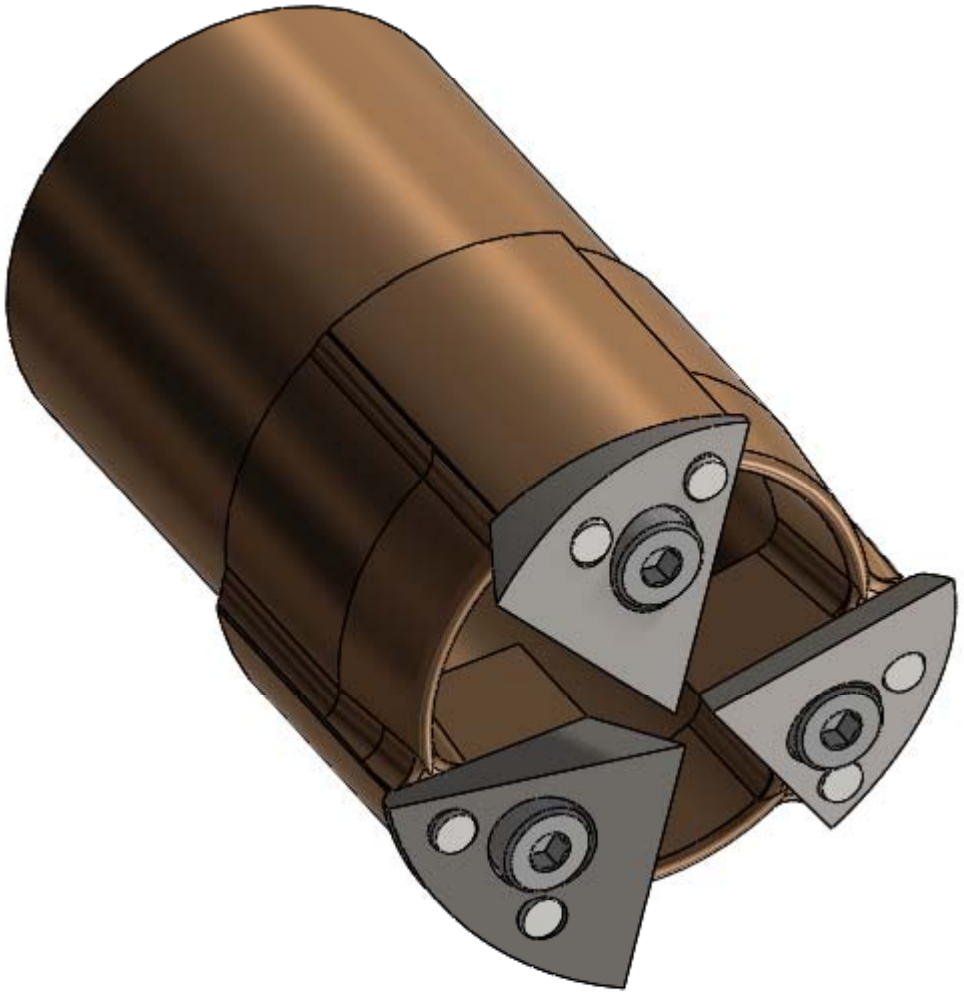
- Continuous drilling with reverse-circulation
- 62.5mm borehole diameter
- Stabilized with Ice Reaming Shells



Down-hole Tooling Components

Ice Access Hole Bit

- **Three replaceable A2 R58c tool steel cutters with cryogenic treatment for durability**
- **30-deg rake angle**
- **15-deg clearance angle**
- **Up to 2 m/min penetration rate @ 200 RPM (minimum)**
- **Bit body machined with box thread for Sandvik TK56 BHA**



Down-hole Tooling Components

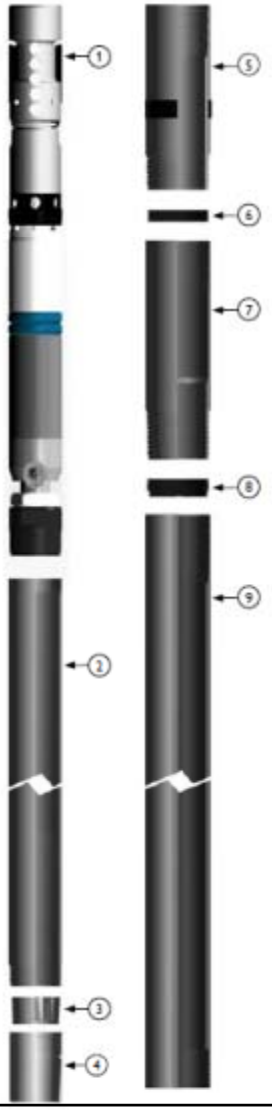
Sandvik TK56 Wireline System

- **39.0mm core diameter; 58.8mm borehole diameter**
- **Allows for wireline recovery of ice and rock cores without removal of drill rods**

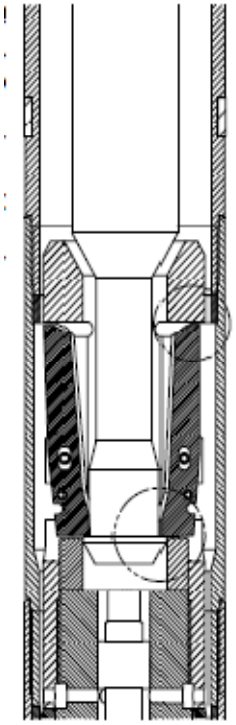
Down-hole Tooling Components

Sandvik TK56 System

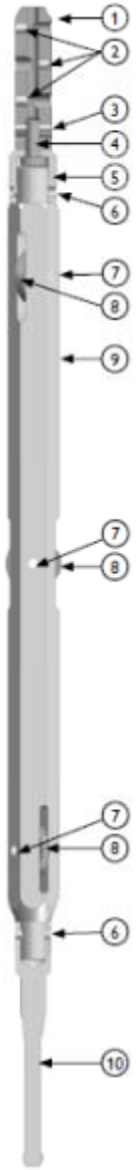
- **Outer Tube Assy**
  - Locking Coupling
  - Outer Tube
  - Reamer Shell(s)
  - Core Bit
- **Core Barrel Assy**
  - Head Assembly
  - Inner Tube
  - Core Lifter Assy
- **Overshot**
  - Deployed on wireline
  - Latches to Head Assy to retrieve Core Barrel Assy



Core Barrel and Outer Tube



Cross-section of latching mechanism

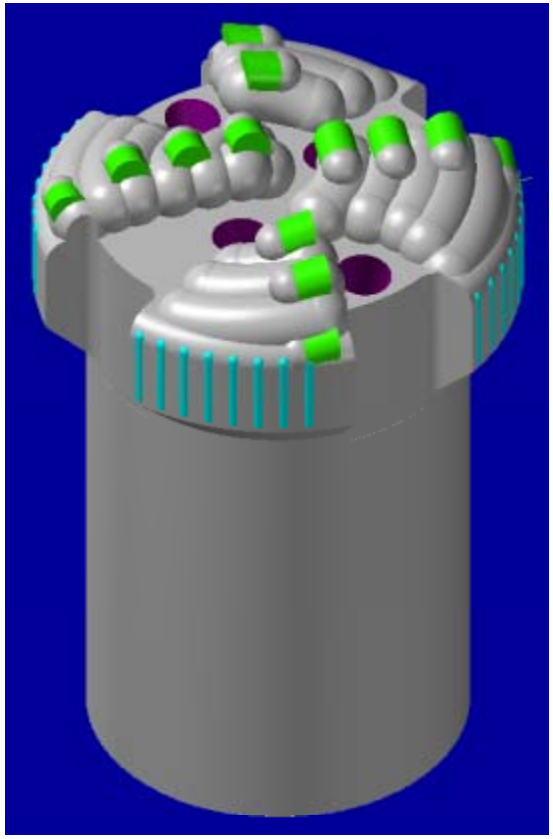


Overshot

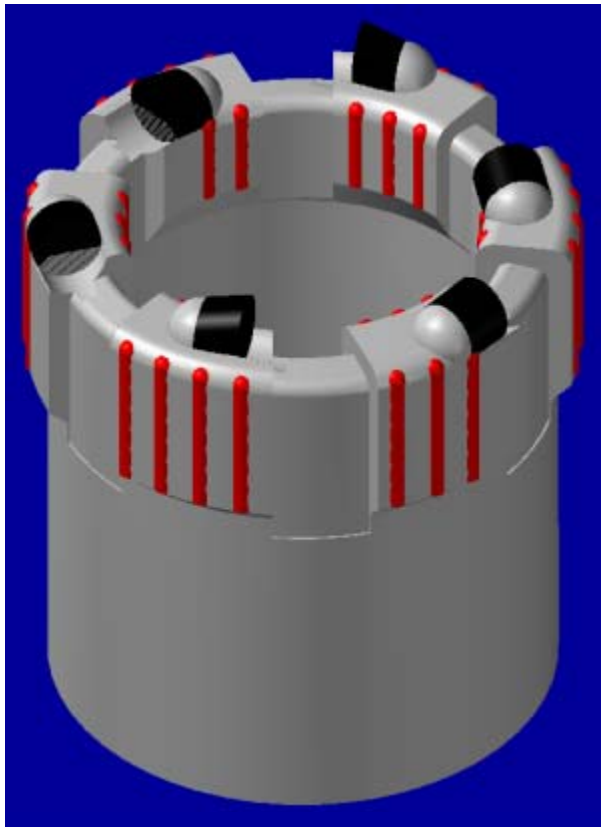
Down-hole Tooling Components

Drill Bits for Rock and mixed Ice/Rock

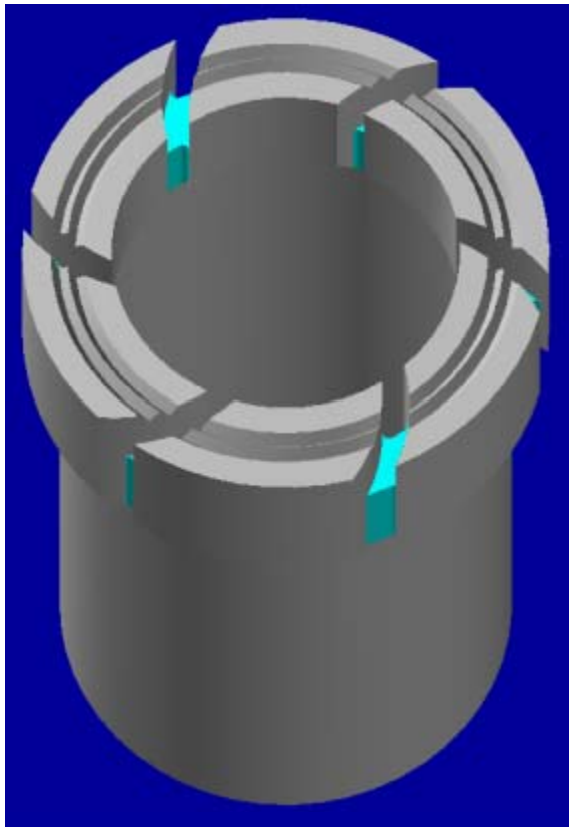
- Custom diamond-impregnated and PCD (polycrystalline compact diamond) coring bits by Scorpion Engineering



Full-face PCD



Coring PCD



Coring Diamond-Impregnated

Down-hole Tooling Components

Reaming Shells

- Ice and Rock models
- Stabilize and center bottom-hole assembly
- Thread to TK56 Outer Tube Assy

Ice Access Hole and Coring

Rock Coring

Down-hole Tooling Components

Water Swivel

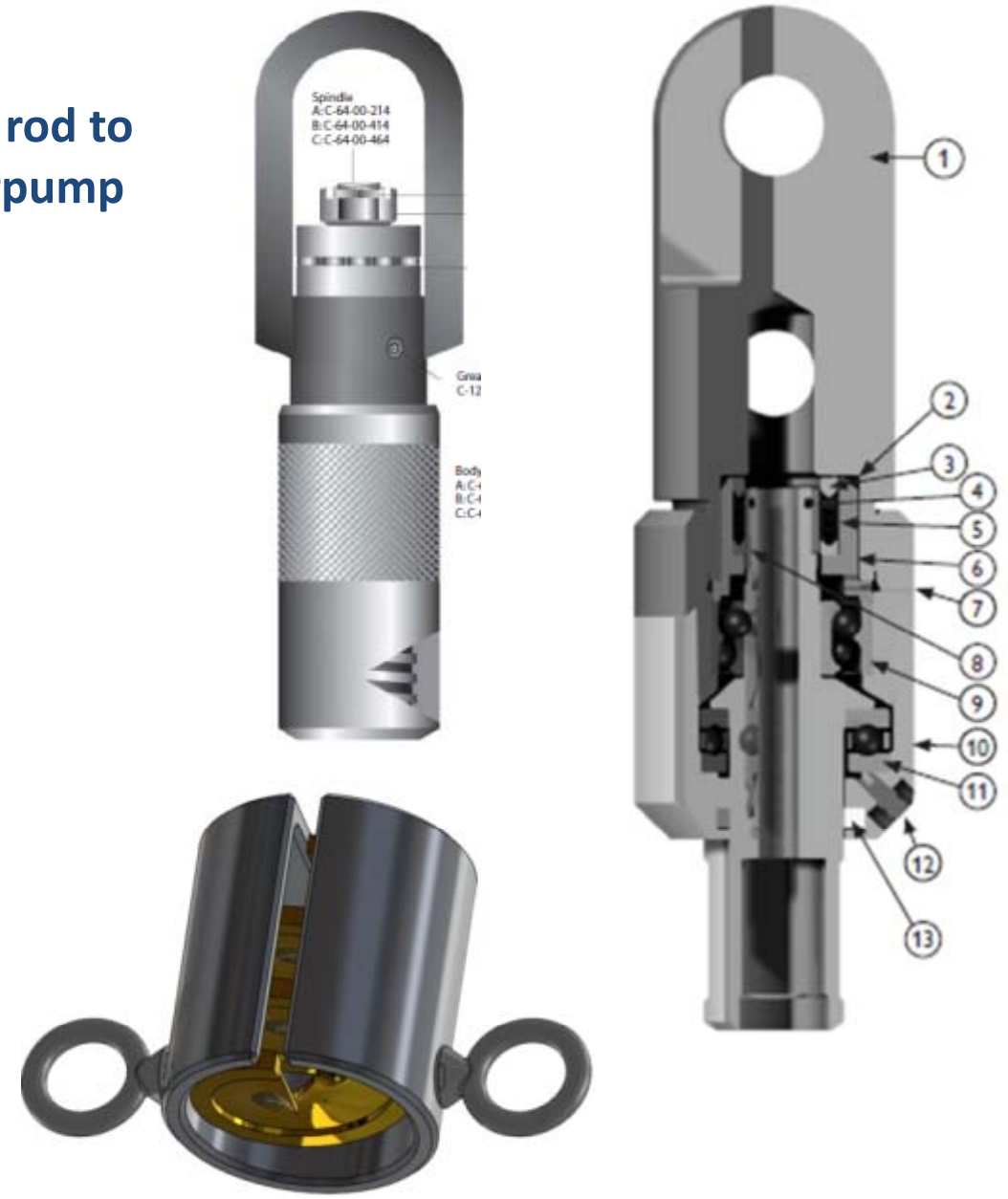
- Routes fluid to/from drill rod to filtration system or waterpump
- Sandvik Compact model
- 1-inch NPT outlet
- 1.5-inch hose

Hoisting Plug

- Used to lift drill rod(s) with the wireline winch

Wireline Wiper

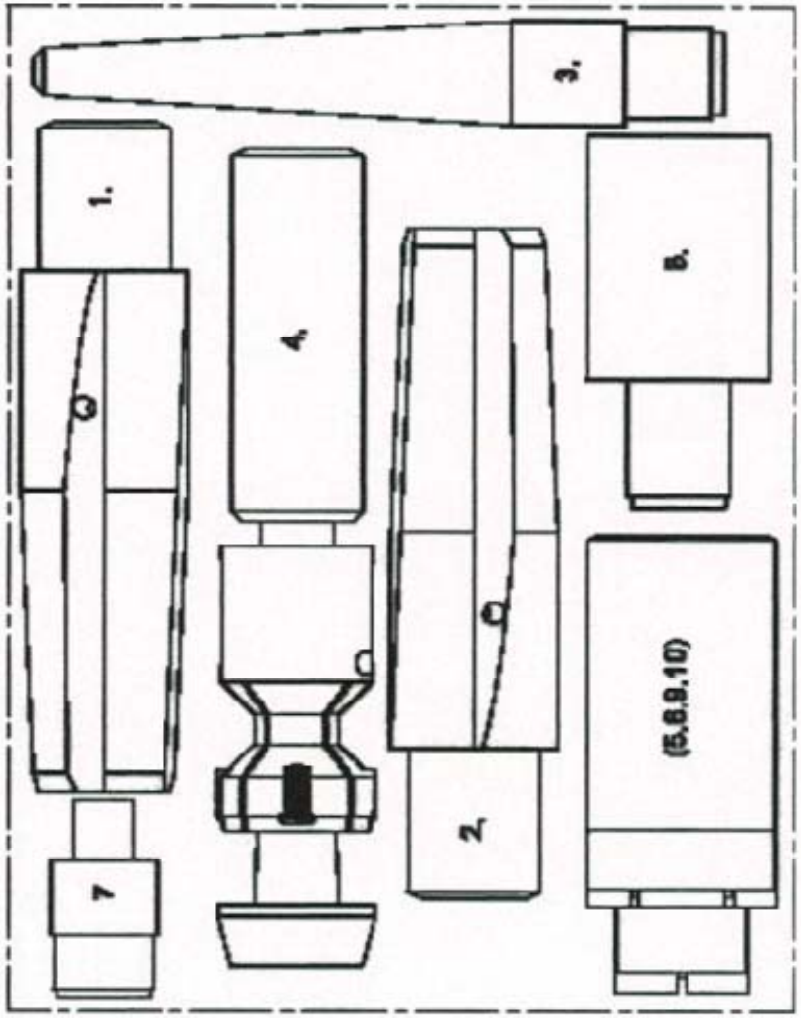
- Brass helical brush to remove excess drilling fluid
- Tethered to rig with custom housing



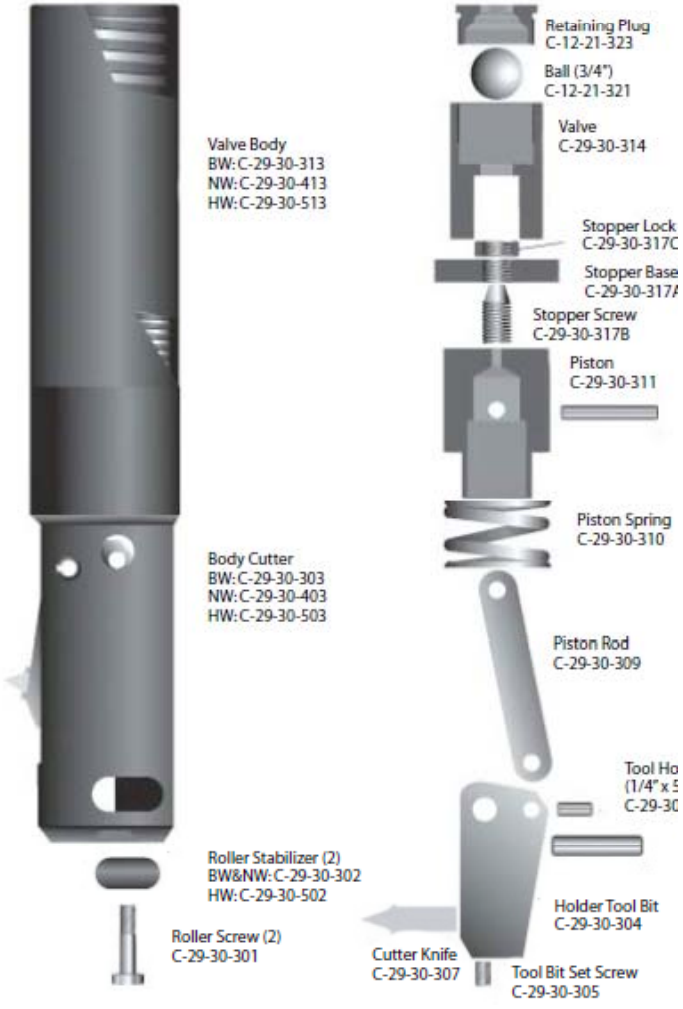
Down-hole Tooling Components

Recovery Tools

Sandvik TK56 Recovery Kit



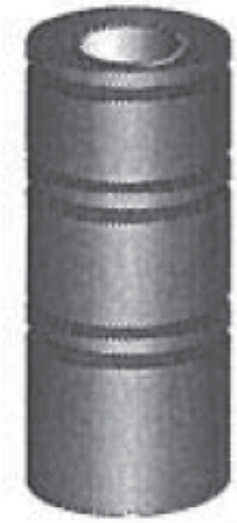
Casing Cutter (Scorpion)



Down-hole Tooling Components

Drill Fluid Swab Assembly

- Used to recover drilling fluid for reuse upon completion of a borehole
- Various cup types and materials available
- Deployed via wireline
- Recovered fluid directed to sump-pit or directed to filtration system



All-rubber Cup

Wire-reinforced Cup

Swab Mandrel with Cups


Circulation System

Drilling Fluid Selection

Numerous Fluids Evaluated:

- **Existing Ice Drill Fluids**
- **New Off-shore Drill Fluids**

Two Fluids for ASIG Identified

- **Isopar K: Used with DISC and Currently Available**

[Planned Fluid for 2016-17 Field Season]

- **EFC Crystal 200: Production Planned in US Q3-'15**

[Continue Evaluation]

Isopar K and EFC Crystal 200:

- **Low Toxicity**
- **Low Aromatic Content**
- **Low Flammability**
- **Low Viscosity**
- **Compatible with Elastomers**
- **Under-balanced Bore Hole**

	Units	IsoparK	EFC Crystal 200
Density	kg/m^3	763	821
Weight (15 drums)	lb	6038	6429
Viscosity* (-40°C,100RPM)	cp	10	14
Calculated Pump Pressure* (Bore Ø2.462", 9gpm, 700m, -30°C)	psi	246	302
Pour Point	°C	-60	-72
Density (-40°C)	kg/m^3	802	861
Flash Point	°C	58	72
Vapor Pressure (20°C)	hPa	0.65	0.17
Aromatic Content	ppm	<100	<300
Benzene	ppm	<1	<1
Odor		subtle to noticible	noticible
IDDO Field History		DISC/lab	none
Transport Hazard		II	IIIA
Health Hazard		minimal	minimal
Dry in 2 hrs Room Temp		yes	yes
Material Compatibility**		yes	yes
Notes		available	available in US Q3 2015

*Viscosity measurements B. Ellis; Pressure calculator B. Eustes, CSM.

**EPDM exhibts swelling. Viton, Buna N, PVC unchanged after 85days.

Fluid Circulation

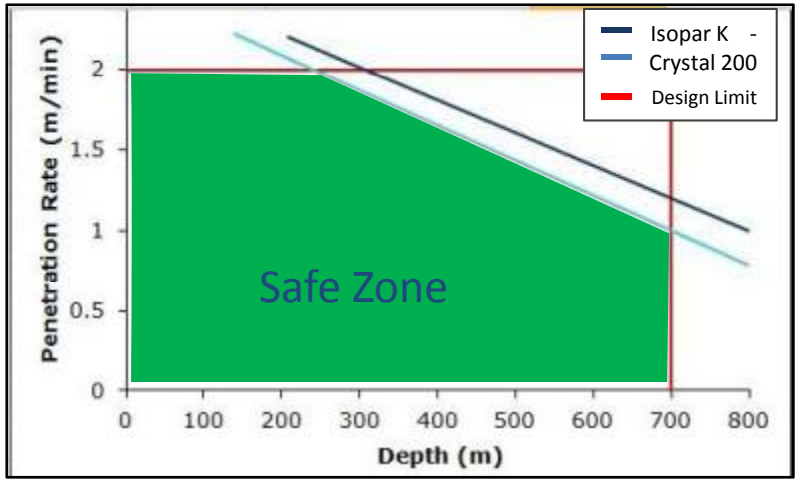
Relatively low pressure limit and high fluid viscosity

- Limit circulation pressure to reduce risk of ice cracking
- Drill fluid viscosity ~10x water
- Bore diameter increased to 2.465”

Peak penetration rate reduced by bore hole pressure

- 250psi RAID fluid pressure limit

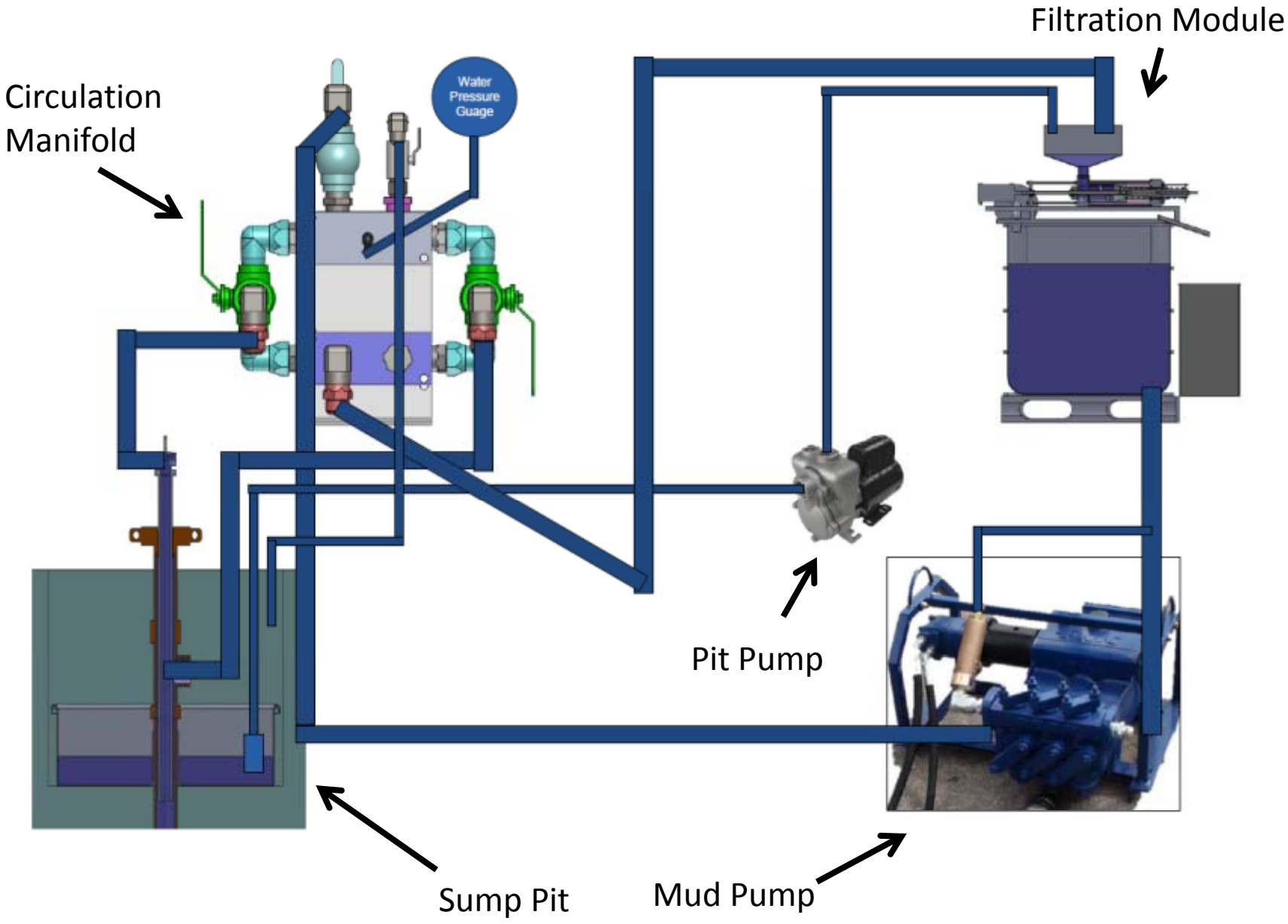
  [Glaciology Background Information for the Rapid Access Ice Drill (RAID), Jeff Severinghaus]
- Operation target 200psi pump pressure
- Design limit 2m/min to ~300m



Assumptions:
10% Chip Density
200psi target pump pressure
923kg/m3 ice density

Operation Limits

Circulation System Overview



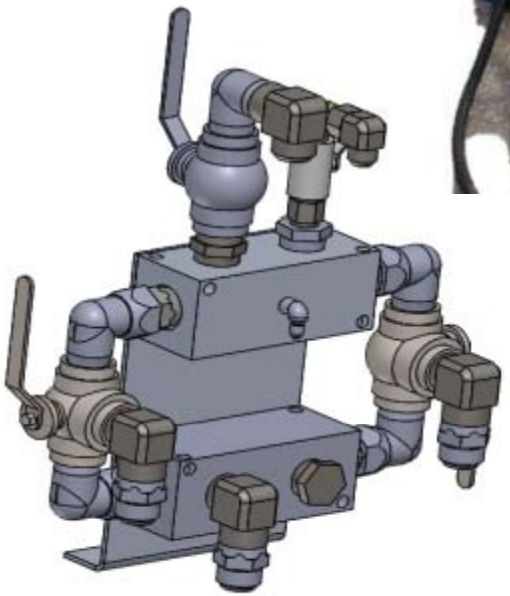
Circulation System Components

Mud Pump

- E0413C quadruplex piston pump
- Char-Lynn hydraulic motor
- 550 psi; pressure relief valve set to 350 psi
- 20 gpm
- 130 lbs

Circulation Manifold

- Forward /Reverse Circulation
- Flow Control
- Pressure Relief
- Pressure Gauge



Hose - Parker Arctic Edge

- -70°C temperature rated
- 350 psi working pressure
- 0.83 lbs/ft
- #20 JIC 37° swivel fittings
- Whip restraint cable at all connections
- Spare field attachable fittings

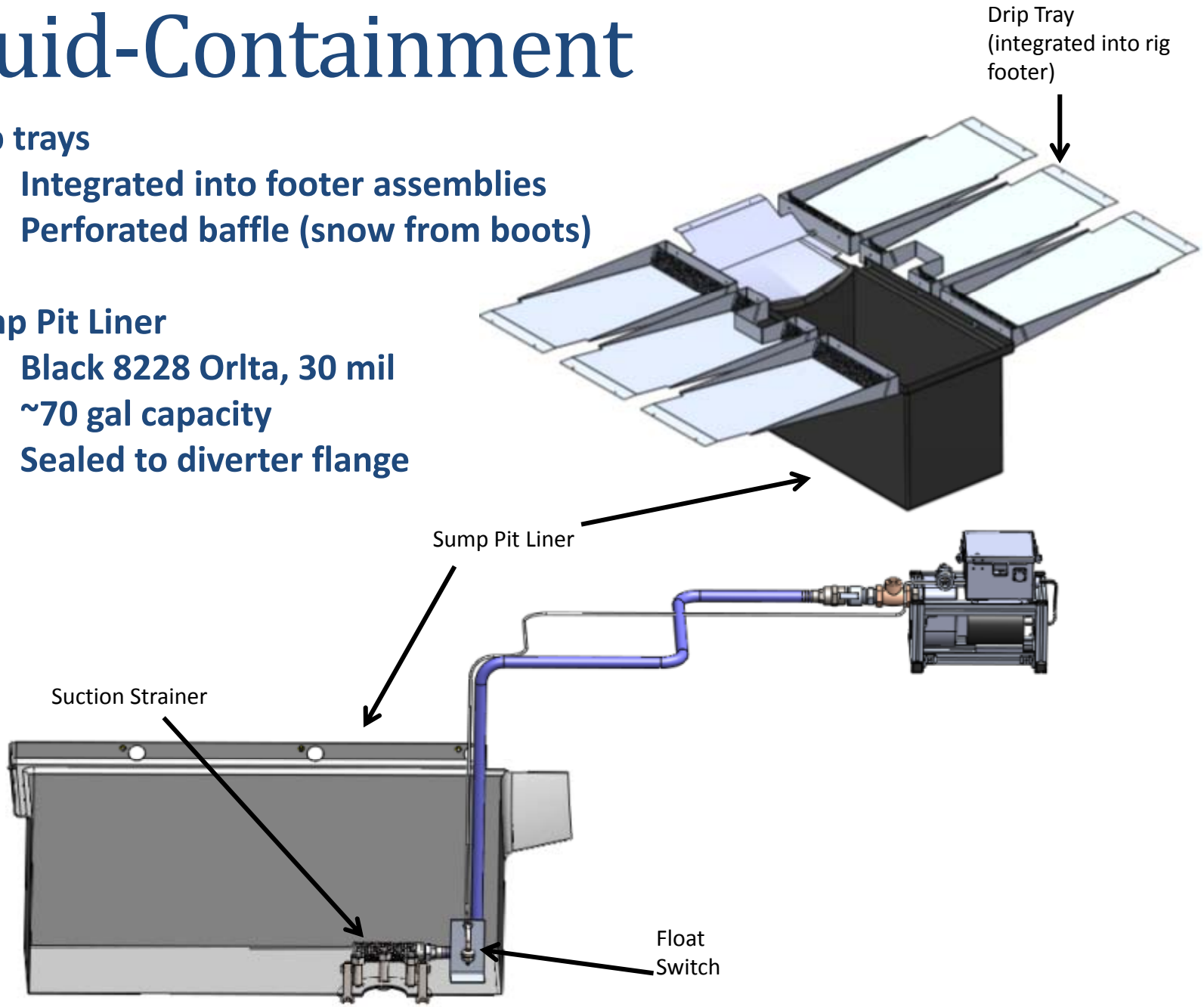
Fluid-Containment

Drip trays

- **Integrated into footer assemblies**
- **Perforated baffle (snow from boots)**

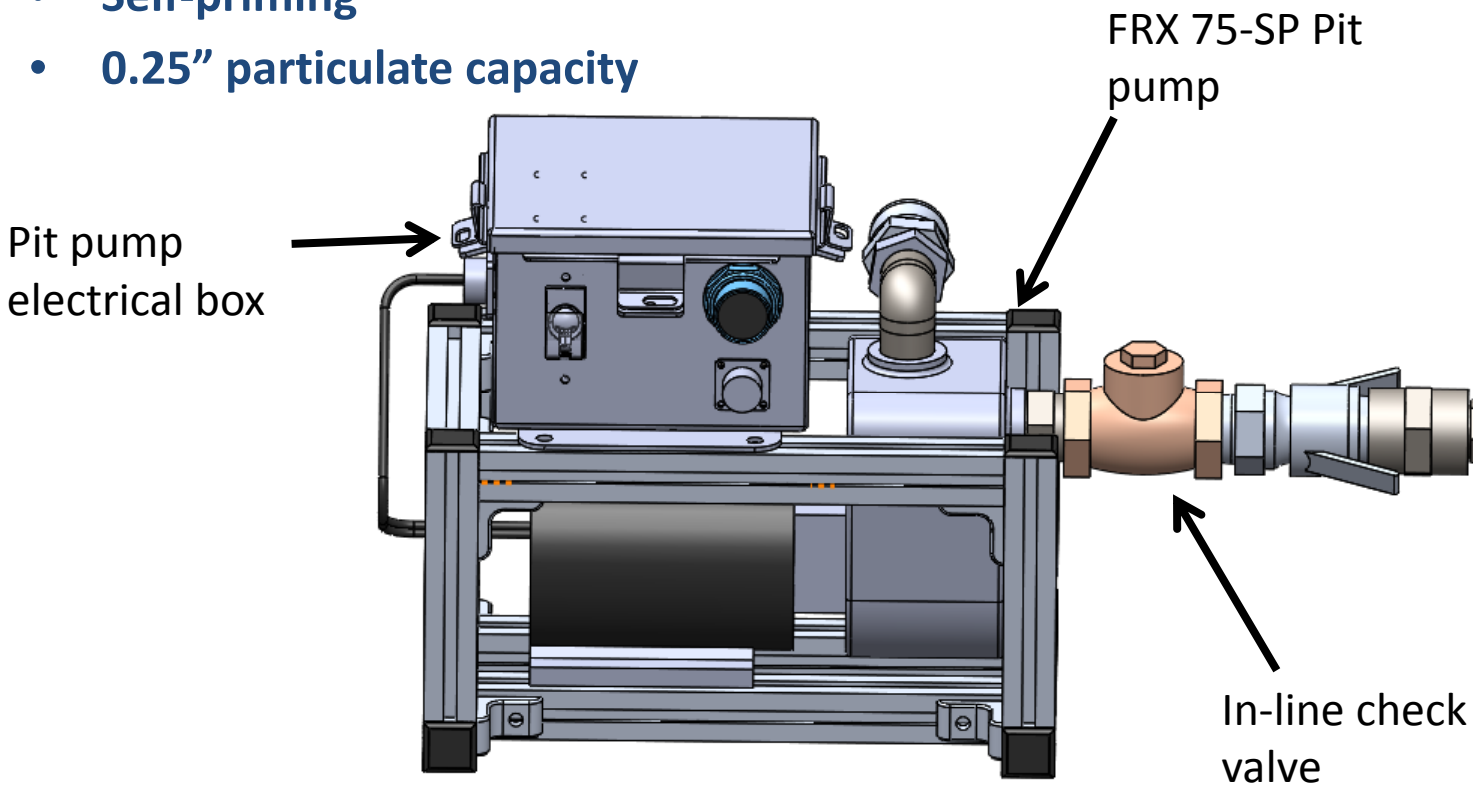
Sump Pit Liner

- **Black 8228 Orlta, 30 mil**
- **~70 gal capacity**
- **Sealed to diverter flange**



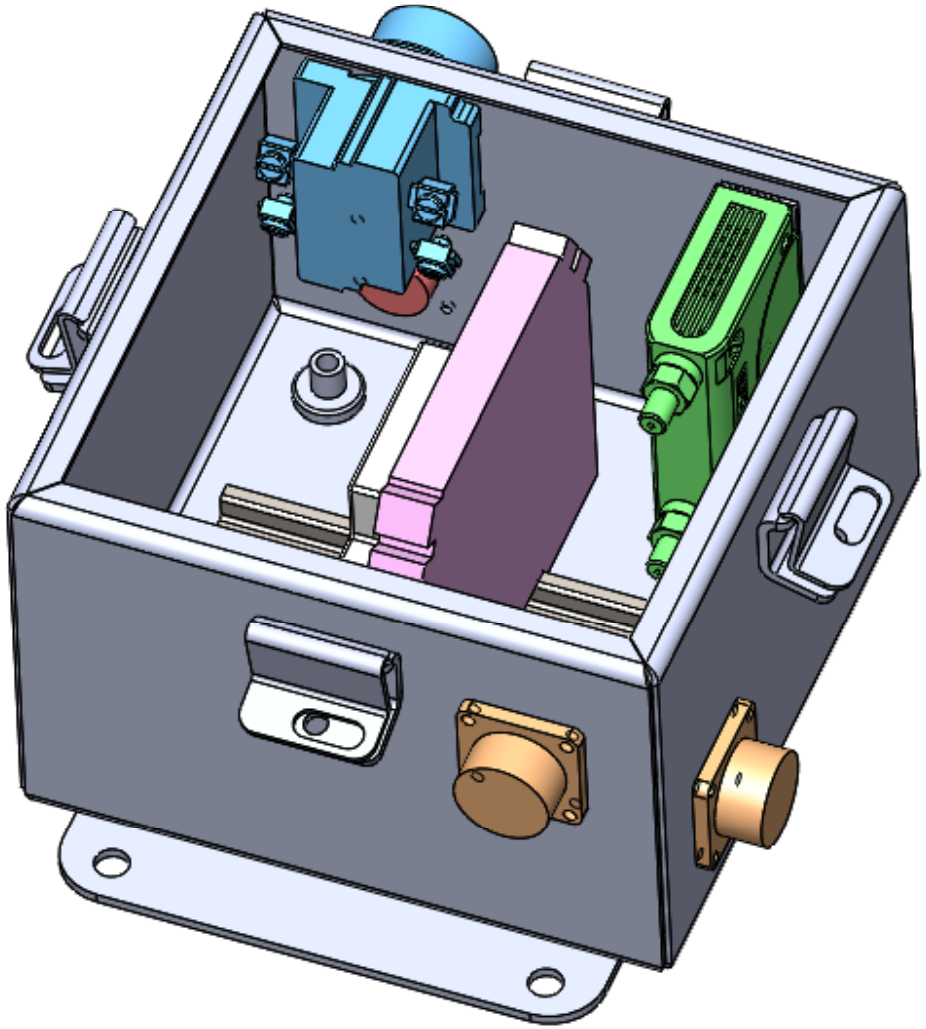
Fluid-Containment – Pit Pump

- **MP Pumps FRX 75-SP**
- **Adjustable float height; expected lower fluid level 1.63”**
- **0.19” perforated suction strainer**
- **15 gpm**
- **12v DC, 15A**
- **Self-priming**
- **0.25” particulate capacity**



Pit Pump Electrical Box

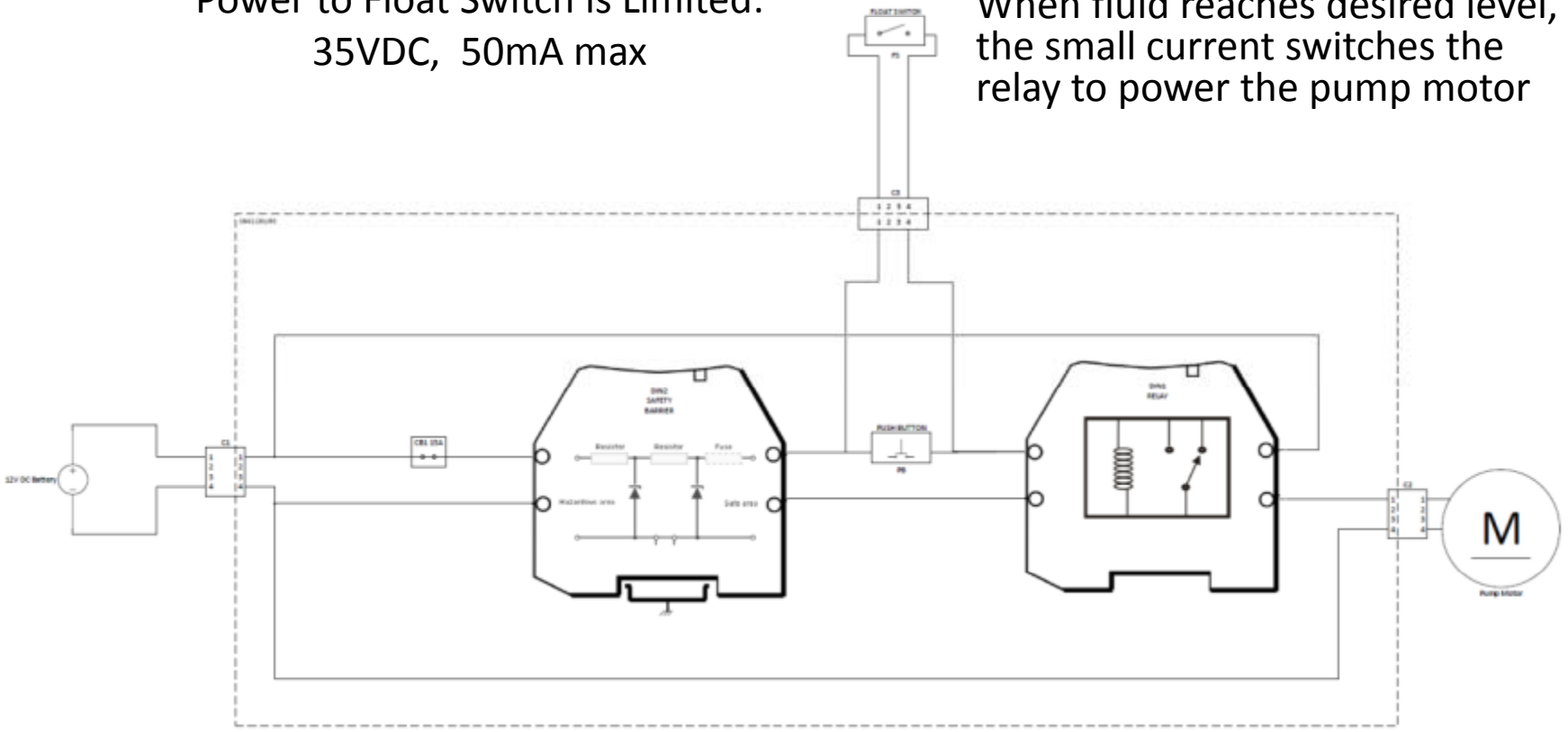
- **Off-the-shelf-components**
- **Intrinsically safe operation**
- **Limits the energy going to the float-switch and limits risk of sparking**
- **-40°C Operation**
- **NEMA 4x rated enclosure**



Pit Pump Wiring Diagram

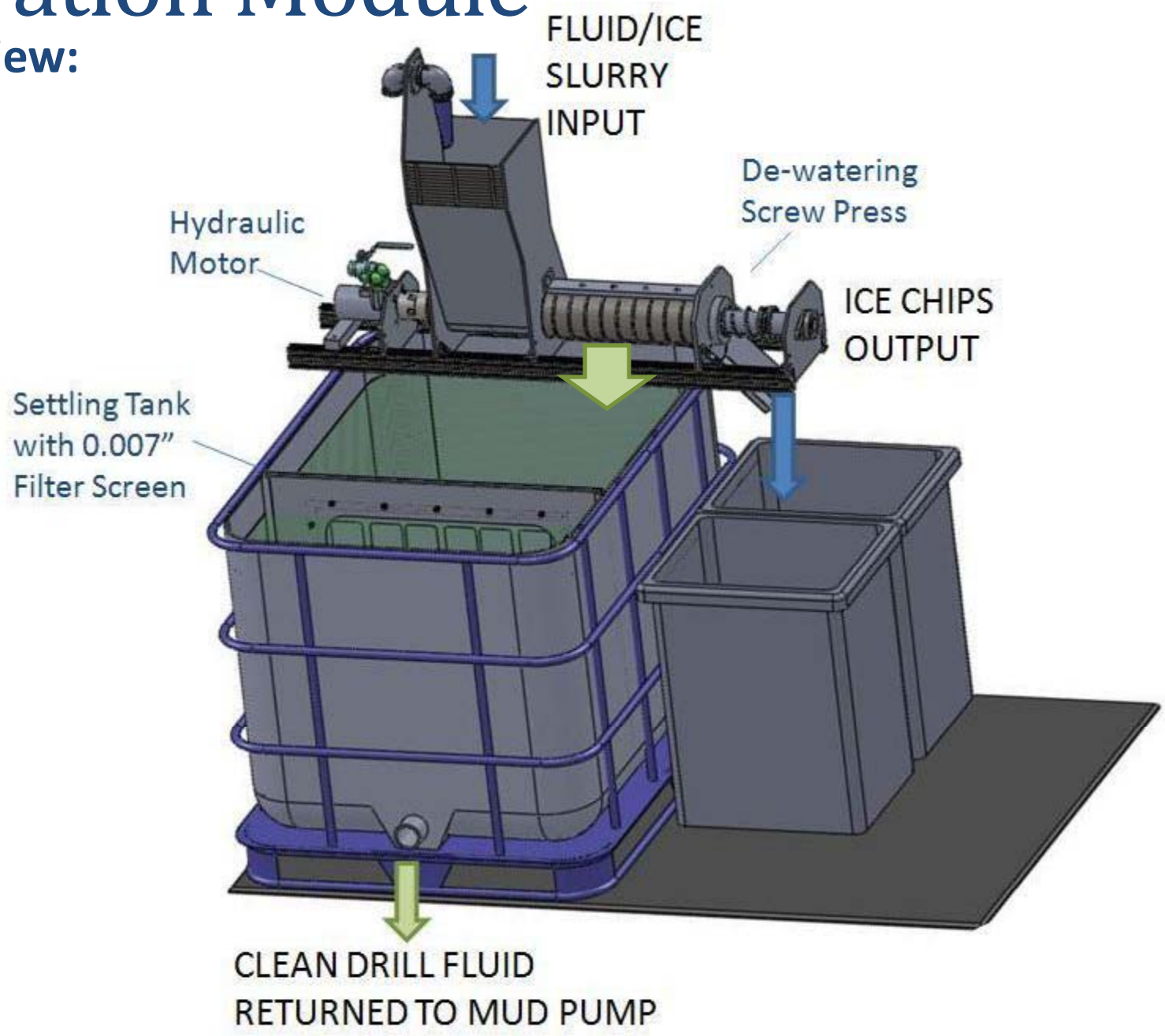
Power to Float Switch is Limited:
35VDC, 50mA max

When fluid reaches desired level, the small current switches the relay to power the pump motor



Filtration Module

Overview:



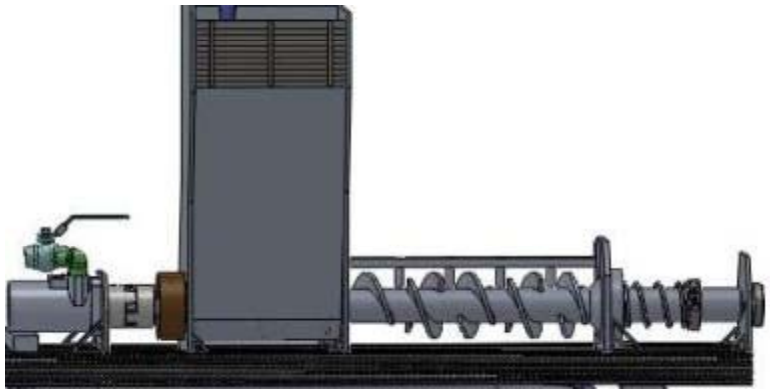
Filtration Module

Test Results Rental Press:

- De-watering Press
- 450lbs
- 1.5HP Electric Motor
- Performance Parameters:
  - Peak Torque 66 ft-lb
  - Speed 60RPM
  - 35 to 70 lb back pressure
  - Ice Chip Output Rate: 0.7 gallon/min
  - Less than 20% vol. Fluid in Melted Chips

Reduced-Weight Hydraulic Press:

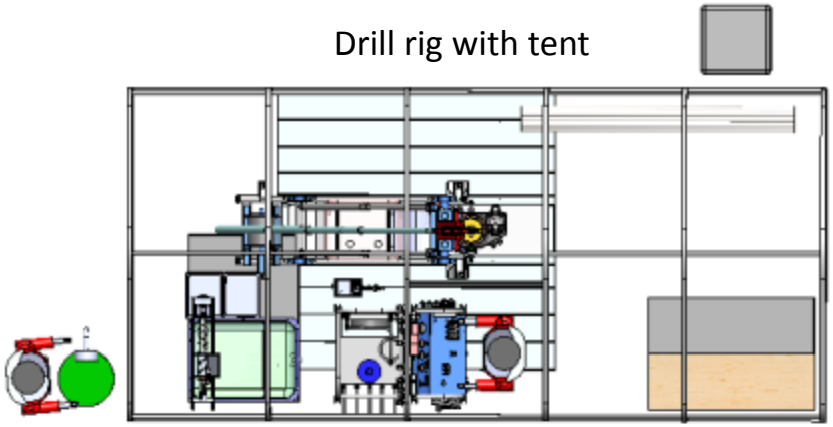
- Rig Control Module provides 1000psi and 0 to 5 gpm [Mud Mixer Circuit]
- Char-Lynn H-Series Gerotor 97cc Motor: 100 ft-lb, 0 to 120 RPM
- Press weight <100 lbs with hydraulic motor
- Fluid/Chip ratio comparable to centrifuge
- 0.007” well screen
- Drilling rate 5 minutes per 3m rod
- 6 gallon hopper buffer
- Redundant press option (pending testing)

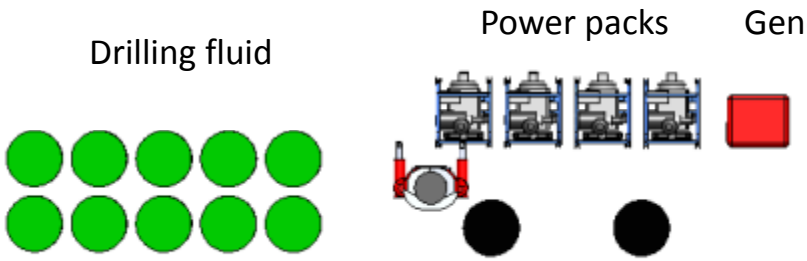


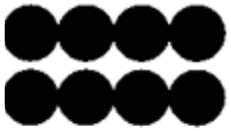

Site-Equipment

Site Layout

Plan View



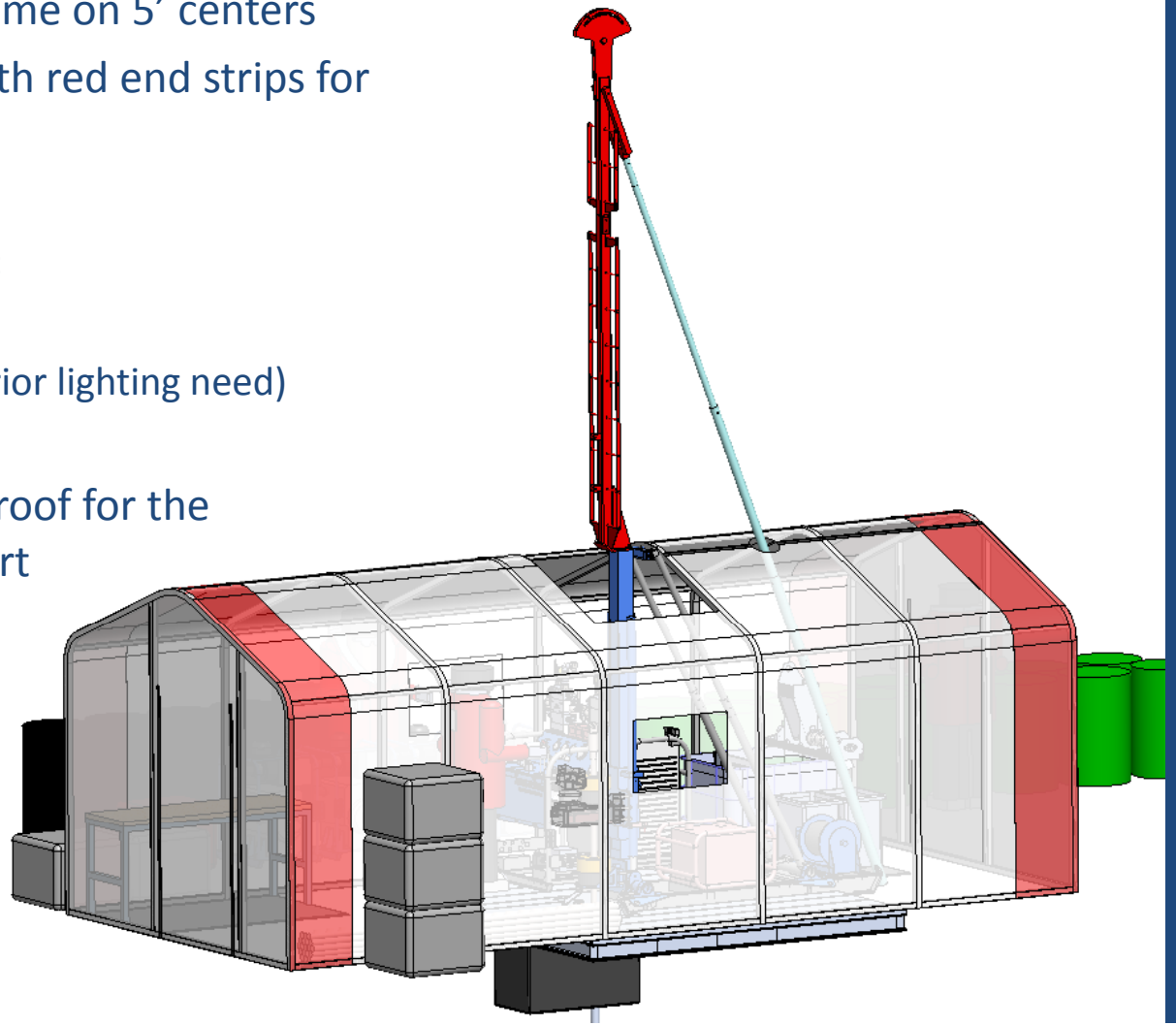




Drilling fluid, fuel, and drill rod quantities shown are for a 300 m deep hole.

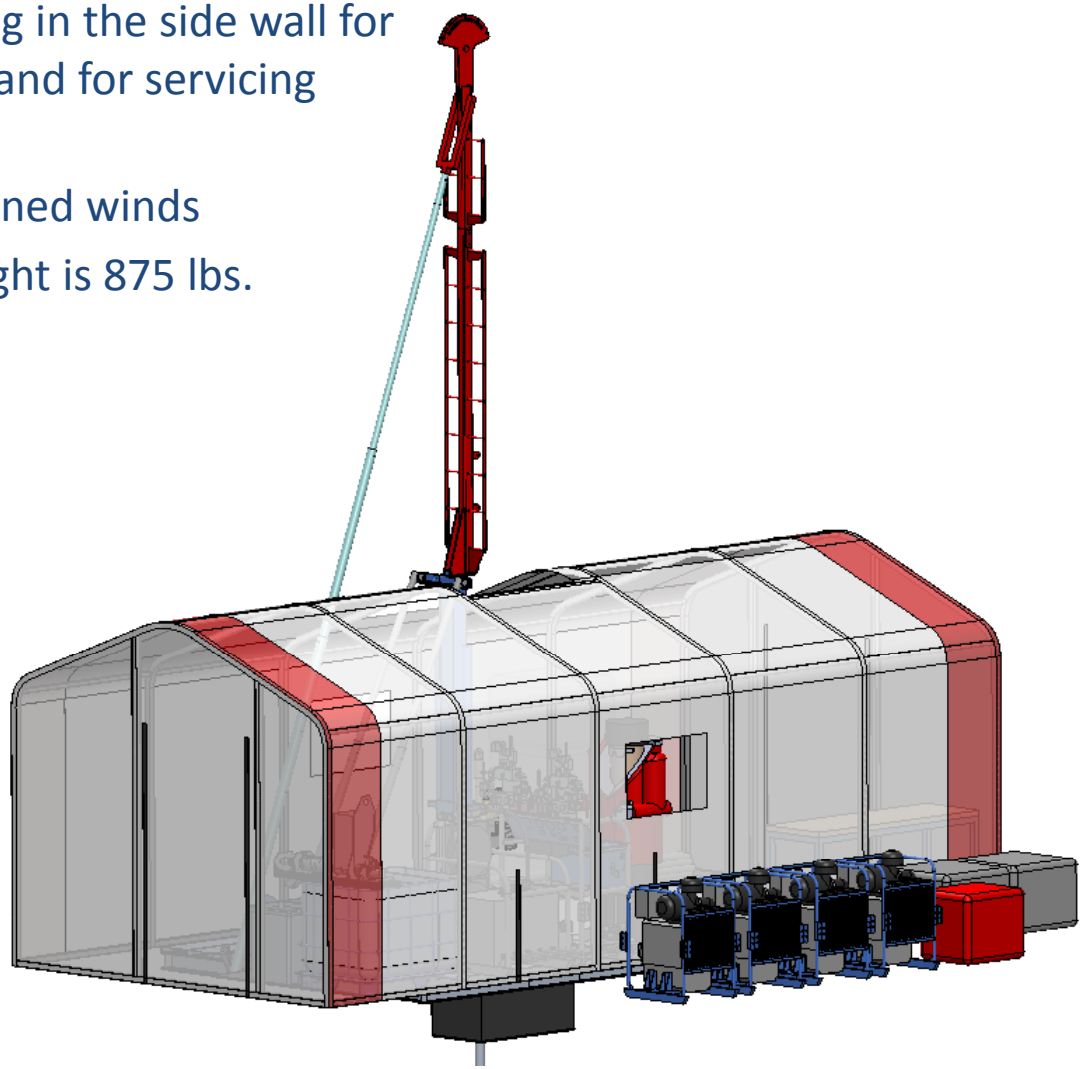
Drill Tent

- 12’ wide x 25’ long x 10’ peak tensioned fabric building
- Designed to be set-up after the drill rig is in place
- Tubular aluminum frame on 5’ centers
- 18 oz. white fabric with red end strips for improved visibility
  - PVC Vinyl coating
  - Polyester base fabric
  - -51° c cold crack
  - Translucent (no interior lighting need)
  - 24” wide snow skirt
- Closable ports in the roof for the mast and mast support



Drill Tent (cont.)

- 4’ wide x 7’ high zipper closure doors on either end
- One window on either side wall
- 5’ wide x 3’ high opening in the side wall for hydraulic lines passage and for servicing equipment
- Rated for 57 mph sustained winds
- Estimated shipping weight is 875 lbs.
- 2 hour set up time



Electrical Power Budget

120 Volts AC	Watts
Tank Heater	396
Battery Heaters (4 x 50.4 W)	202
Oil Pan Heaters (4 x 99.6W)	398
Engine Block heater (4 x 396w)	1584
Total Watts	2580

12Volts DC	Watts
Hydraulic Cooler Fans (2 x 125W)	250
Sump Pump	180
Display Units (3 x 5W)	15
Linear Encoder	2
Rotary Proximity Sensor	2
Total Watts	449

Honda eB5000 5kW generator recommended (212lbs)

Interstate 24M-HD 12VDC 500CCA batteries supplied (35lbs x4)

Logistics

Base Drill Configurations

	200m	700m
	lbs	lbs
Drill Rig	4,500	4,500
Drill Rod	2,366	7,244
Tools and Other Equipment	5,900	5,900
Total Base Drill	12,766	17,644
Estimated Twin Otter Flights	**6 to 8**	**8 to 10**

Note: Number of flights based on a 250nm flight and the standard fuel capacity with no optional cabin auxiliary tank. Actual cargo capacity will vary with specific conditions and the amount of fuel required.

Consumables

	200m	700m
	lbs	lbs
Casing	400	400
Drill Fluid	2,000	5,800
Fuel	3,000	4,200
Total Consumables	5,400	10,400
Estimated Twin Otter Flights	**3 to 4**	**6 to 7**

Notes: BW-size casing 23lbs/m. Drill fluid 1.5x borehole volume.
Fuel for drill system only at 6gal/hr, w/20% contingency, excludes tear-down.

Logistics (cont.)

Time-to-Depth*

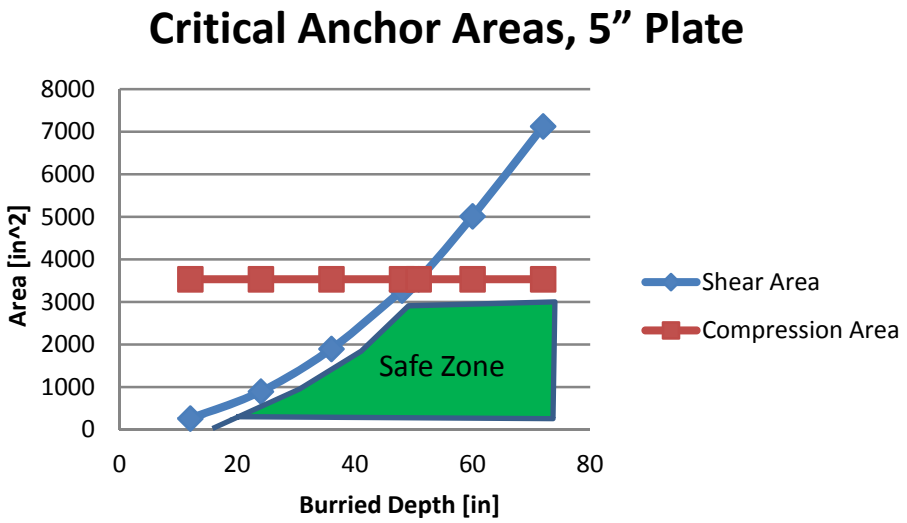
	200m Depth (hours)	700m Depth (hours)
System Set-up	20	20
Pilot Hole/Set Casing to 40m depth	14	14
Drill Ice Borehole to Bedrock (no core)	6	21
Bedrock Coring to 10 meters:	5	10
System Teardown/Packing	12	12
Total:	**57**	**77**

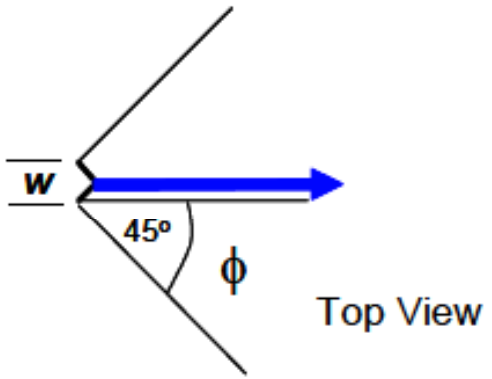
*Assumes mature system with 4 experienced drillers/core handlers


Reference Material

Anchor Calculations

- Compression Strength is a function of the fontal area of the anchor. As seen the graph, this is independent of buried depth. Compression failure results in “creep” through the snow.
- Shear area is the cone projected up to the surface at a 45° angle. Area is a function of buried depth. Failure is sudden and catastrophic.





“Snow Anchors” Don Bogie

Anchor Calculations

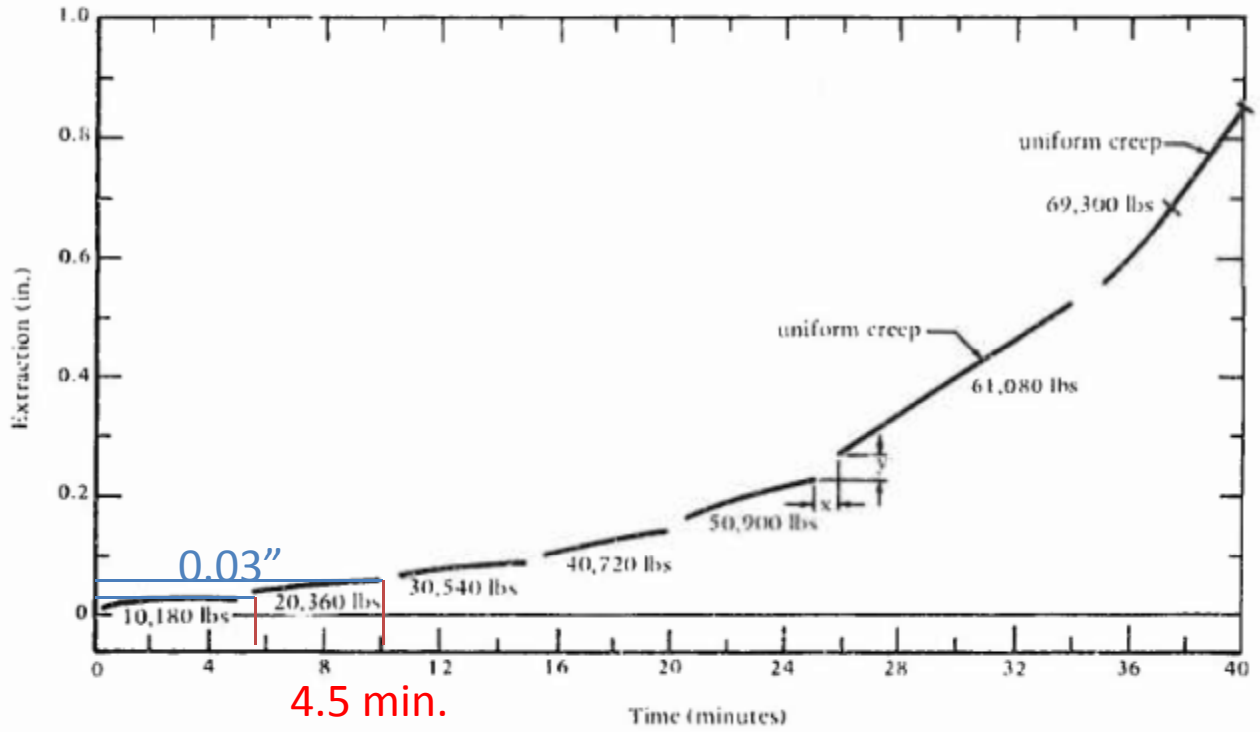
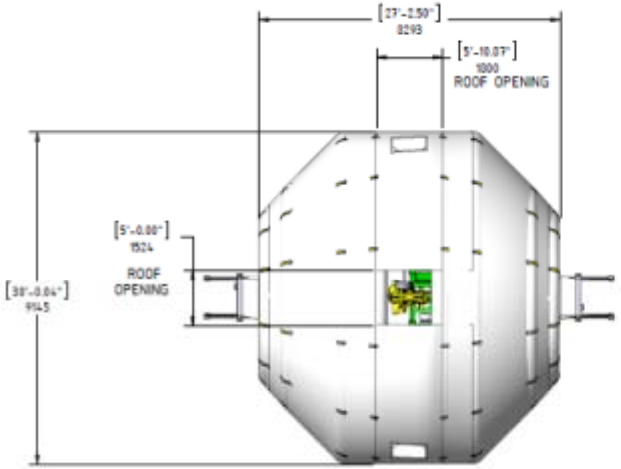


Figure 7. Extraction versus time for a 12-inch-diameter, 1-inch-thick plate anchor embedded 10 feet in snow. (From Reference 10.)

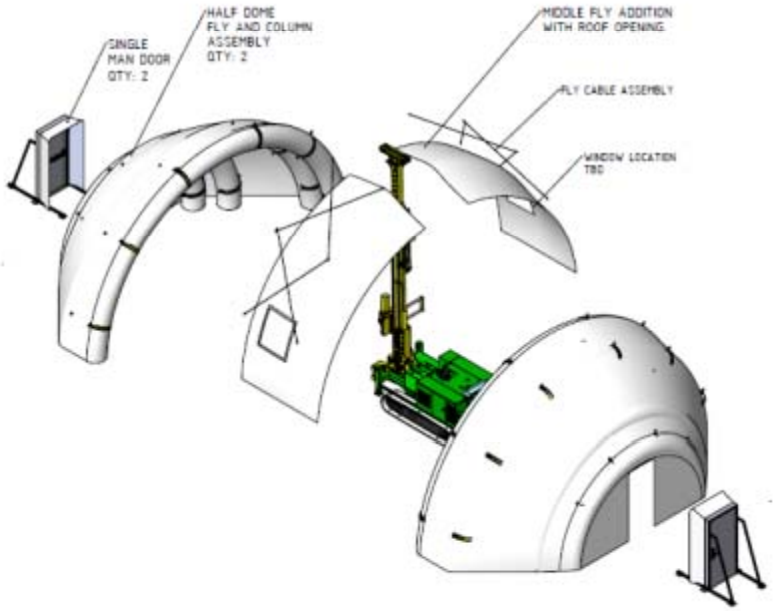
Inflatable Drill Tent

Drill tent concept by Dynamic Air Structures – not selected due to cost

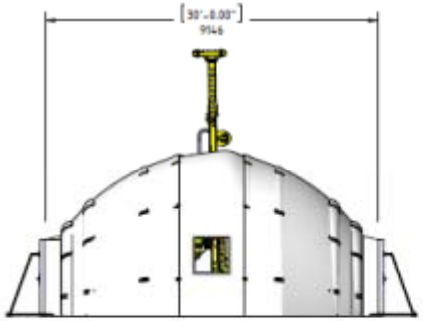
- 0.6 m Ø air columns support the shell
- Self erecting design
- ~ 600 lbs. as shown
- 4-5 times the cost of a tensioned fabric bu



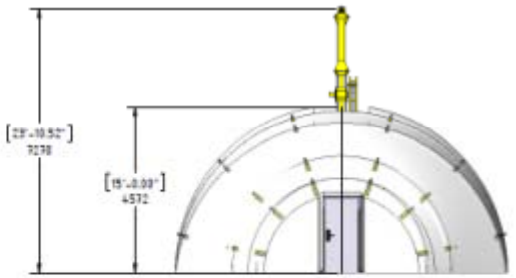
PLAN VIEW



EXPLODED VIEW



FRONT ELEVATION



SIDE ELEVATION

Future Expansion Potential

- **Larger Borehole Diameter**
  - **Initial testing and field project to use B-size drill string components.**
  - **Drilling rigs under consideration can handle up to H-size components.**

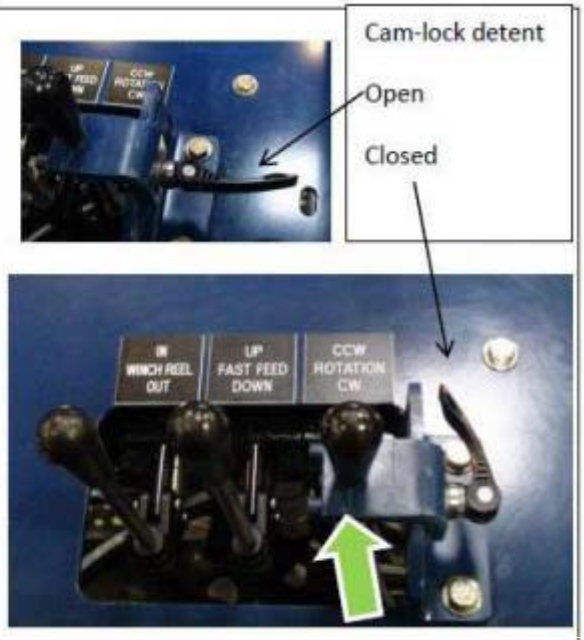
Letter size	Outer Φ x inner Φ, inches	Outer Φ x inner Φ, mm	Rock Core Φ inches (mm)	Hole Φ inches (mm) in rock	Approx. max. depth (m)
B	2.2 x 1.8	55.6 x 46.1	1.43 (36.4)	2.36 (60)	1000
N	2.75 x 2.38	69.9 x 60.3	1.88 (47.6)	2.98 (76)	600-800
H	3.50 x 3.06	88.9 x 77.8	2.50 (63.5)	3.78 (96)	300-500

- **Wireline Intermittent Ice Core Recovery**
  - **Non-coring drilling using an ice coring bit with an overshot-retrievable center bit**
  - **For coring the center bit is pulled and replaced with a core barrel assembly, all via wireline.**
  - **Increases overall efficiency for projects requiring frequent intermittent ice cores**

Rig Control

Rotation

- Rotation handle controls drill RPM
- Stop rotation in "NEUTRAL" position
- Pull to rotate "CLOCKWISE"
- Push to rotate "COUNTER-CLOCKWISE"
- Cam-lock detent will hold handle at desired rotation speed
- Movement of handle is proportional to head rotation speed from 0 to MAX RPM in that direction. The further the handle is shifted off neutral, the faster the drill will turn
- The setting for minimum displacement has been set according to a 3 engine system. If running all 4 engines together this setting will need to be adjusted in order to prevent over-speed of top drive



Torque Range & Adjust

- Turning the "TORQUE RANGE" valve varies the TOP DRIVE MOTOR DISPLACEMENT
- Turn valve CCW to INCREASE displacement & therefore increase max. achievable torque
- Turn CW to DECREASE displacement & therefore decrease max. achievable torque

Rotation speed is inversely proportional to motor displacement; increased displacement will result in lower motor RPM.

- Turning the "TORQUE ADJUST" valve varies the maximum achievable motor pressure & therefore maximum achievable motor torque(motor pressure is read on gauge above torque adjust valve)
- Turn valve CW to INCREASE max. pressure
- Turn valve CCW to DECREASE max. pressure

Rig Control (continued)

Chuck & Synchro

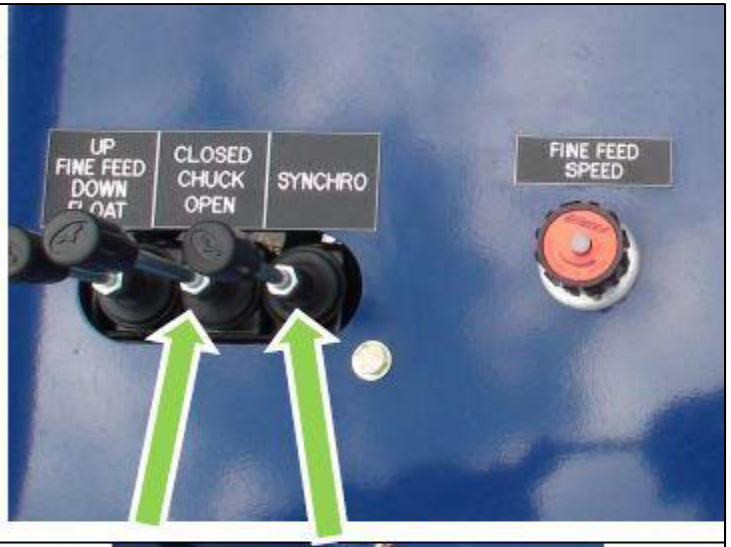
NEVER USE THESE FEATURES WHILE ROTATING

Chuck will hold the drill string when in "CLOSED" position

- Push handle to "CLOSED" to engage
- Pull handle to "OPEN" to release

"SYNCHRO" feature sequences the opening and closing of the Chuck and Clamp as a single function

- Push: 1) CHUCK CLOSED 2) CLAMP OPEN
- Pull: 1) CLAMP CLOSED 2) CHUCK OPEN



Feed / Pull Back

"FAST FEED" controls the feed cylinder motion which moves the TOP DRIVE up and down the mast

- Push handle "UP" for PULLBACK
- Pull handle "DOWN" for FEED

Location of control knobs may vary.

Rig Control (continued)

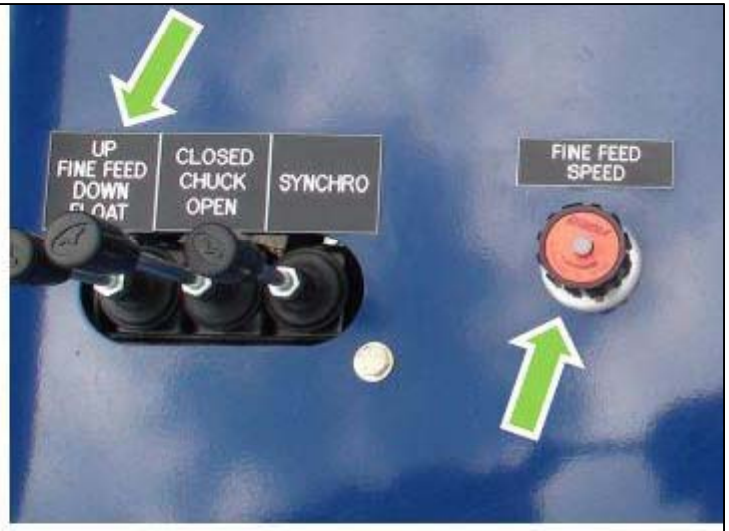
Fine Feed

"FINE FEED" controls the feed cylinder motion which moves the TOP DRIVE at a slower speed than "FAST FEED" function

- Push handle "UP" to lift TOP DRIVE
- Pull handle "DOWN" to FEED
- Pull handle to "FLOAT" (with detent) opens both cylinder ports to tank allowing the TOP DRIVE to be moved by external forces (i.e. weight of drill string)

Adjust the "FINE FEED SPEED" by rotating the knob

- Rotate CW to DECREASE speed
- Rotate CCW to INCREASE speed



Feed & Holdback Pressure

Feed pressure and Holdback functions are only active when using fine feed. Feed pressure is adjustable by means of the valve below the gauge:
Turn clockwise to increase pressure, counterclockwise to decrease pressure
The holdback gauge will display the holdback pressure which adjusts up or down with the fine feed speed control knob

Location of control knobs may vary.

Rig Control (continued)

Mud Mixer

Mixer speed is controlled by a 10 position indexed valve with: OFF at "0" and MAXIMUM RPM at "9"

- Rotate CCW to INCREASE speed
- Rotate CW to DECREASE speed
- Maximum hydraulic drive pressure is limited by the pump controller and should not be adjusted

Water Pump Drive

Water flow is controlled by a 10 position indexed valve with: "NO FLOW" at "0" and "MAX FLOW" at "9"

- Maximum hydraulic drive pressure is limited by the pump controller and should not be adjusted
- The water pressure is limited by a water relief valve and should not be adjusted

Location of control knobs may vary.