IceCube Upgrade NSF Re-Baseline Review
April 26-28, 2022

Terry Benson

Drill Breakout - Technical Status

Enhanced Hot Water Drill (EHWD)

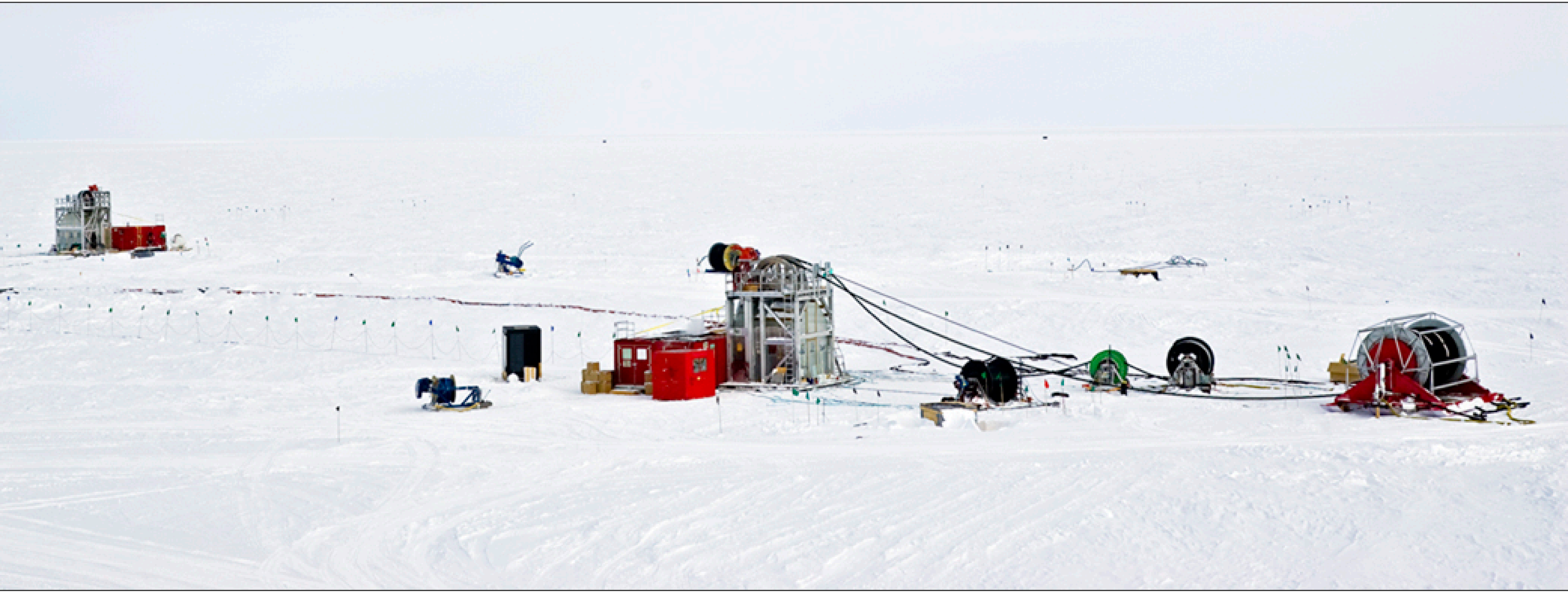
IceCube, South Pole 2004-2022

Seasonal Equipment Site (SES), aka Drill Camp

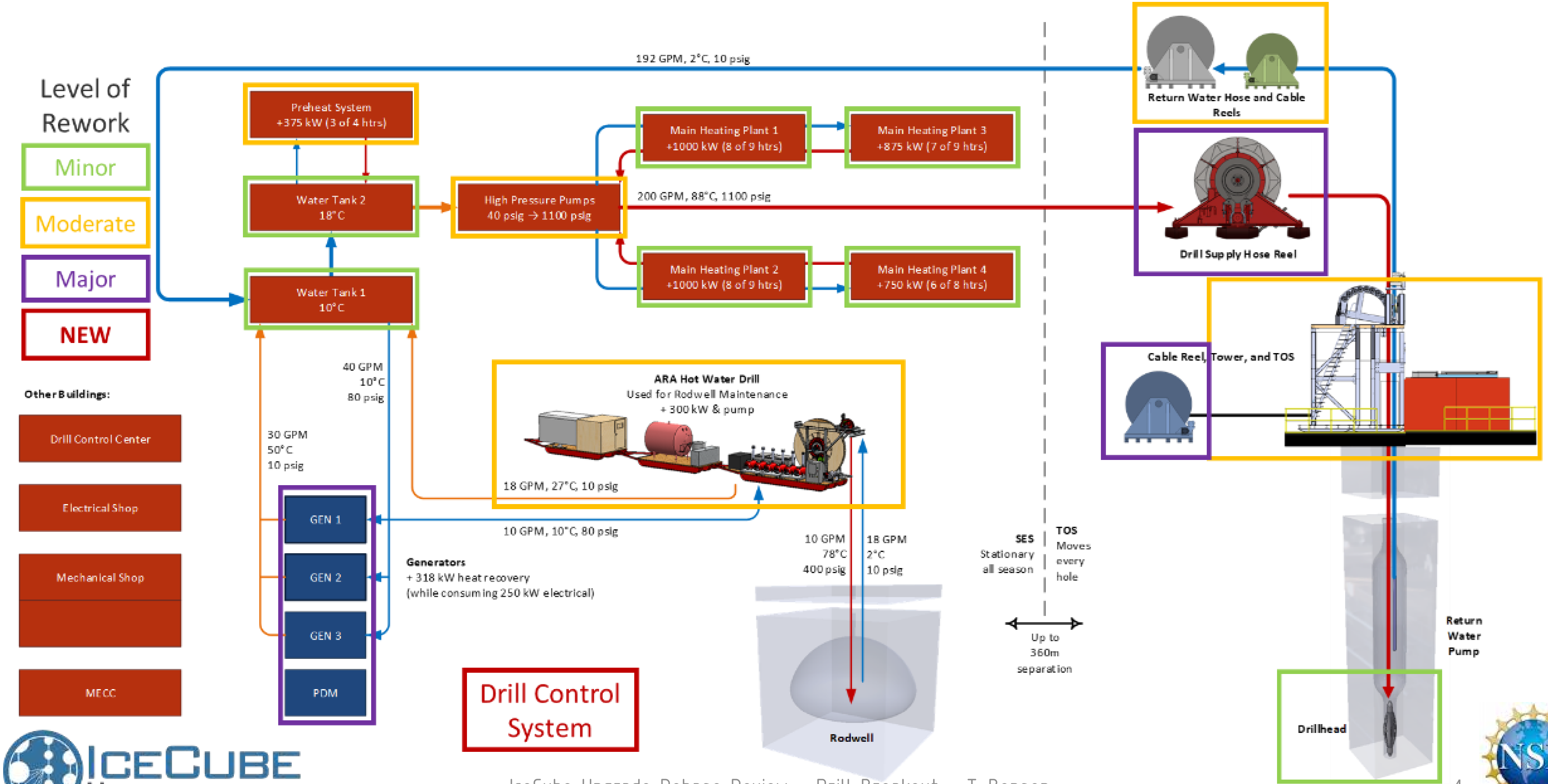
Enhanced Hot Water Drill (EHWD)

IceCube, South Pole 2004-2022

Tower Operations Site (TOS)



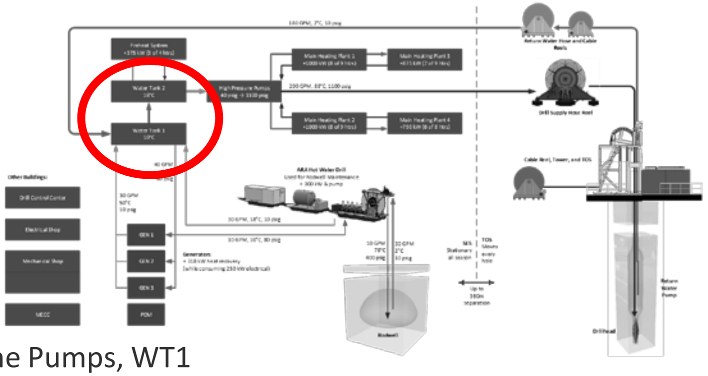
ICU Drill Schematic



Water Tanks (WT1 & WT2)

2x Tanks, 10000 gal capacity each

Wisconsin (ready / *in-progress*)
Port Heuneme
McMurdo
Spole
Mix
As of April 2022



Rework:

Pumps: 3x Vertical Turbine Pumps, 8x Charge Pumps, 4x Transfer Pumps
Railings, Ladders, and Doghouse building materials
Plumbing and instrumentation

WT2

Vertical Turbine Pumps, WT1

High Pressure Pumps (HPP)

4x Triplex Pumps, 50 gpm @ 1200 psi & 50 HP each; plumbing, instrumentation, controls

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Port Heuneme
McMurdo
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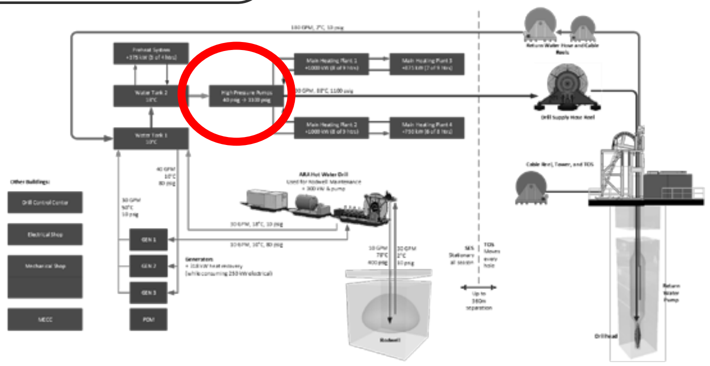
As of April 2022



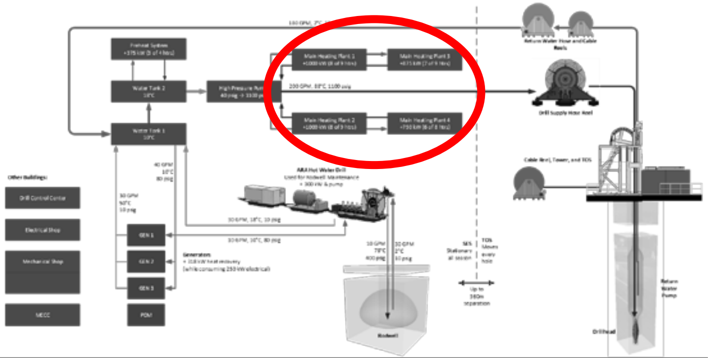
Rework:

Pressure Relief Valves
Pulsation Accumulators
Sensor patch panels
Flow-Temp-Pressure Instrumentation
8x Motor Drives
Network/PLC/Estop control panel

Main Heating Plants (MHP)

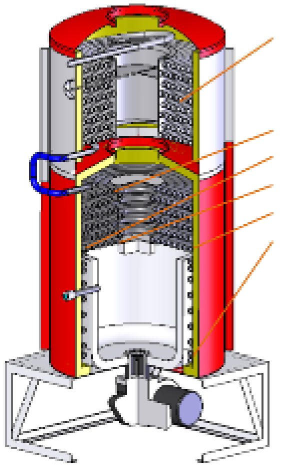
Wisconsin (ready / *in-progress*)
Port Heuneme
McMurdo
Spole
Mix
As of April 2022

4 buildings, 34x Custom High-Efficiency Fuel-Fired Water Heaters, 125 kW each; Plumbing, Instrumentation, and Controls



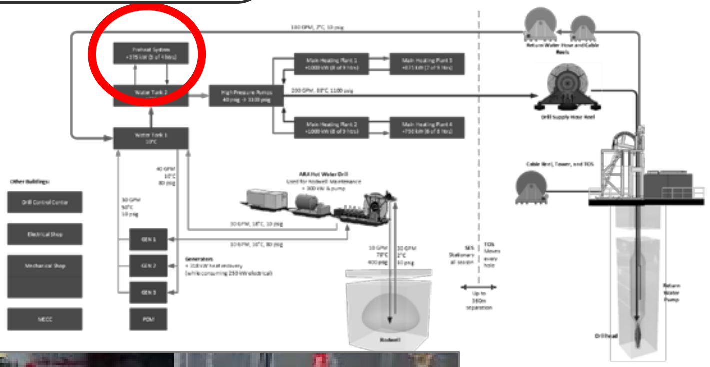
Rework:

- Heater outlet flowmeter assemblies
- *Heater local control boxes*
- Condensate collection systems
- Plumbing replacements
- *Network/PLC/Estop control panels*



PreHeat System (PHS)

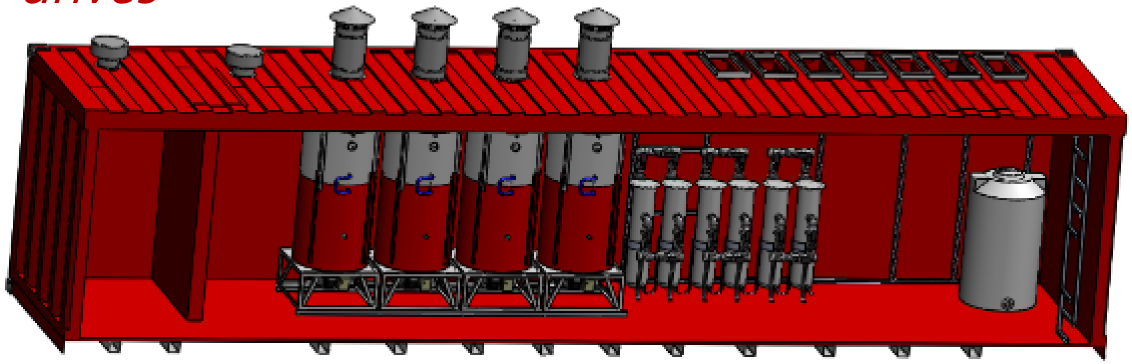
Wisconsin (ready / *in-progress*)
Port Heuneme
McMurdo
Spole
Mix
As of April 2022



4x Water Heaters and 3x Pump Control Systems maintain WT2 level and temperature; Main system filtration; Condensate collection and handling system

Rework:

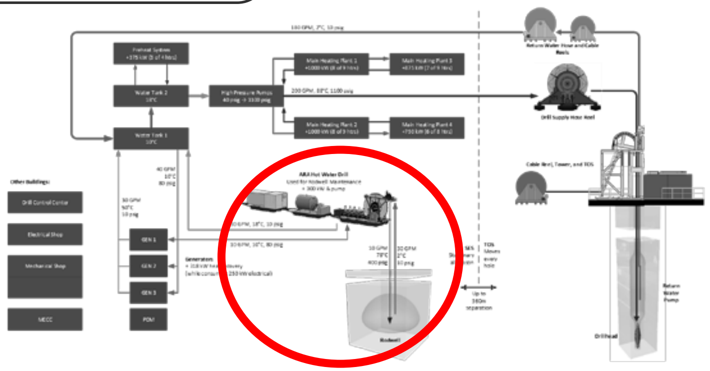
Main system filters and plumbing
Heater outlet flowmeter assemblies
Heater local control boxes
Condensate collection/handling system
Plumbing replacements
Network/PLC/Estop control panel
3x Motor drives



Rodwell and Makeup Water

Wisconsin (ready / *in-progress*)
Port Heuneme
McMurdo
Spole
Mix
As of April 2022

Existing ARAHWD drill system at Pole, to be integrated into ICU drill as Rodwell support system (original Rodwell system no longer exists)



Rework:

"White Generator" and electrical distribution sled

ePump – main pumping system

ePump control panel

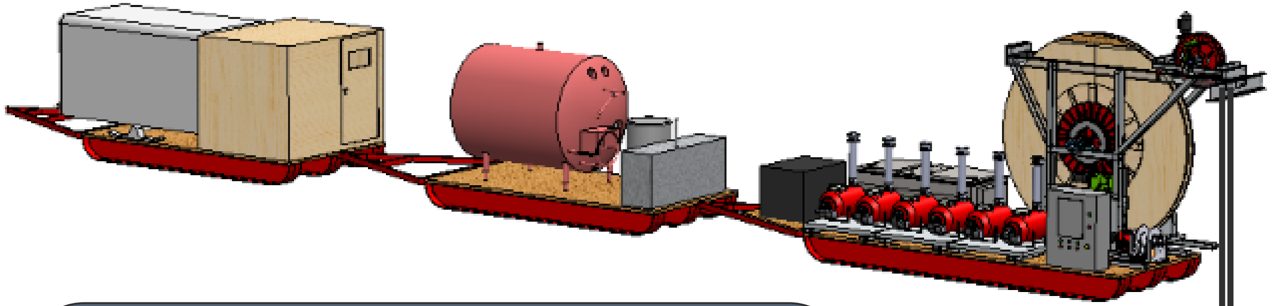
Downhole pumps and nozzle stems

Downhole pump control panels

Network/PLC/Estop control panel

Sensors and controls

Downhole camera



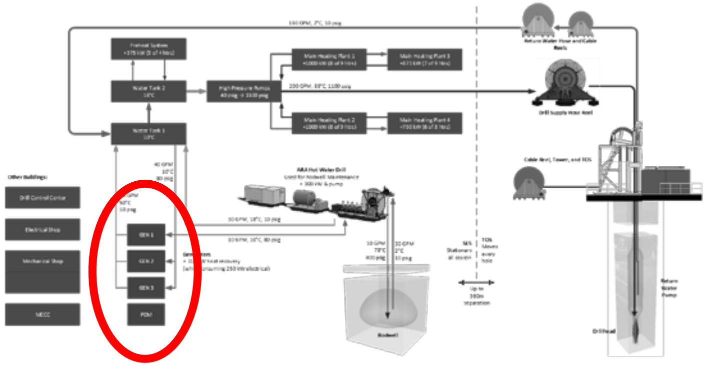
ARA HOT WATER DRILL SPECS

- Hot water to make dry holes
- Drill/pump-out simultaneously
- 3-sled train configuration, 34klb (15t) dry weight
- 300kW thermal power, requires 30kW electrical
- 12gpm (45 lpm), 85°C, 1000psi (7Mpa) local supply
- OR, supply from main ICU Drill thermal plant
- 30 gpm return from hole capability

Generators and Power Dist. Module

Wisconsin (ready / *in-progress*)
Port Heuneme
McMurdo
Spole
Mix
As of April 2022

3x generators, 165kW each (at altitude), 2x needed during deep drill operations, Power Distribution Module (PDM) contains syncing controls and distribution to various drill subsystems



Rework:

Generator 1

*Generator 2**

Generator 3

Power Distribution Module (PDM)

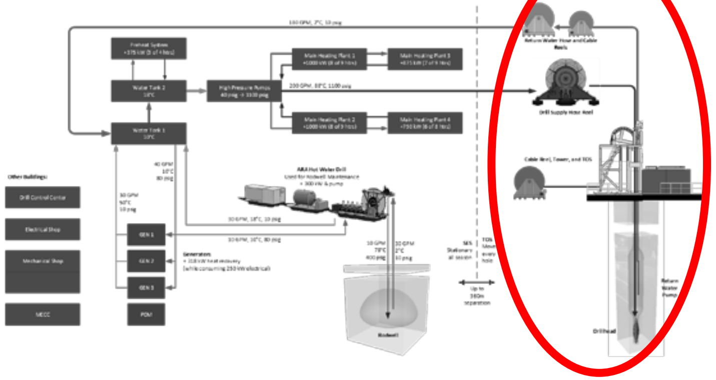
Tower Operations Site (TOS)

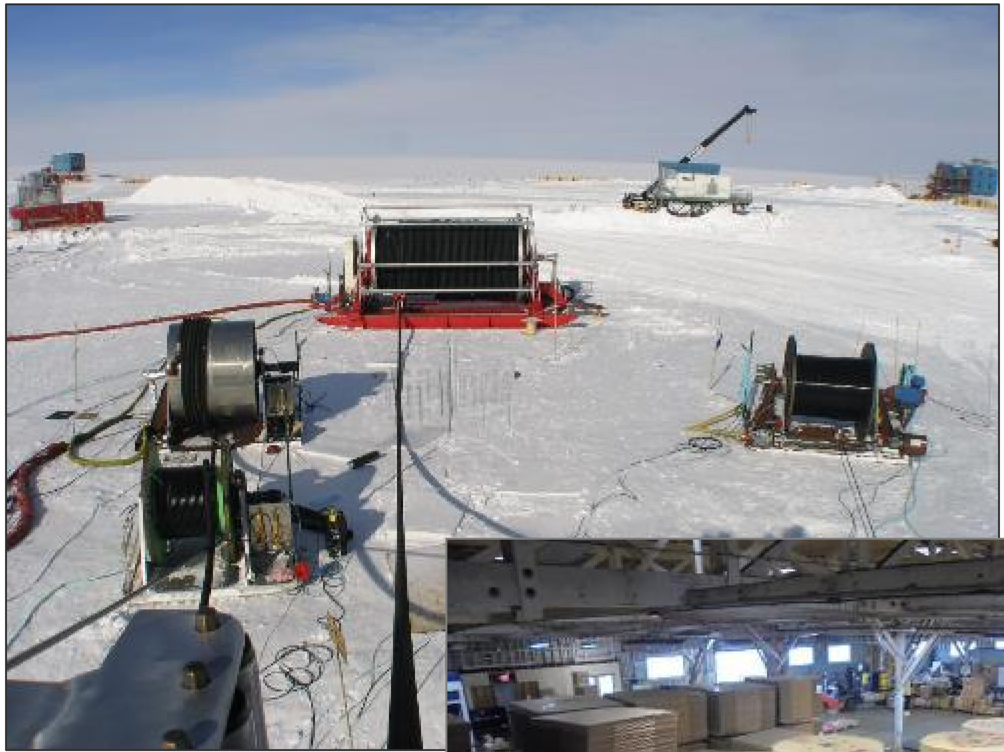
Wisconsin (ready / *in-progress*)
Port Heuneme
McMurdo
Spole
Mix
As of April 2022

Tower (2x), Tower Operations Structures (2x), Drillheads (3x), Reels and winches (9x), Main drill cable and hose, motion control system, Instrument Installation Support

Rework:

Drill Hose
Drill Cable(s)
Return Water Combo Cable(s)
Main Hose Reel Manifold and Repair Parts
Main Cable Reel
Return Water Cable Reel
Return Water Hose Reel Repair Parts
Return Water Pumps
TU-20 Winch Repair Parts
Bullwheel Tensioner
Spare Tower Hoist
Tower/TOS Repair Parts
Weightstack
Drillheads
I/O Control Panels
Network/PLC/Estop Control Panels
16x Motor Drives
Pendants
Computer Racks and Peripherals

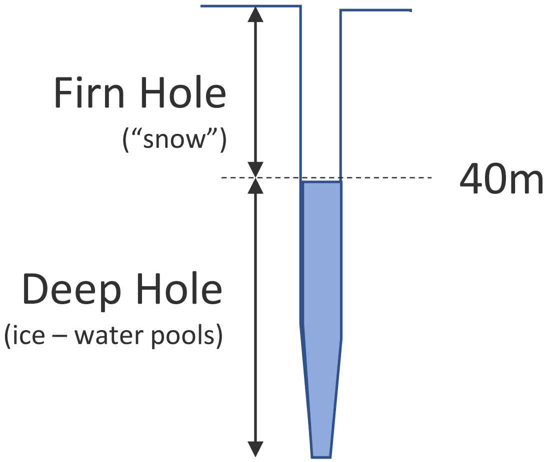




Independent Firn Drill (IFD)

Makes the firn holes needed to commence deep drilling independent of main drill system, closed loop electrically-powered glycol system

Rework:
IFD sled
IFD sheave
IFD carrot
IFD do not freeze (DNF)

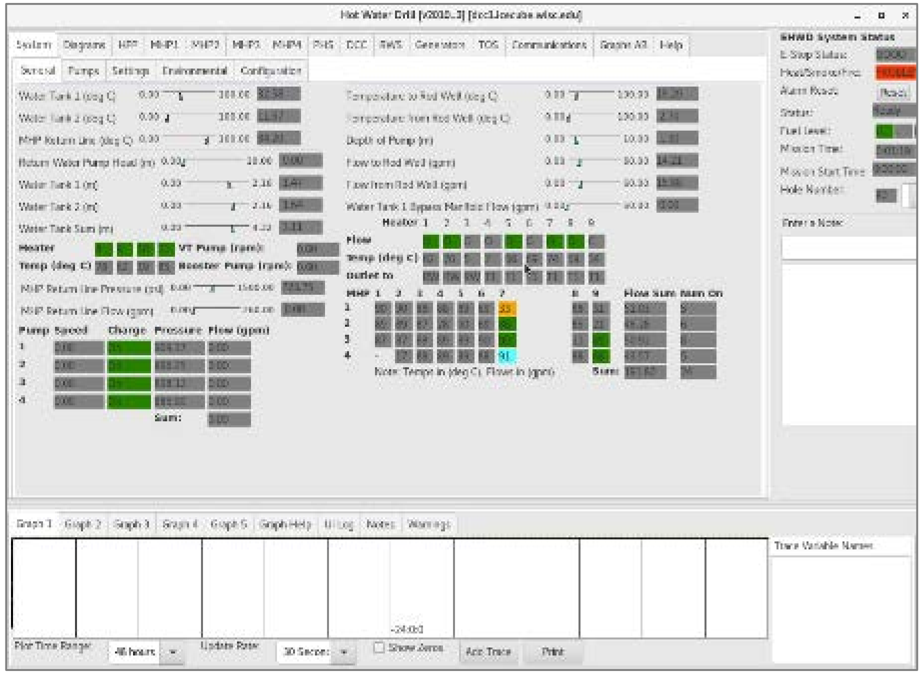


Control System

Wisconsin (ready / *in-progress*)
Port Heuneme
McMurdo
Spole
Mix
As of April 2022

New architecture: Updated motor drives, industry-standard PLC controls, SCADA monitoring, and database

- *Monitoring*
- *Logging*
- *Safety interlocks and alarms*
- *1x critical control loop (reel motion control)*
- *E-stop system*



Rework:

Drill Control Center (DCC)
Core PLCs (DCC and 2x TOS)
Core SCADA (Ignition) monitoring
Core database
Motor drives
Sensors
DGH/gateway signal processing
Network box reconfigurations
Estop system reconfiguration

1.2 What has been done?

A sampling of major completed tasks
BOLD items worked on / completed during COVID

WBS	Name	$$ Spent through Feb22	What has been done?
1.2.1	Management and Systems Engineering	$1,609,412	**LOE (Implementation and Drill Managers, System Engineering)**, non-field season travel, logistics, **replanning**, rebaselining
1.2.2	Thermal Plant	$79,399	MHP mechanical rework, **complete rebuild all flowmeter assemblies**, most of fuel system, MHP field testing, **condensate system replace**, component-level replace
1.2.3	Tower Operations Site	$2,211,683	**Main drill hose, main drill cables, Main Drill Cable Reel, Drill supply hose reel plumbing, Return Water Cable Reel refurb and combo cable,** crescent refurb, **hose heating system, weight stack eval and ship, drillhead comprensive testing and upgrades, end-to-end drillhead comms testing**
1.2.4	Control System	$1,594,209	Trade study of options, architecture, **motor drives, DGHs, I/O boxes, PLC trials and selection, end-to-end tests in TestBed, reel motion control (partial), SCADA evaluation and selection**, estop redesign, subsystem reconfiguration plans, **retro hardware for rebuild**, key reconnaissance
1.2.5	Power Generation and Distribution	$521,126	Acquire original gensets, Generator 1 refurb in CA, generator and PDM upgrade and integration season in McMurdo, **fab and ship 5x ski sets, new hoods**
1.2.6	Water Handling Systems	$423,186	Water tank upgrades, **new submersible pumps**, HPP rebuild, **vertical turbine pump upgrade/test/ship, PHS filtration upgrade, surface hose and camp hose**, ARA system upgrades and integration (PY4)
1.2.7	Support Equipment	$631,716	**Mechanical and electrical shops restock**, full Spole inventory, IFD refurbish and ship, 287 skid steer, snowmobiles
1.2.8	Drill Field Seasons	$649,421	18/19 and 19/20 field seasons
1.2.9	Installation – Off Ice	$255,502	**Install management, Installation hardware trials, install procedures, DHF design**
1.2.10	Installation – On Ice	$0	(this L3 not in baseline)
		$7,975,654	**Spent so far**

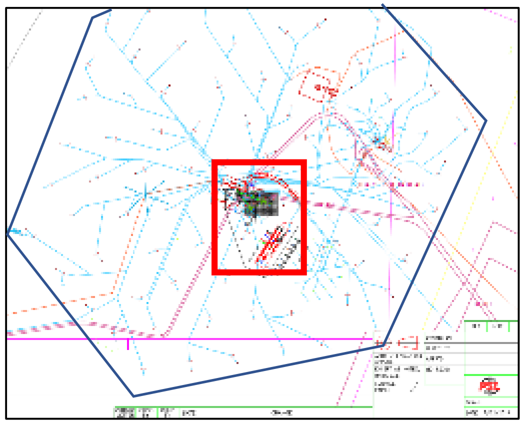
1.2 What is left to do?

WBS	Name	PY4 Remaining Mar22-Sep22	REBASE PY5-PY8	What is left to do?
1.2.1	Management and Systems Engineering	$321,898	$2,395,319	LOE (Implementation, Installation, and Drill Managers, System Engineering), non-field season travel, logistics
1.2.2	Thermal Plant	$69,403	$95,123	PHS, fuel tower, HPU, Seasonal resupply
1.2.3	Tower Operations Site	$171,157	$128,644	TU20 slip rings, Load cell calibration hardware, Seasonal resupply, driller tape
1.2.4	Control System	$419,519	$1,110,838	Core computing and PLC, sensors, global e-stop, integration hardware by subsystem (motor drive config and install kits, network box rework, I/O box rework), software, resupply
1.2.5	Power Generation and Distribution	$7,928	$64,401	Generator 2 repair subcontract, resupply
1.2.6	Water Handling Systems	$56,809	$57,615	Resupply after further FS evaluation
1.2.7	Support Equipment	$26,814	$163,036	Mechanical and electrical shops restock, PSL TestBed
1.2.8	Drill Field Seasons	$0	$3,555,137	Labor, training, travel, and PQ associated with field season drill work
1.2.9	Installation – Off Ice	$122,707	$273,576	Production install hardware, Paros, procedure development
1.2.10	Installation – On Ice	$0	$98,922	Labor, training, travel, and PQ associated with field season install work
		$1,196,235	**$7,906,611**	**Total Left to Go = $9,102,846**

Budget Increase

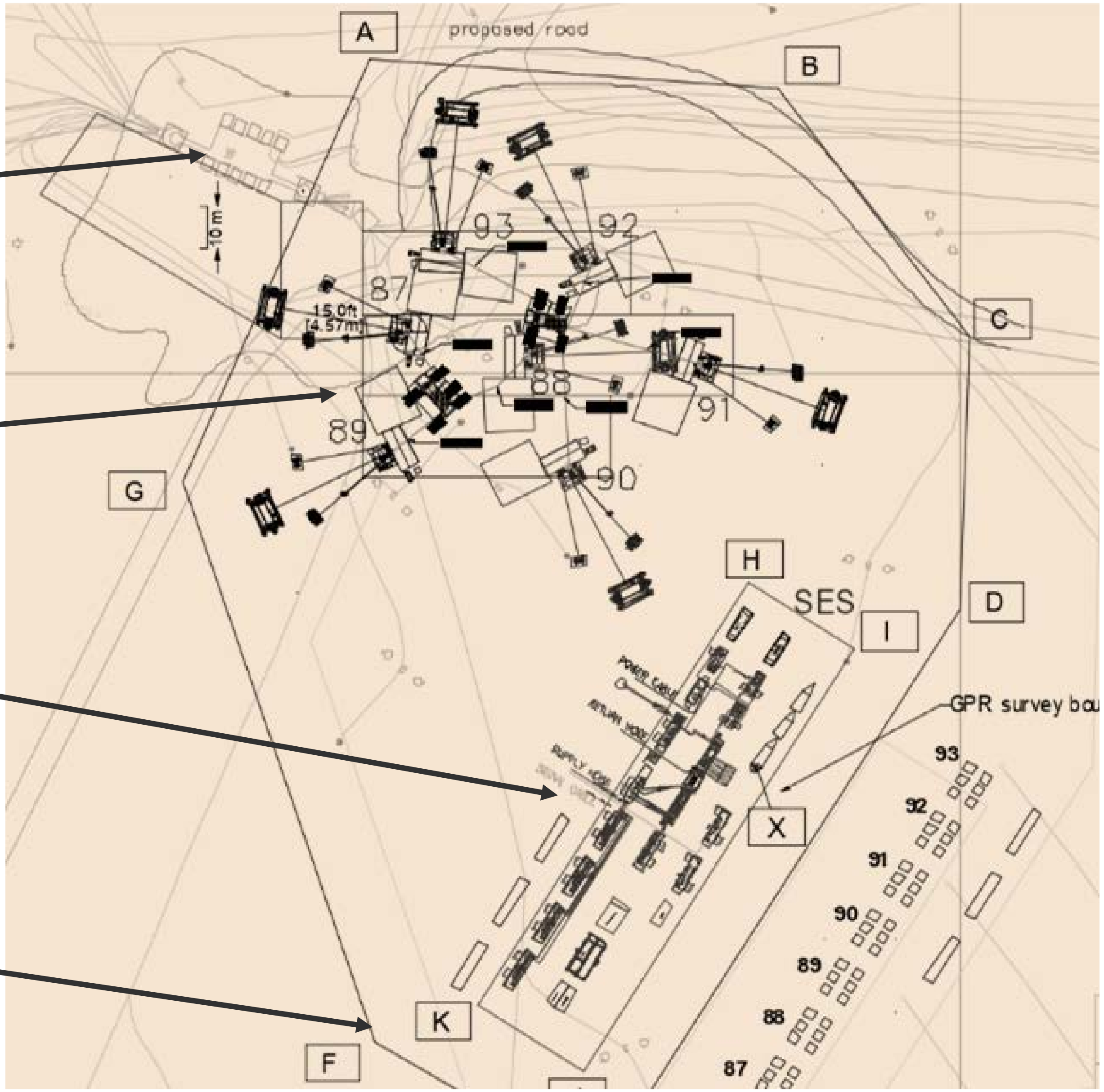
	ORIGINAL BASELINE	NOW	INCREASE to 1.2 IMPLEMENTATION $M	NEW
System-wide	Vast unknowns, equipment in long-term storage at Pole or lost	18/19 recon and 19/20 deep dive seasons behind us. Lost equipment retrieved/replaced. Scope better understood.	0.5 M	
Generator system	New microturbine system w/sled	Legacy Blue Generators w/refurb	-1 M	
Drill cable procurement	Buy 1 cable, rejacket EHWD cable	Cannot re-jacket, buy 2 new cables	0.2 M	
Controls	Assume most of the EHWD controls could be ressurrected	Entirely new PLC and SCADA control system	1 M	
Underestimated EE work	Not costed	Significant EE support than planned for mechanical-centric tasks and off-ice testing	0.2 M	
Contributed drillers	3 + 3 + 3 + 15 = 24	None	1.5 M	
Installation	Underestimated		0.5 M	
COVID and Programmatic Delays	Not planned	3 year extension, reduced work efficiency (esp. hardware-centric work), bolster test capabilities in the North. Increased logistics costs	2.0 M	
BUDGET FOR 1.2 IMPLEMENTATION	**$12,186,060**		**$4,892,440**	**$17,078,500**

Operations



IceCube

IceCube Upgrade



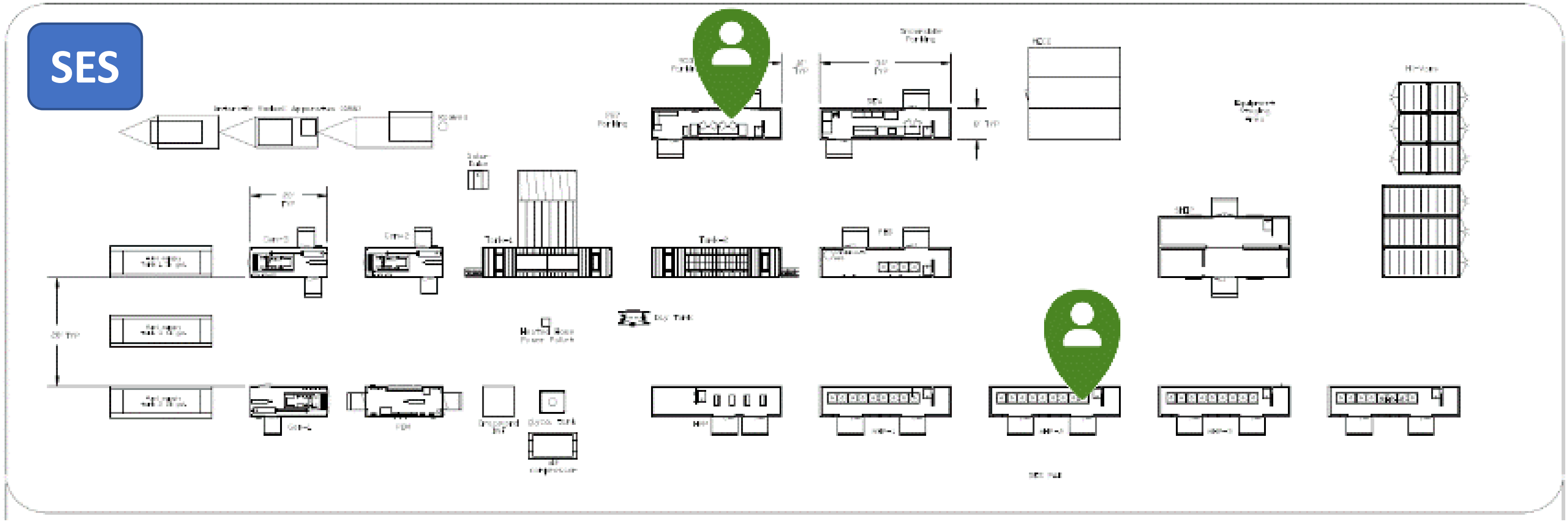
- IceCube Lab (ICL)
- Drilling
- Drill Camp (SES)
- Compacted Pad Boundary

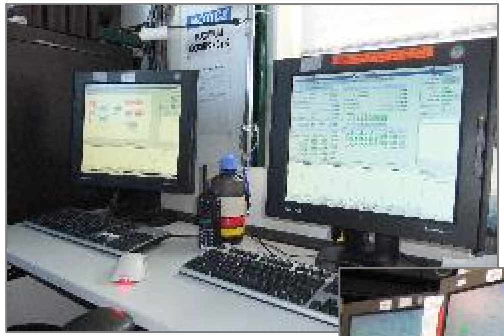
Operations (FS3)

Once water is in the system, drill operations run 24/7

- Commissioning
  - System startup
  - Establish water circulation
  - Startup checklists and testing
- Rodwell Development
  - Create makeup water reservoir
- Drilling
  - Firn Drill (FS2)
  - Deep Drill (down)
  - Deep Ream (up)
- Installation
  - Install instrumentation
- Idle
  - Surface circulation
  - Maintain and manage Rodwell
  - Maintenance and repair
- Decommissioning
  - System shutdown and winterize

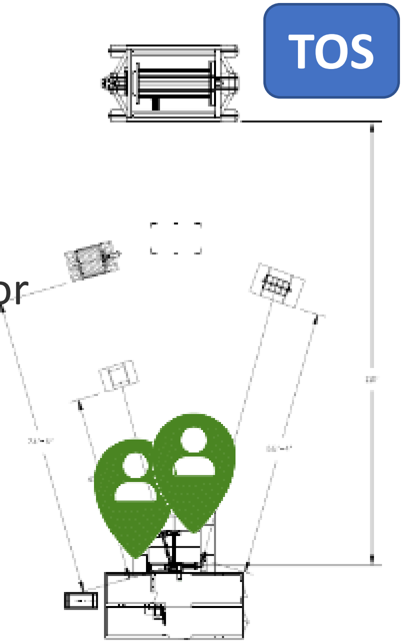
4 People minimum during smooth drilling





DCC Operator
SES Runner

TOS Operator
TOS Runner



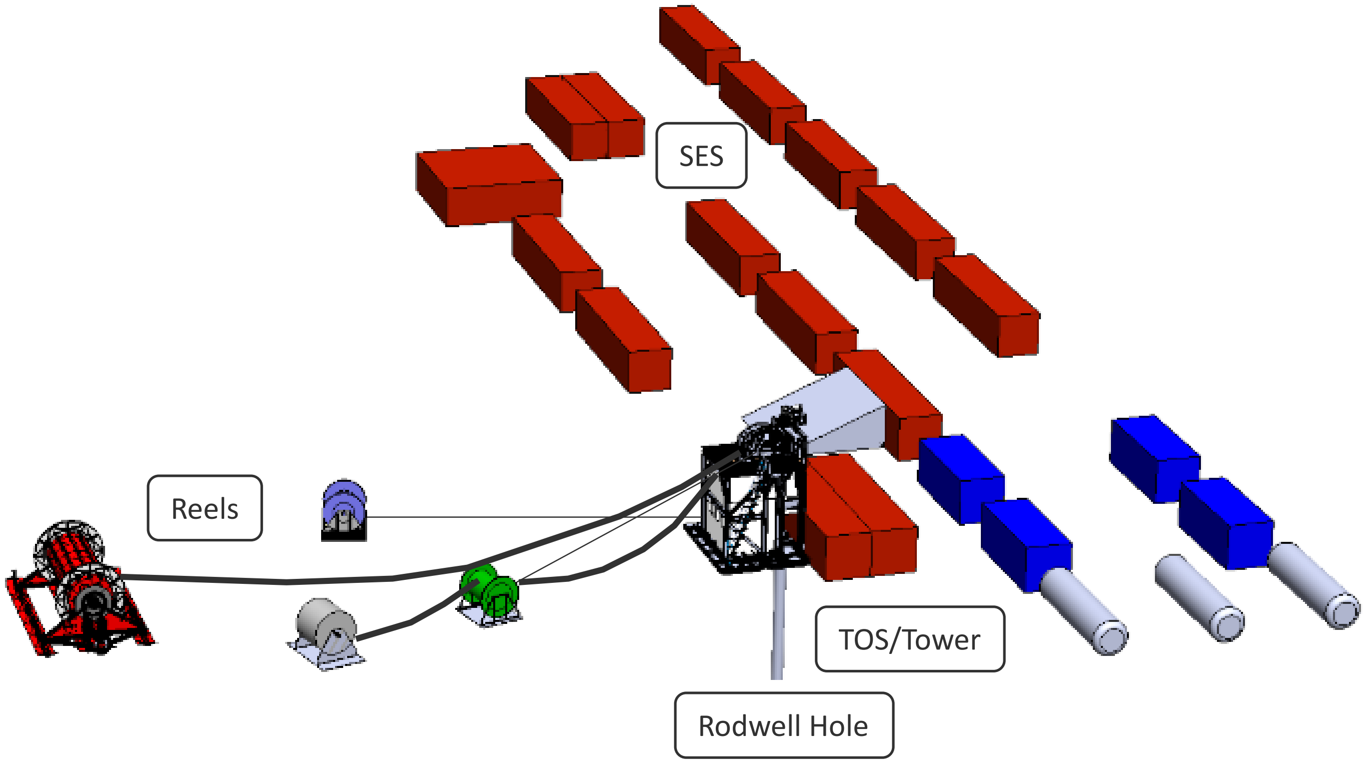
On-Ice Integration, Verification, & Testing (IV&T)

FS1

- Subsystems will be upgraded and checked-out one-by-one
- Control system installation IV&T will be done with a “mobile-DCC”
- Most subsystems to be brought to “plug-and-play” status

FS2

- System connected together and fully integrated
- TOS motion control
    - Setup TOS over Rodwell firn hole
    - Hose/Cable synchronization tuning and demonstration
    - Hole operations training
    - 12 days
- Full system wet testing
    - 200 gpm (full system flow), full pressure, cold
    - 50 gpm (full MHP flow), full pressure, hot
    - Full pressure, hot, through hose reel
    - 9 days
- Objectives
    - Piecewise validation of whole system
    - High fidelity on-the-job training



Thank you!

Backup

1.2 Implementation - Drilling

Seasonal Equipment Site (SES)

REQUIREMENTS

- 7 holes, 2600m max depth, 52cm dia for up to 55hr
- 22m hole spacing
- Improved hole ice quality from Gen1
- 1 drill field season to complete work
- Compatible with South Pole environment and logistics
- Equipment supports drilling AND installation
- Maintain safe and predictable operations

SPECS and PERFORMANCE

- 5 MW capacity (4.7 MW thermal, 0.3 MW electric)
- 200 GPM (760 LPM), 88°C (190°F), 1100 psig (76 barg)
- 2.2 m/min maximum drill speed
- Average time to drill hole = 53 hr
- Average fuel to drill hole = 8500 gal*
- 1.2 million lb
- 24/7 operation, total crew of 28+1

* 7654 gal deep (ave) + 600 gal makeup water + 300 gal firn drill ~ 8500 gal

ICU Drill System Requirements

	EHWD (Gen1)	ICU
HOLE DEPTH	2450 m	2600 m
HOLE SIZE	45 cm dia for 37 hr lifetime	52 cm dia for 45-55 hr lifetime
ARRAY	125 m hole spacing	22 m hole spacing, center of IceCube
ICE QUALITY	NA	Better and less bubbles
HOLES	86 holes in 7 seasons	7 holes in 1 season
DRILL TEAM	30	28
LOGISTICS	LC130, primarily	Vessel and Traverse, primarily

Enhanced Hot Water Drill (EHWD)

IceCube, South Pole 2004-2022

Papers:

IceCube Enhanced Hot Water Drill functional description, 2014, Benson et.al.

Modeling hole size, lifetime and fuel consumption in hot-water ice drilling, 2014, Greener et.al.

IceCube Enhanced Hot Water Drill functional description

T. BENSON, J. CHERWINKA, M. DUVERNOIS, A. ELCHEIKH, F. FEYZI, L. GREENLER, J. HAUGEN, A. KARLE, M. MULLIGAN, R. PAULOS

Modeling hole size, lifetime and fuel consumption in hot-water ice drilling

L. GREENLER, T. BENSON, J. CHERWINKA, A. ELCHEIKH, F. FEYZI, A. KARLE, R. PAULOS

Drilling Season Cadence – High Level

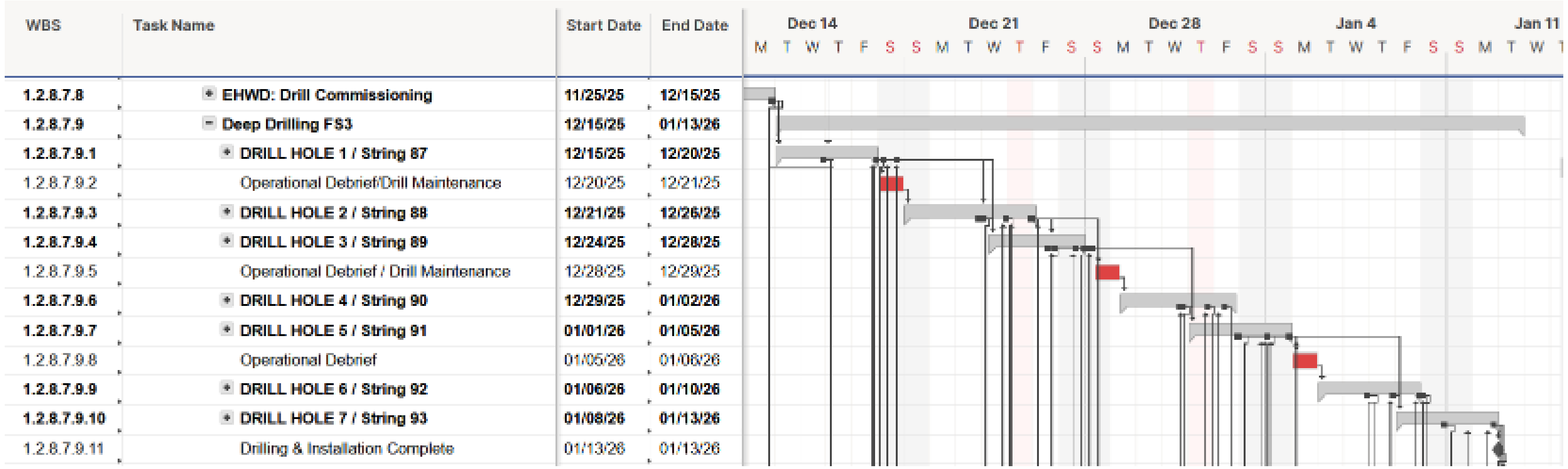
SmartSheets Schedule

Drilling Start: 12/15

Install End: 1/13

Includes days off

Overall duration: 28.3 days



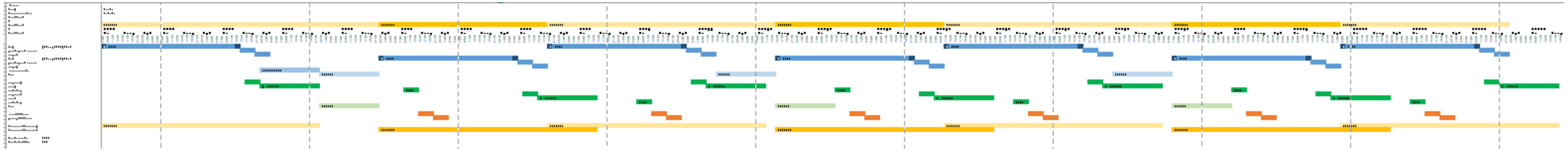
WBS	Task Name	Start Date	End Date
1.2.8.7.8	EHWD: Drill Commissioning	11/25/25	12/15/25
1.2.8.7.9	Deep Drilling FS3	12/15/25	01/13/26
1.2.8.7.9.1	DRILL HOLE 1 / String 87	12/15/25	12/20/25
1.2.8.7.9.2	Operational Debrief/Drill Maintenance	12/20/25	12/21/25
1.2.8.7.9.3	DRILL HOLE 2 / String 88	12/21/25	12/26/25
1.2.8.7.9.4	DRILL HOLE 3 / String 89	12/24/25	12/28/25
1.2.8.7.9.5	Operational Debrief / Drill Maintenance	12/28/25	12/29/25
1.2.8.7.9.6	DRILL HOLE 4 / String 90	12/29/25	01/02/26
1.2.8.7.9.7	DRILL HOLE 5 / String 91	01/01/26	01/05/26
1.2.8.7.9.8	Operational Debrief	01/05/26	01/06/26
1.2.8.7.9.9	DRILL HOLE 6 / String 92	01/06/26	01/10/26
1.2.8.7.9.10	DRILL HOLE 7 / String 93	01/08/26	01/13/26
1.2.8.7.9.11	Drilling & Installation Complete	01/13/26	01/13/26

Independent Detailed Exercise

"Nominal" schedule

Includes days off

Overall duration: 24.6 days



Schedule currently has overall drilling duration ~15% longer than nominal

Continuing to work on increasing this as much as possible

Safety

Hazards

- High voltage
- Hot water
- High pressure
- High tension
- Fire
- Noise
- Cold
- Freezing water lines
- Heavy equipment
- Lifting
- Trips, falls, cuts and scrapes

Strong Safety Culture is a key priority

- See separate safety talk

Drill Crew Makeup

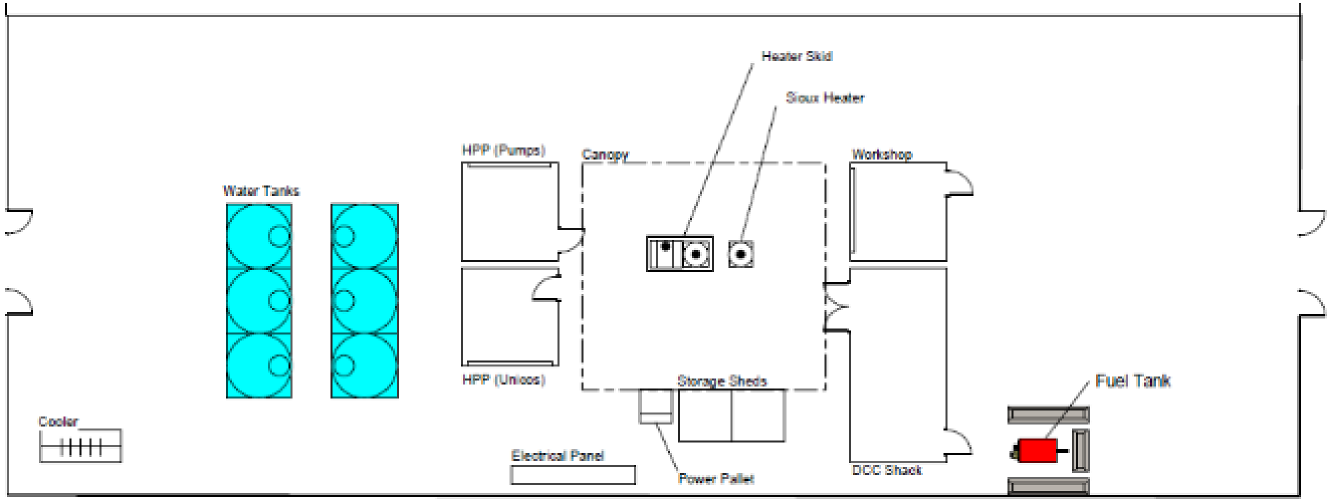
24/7 Operation
3 Shifts
9 Drillers/Shift + Drill Manager
28 People

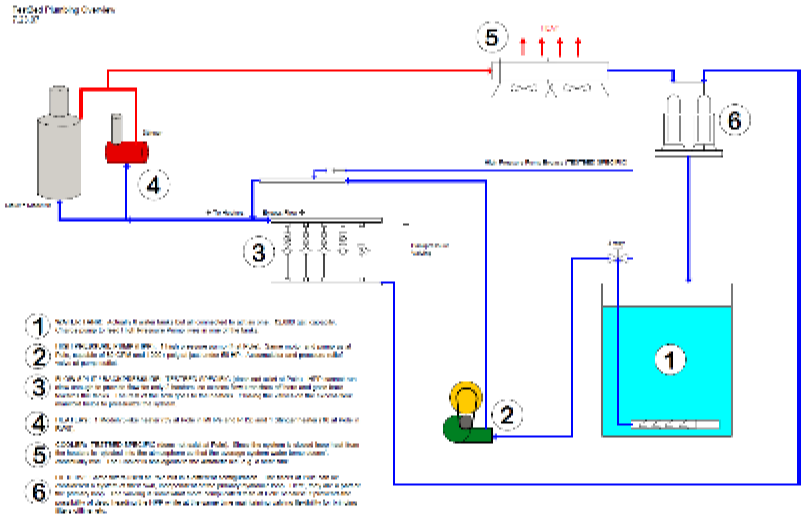
SKILLSETS

- Drill Manager
- Each Shift
  - Shift Lead
  - Deputy Shift Lead, Shift Safety Officer
  - DCC (SES) Operator
  - TOS Operator
  - Heater Expert
  - Electrical/Controls Expert
  - Mechanical Expert
  - Installation Experts
  - Equipment Operator
- Cross-Shift Expertise Required On-Site
  - Drill Engineer
  - Software Expert
  - Generator Tech
  - Electrician

Some key operations – examples of why 9 drillers/shift are required	
Smooth Drilling • 2 SES (DCC operator + oversight) • 2 TOS (TOS operator + taping/oversight) • 2 Setup other TOS • 2 Maintenance and repair • 1 Person off **9 TOTAL**	**Meals** • 2 SES • 2 TOS • 4 Meal • 1 Person off **9 TOTAL**
Hole Move • 1 Installation setup • 1 SES • 1 Hose reel move • 2 Other reels move • 2 Surface supply hose move • 2 Surface return hose move **9 TOTAL**	**Installation** • 3 installation • 3 prepare SES for drilling • 3 prepare TOS for drilling **9 TOTAL**

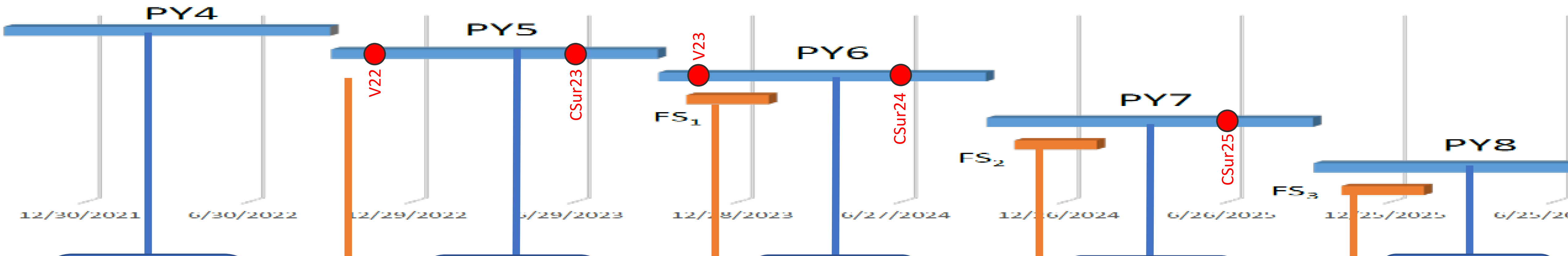
PSL Drill TestBed





Drill system development and proving grounds

1.2 Drill Major Efforts Summary (PY4-8)



PY4 Off-Ice
- Controls HW
- Sensors
- Mech wrap-ups
- Condensate dispose
- ARA system
- Hose heating
- Load sharing

PY5 Off-Ice
- Controls HW
- Sensors
- Controls Main PLC
- Controls SW
- Load sharing
- Training

PY6 Off-Ice
- Controls SW
- Procedures, HAs
- Resupply
- Training

PY7 Off-Ice
- Controls SW
- Procedures, HAs
- Resupply
- Training

PY8 Off-Ice
- Debrief
- Lessons learned
- Documentation

FS0
- Cargo
- Pad prep
- Generator2
- Winter heating elec

FS1
- Subsystem install, update, test at Cryo
  - MHPs
  - HPP/PHS
  - ARA/IFD
  - TOS/Reels
  - Gensets
- Build up SES
- Commission ARA drill
- Commission IFD
- Hose heating install/test

FS2
- DCC, Daytank, WT controls
- Genset controls
- HPU
- Turn on control system
- Hook everything together, troubleshoot
- IFD: drill firn holes
- ARA: SES pilot holes, mini-Rodwell
- Wind up hose
- Load share tuning
- Full systems wet test

FS3
- Drill/Install 7 holes

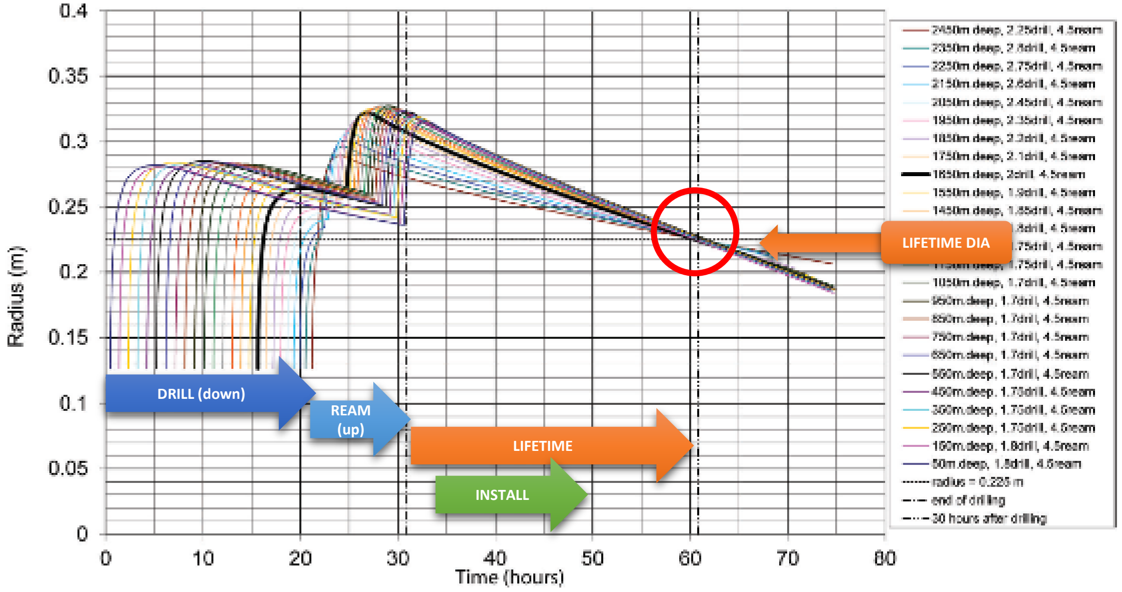
ICECUBE UPGRADE

Hole Modeling, Type, and Possible Downscope

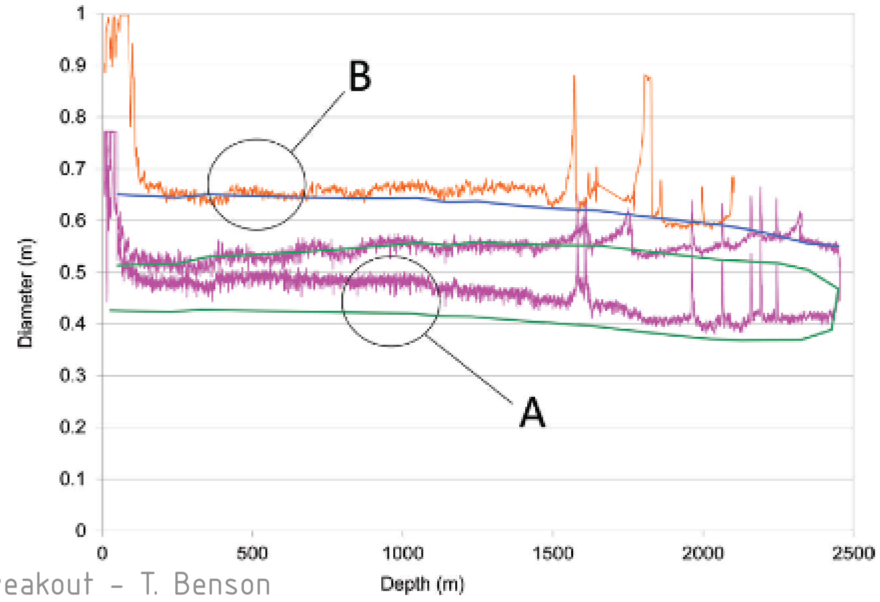
Thermal Drilling Model

- Model predicts hole profile during course of drilling/reaming
- Based on first-principals thermodynamics and heat transfer
- Includes heat loss through hose, ice temperature vs. depth, and freezeback
- Provides drill speed strategy, ream speed charts, drill time, fuel usage
- Compared against actual freezeback during Gen1
- Gen1: 45 hr holes -> 24 hr holes
- [Modeling hole size, lifetime and fuel consumption in hot-water ice drilling](), 2014, Greener et.al.

Drill speed is iterated for constant assumed ream speed such that all depths are at the lifetime diameter at the expiration of the hole lifetime



A comparison of predicted (smooth line) and measured (jagged line) hole sizes (diameter vs depth in hole 40): (A) during drilling; (B) 4 hours after drilling was completed.



Hole Type, Possible Downscope

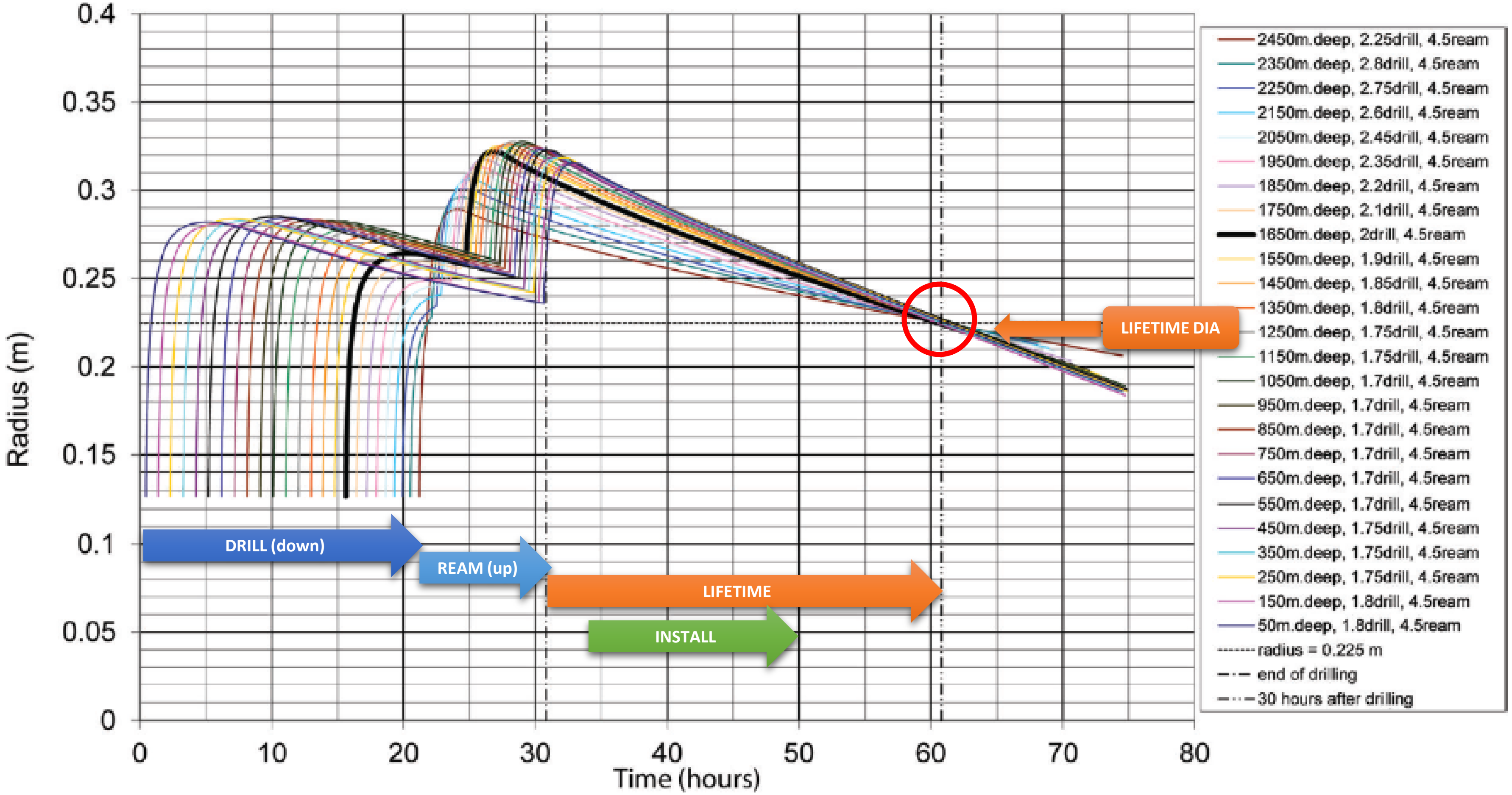
FROM HOLE MODELING	IceCube Upgrade			
Modeling results as of 1.29.2021 (JN)	hot	hot + log	1000m cold	500m cold deep
Depth (m)	2600	2600	2450	2600
Instrumentation Dia (cm)	47	47	47	47
Lifetime Dia (cm)	52	52	52	52
Degassing Cold Ream (m)	none	none	1375-2450	2100-2450
Hole Lifetime (hr)	45	55	50	50
Drill Time, full heat (hr)	33.9	38.9	40.0	38.8
Cold Ream Time, low heat (hr)	0	0	9.3	5.6
Hot Ream Time, full heat (hr)	11.6	11.6	7.2	8.5
Total Drill Time (hr)	45.6	50.6	56.4	52.9
Max Hole Pre-Ream Dia (cm)	65.5	69.4	74.8	68.5
Drill Fuel, full heat (gal)	4409	5059	5204	5038
Cold Ream Fuel, low heat (gal)	0	0	347	208
Hot Ream Fuel, full heat (gal)	1513	1513	930	1110
Fuel Per Deep Hole (gal)	5923	6572	6481	6357
Deep + % (gal)	**7107**	**7887**	**7777**	**7629**
Mini Rodwell Fuel at each Hole (10%) (gal)				
Total Deep + Mini Rodwell (gal)				
Deep + Mini Rodwell + % (gal)				
	35%	50%	48%	45%
	1.05	1.17	1.15	1.13
Number of each type	1	1	3	2

Degassed holes = “Cold Ream”

Hole Type, Possible Downscope

NORMAL HOLE EXAMPLE

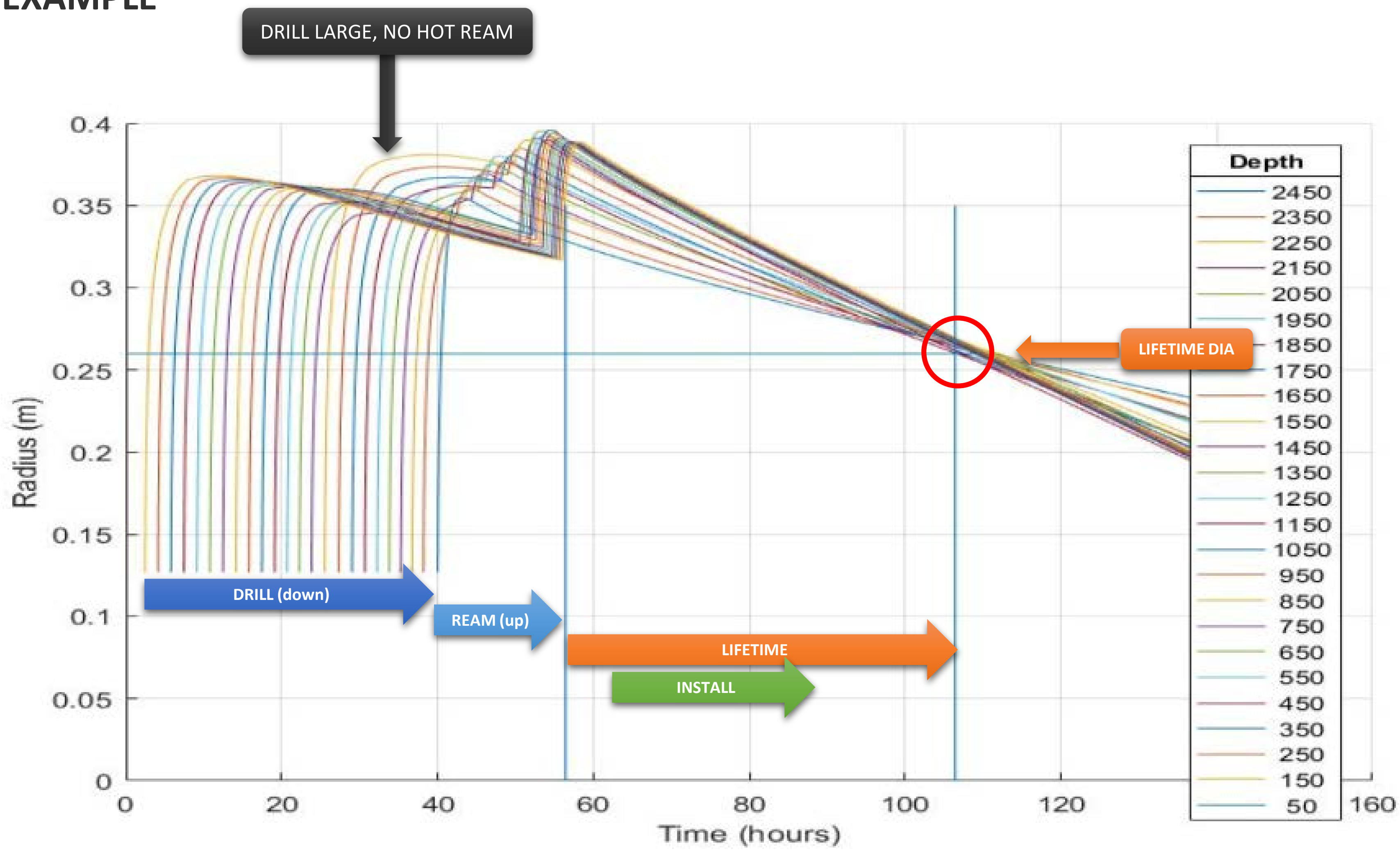
Drill speed is iterated for constant assumed ream speed such that all depths are at the lifetime diameter at the expiration of the hole lifetime



Hole Type, Possible Downscope

DEGASSED “COLD REAM” HOLE EXAMPLE

Cold Ream:
In Region of interest, drill hole large on way down. When reaming this section, adjust ream speed so that meltwater rich in gas is displaced by less-saturated surface water. Minimizing melting in the region (i.e. cold ream) minimizes further addition of saturated meltwater that would be left behind.



Hole Type, Possible Downscope

FROM HOLE MODELING	IceCube Upgrade			
Modeling results as of 1.29.2021 (JN)	hot	hot + log	1000m cold	500m cold deep
Depth (m)	2600	2600	2450	2600
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Deep + Mini Rodwell + % (gal)				
	35%	50%	48%	45%
	1.05	1.17	1.15	1.13
Number of each type	1	1	3	2

Degassed holes = “Cold Ream”

Cold reaming adds approximately:
10% more fuel
20% more drill time

Degassed holes are not a hard science requirement, and can be converted to more traditional style holes in real time to save time and fuel, if needed.

Fuel Projection

V.20211014 (for 2021 November NSF Logistics Review)

	18-19	19-20	20-21	21-22	22-23	Field Season 1	Field Season 2	Field Season 3	Total
							9 firn holes	7 deep holes	
Deep Drilling								53583	**53583**
Firn Drilling							3900		**3900**
Base Fuel	250 (A)	1000 (A)				3643	12346	17584	**34823**
Winter Heating							4305		**4305**
Total	**250 (A)**	**1000 (A)**	**X**	**X**	**X**	**3643**	**20551**	**71167**	**96612**

Contingency

	No Contingency	Contingency	With Contingency
Deep Drilling	44653	8930 (20%)	53583
Firn Drilling	2250	1650 (73%)	3900
Base	34823	0 (0%)	34823
Winter Heating	3588	717 (20%)	4305
Total	**85314**	**11298 (13%)**	**96612**

Base contingency cooked into estimate

Total contingency backed out of summed contributions from each category

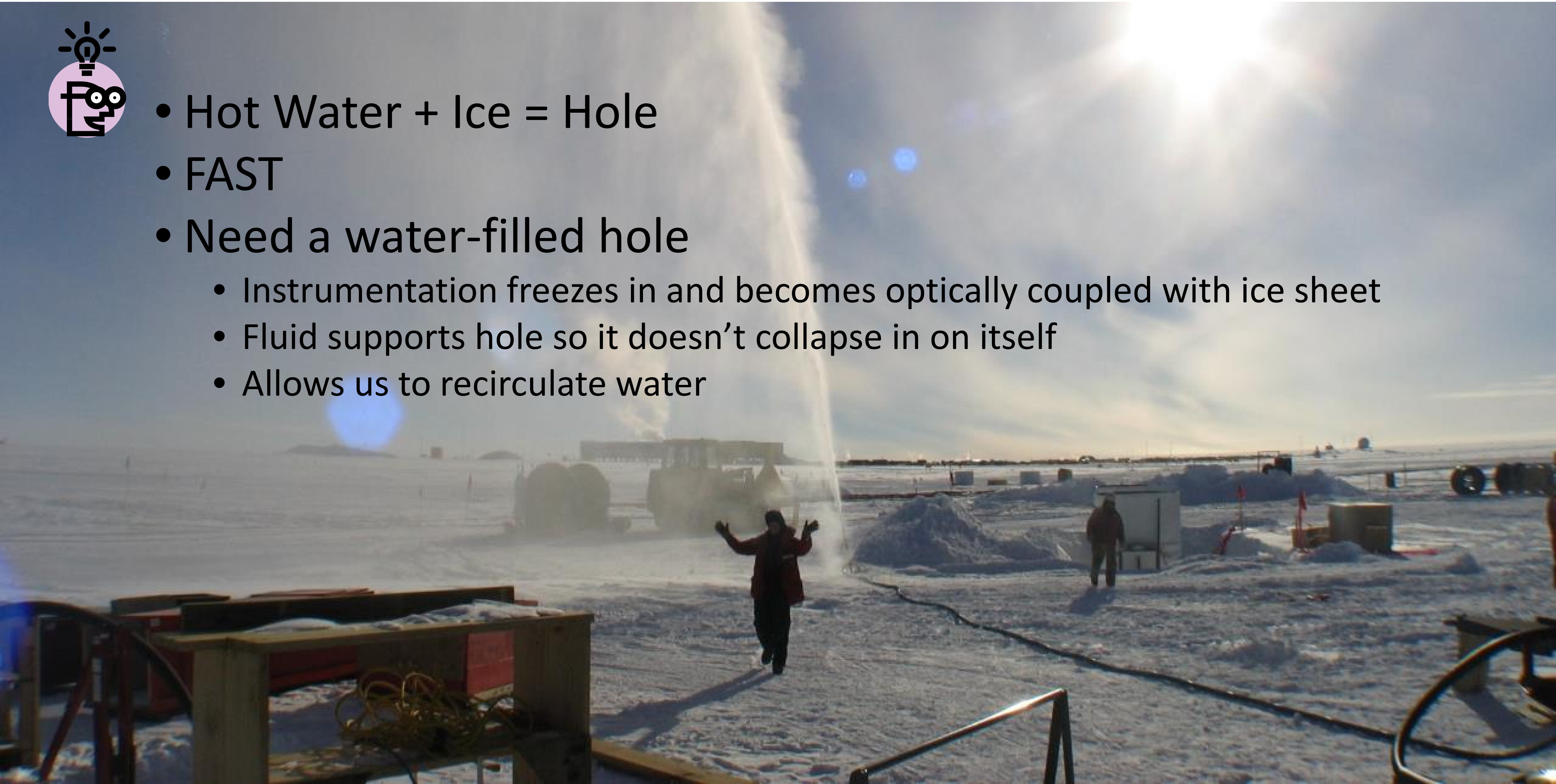
By Field Season

	Field Season 1	Field Season 2	Field Season 3
No Contingency	3191	18178	62694
Contingency	452	2373	8473
Total	**3643**	**20551**	**71167**

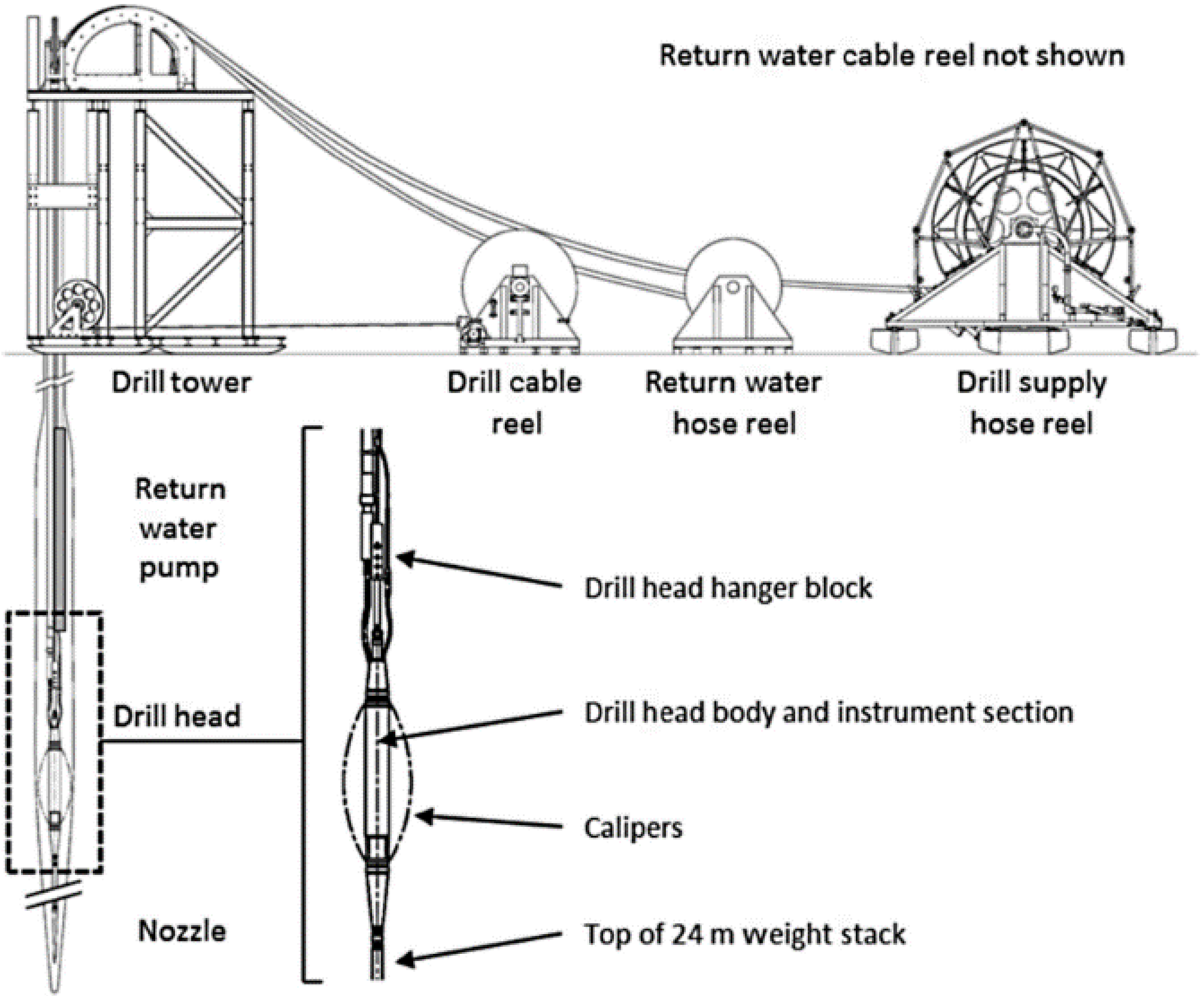
95361 gal to go

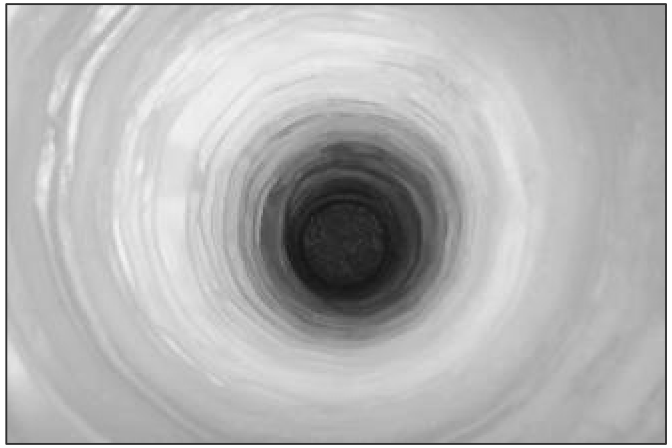
Why a Hot Water Drill?

- Hot Water + Ice = Hole
- FAST
- Need a water-filled hole
  - Instrumentation freezes in and becomes optically coupled with ice sheet
  - Fluid supports hole so it doesn’t collapse in on itself
  - Allows us to recirculate water



TOS - Additional





Risks

Charge Question ST3

In the Risk Register, 1.2 (Drill) has:

(6x) OFF-ice risks
- Control system development
- Loss of expertise
- Novel string install

(21x) ON-ice risks
- Serious injury/incident for each FS
- (1x) consolidated drill season-killer
- Talent acquisition for seasonal drillers
- Some logistics risks
- Many equipment failure risks that result in ~ 1-2 week delay or similar

1.2 (Drill) off-ice risks (snippet)

		Risk Identification and Tracking	Post-Mitigated Risk Evaluation						
			Probability and Impacts				Exposure		
Risk ID	Associated WBS	Risk Description	Risk Probability	Impact on schedule	Impact on cost	Impact on technical performance	Schedule Risk Score	Cost Risk Score	Technical Performance Risk Score
		1.2 Northern Risks							
TECH1	1.2.4	Unable to complete controls system work on-schedule due to cargo front loading and/or staffing limitations.	Low	Low	Moderate	Low	Low	Moderate	Low
TECH2	1.2.4	Unable to make critical controls hardware procurements (motor drives, DGH's servers, sensors, etc) on-schedule due to vendor shortages and transportation delays.	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate
TECH3	1.2.4	Delay in development of user interfaces, control algorithms, and hands-on Integration and test activities due to Test Bed limitations.	Moderate	Low	Moderate	Low	Moderate	Moderate	Moderate
TECH4	1.2	Loss of key drilling expertise/personnel	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
TECH5	1.2	Novel string installation - Final down-hole cable design requires the development of new equipment and processes for installation (i.e. New rope reel with coordinated load sharing)	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate

1.2 (Drill) on-ice risks (snippet)

		Risk Identification and Tracking	Post-Mitigated Risk Evaluation						
			Probability and Impacts				Exposure		
Risk ID	Associated WBS	Risk Description	Risk Probability	Impact on schedule	Impact on cost	Impact on technical performance	Schedule Risk Score	Cost Risk Score	Technical Performance Risk Score
ORG4	1.2	Serious FS3 injury or incident occurance halts on ice activities until full accident investigation	Very Low	Very High	Very High	Low	Moderate	Moderate	Low
ORG5	1.2	Serious FS2 season Injury or Incident occurance halts on Ice activities until full accident investigation is completed	Very Low	Very High	Very High	Low	Moderate	Moderate	Low
ORG6	1.2	Serious FS1 season Injury or Incident occurance halts on ice activities	Very Low	Low	High	Low	Low	Low	Low

Response to Previous Reviews

Charge Question O-5

Nov 2021 Logistics Review

LR8	Include recording accelerometer in sample packaging for first available South Pole Traverse to get a sense of the potential for shock and vibration damage during shipment using the traverse.	Terry Benson	In progress	10/01/22
LR9	Activities planned for the same construction season should be prioritized before the start of the season to ensure resources are applied to the most critical activities should delays begin to be experienced.	Dar Gibson, Ian McEwen	Closed	01/20/22
LR10	Drilling activities in the schedule should be broken down into smaller duration activities to allow for better visibility of the entire drilling process and to allow planned efficiency when staff are expected to move from one hole to the next.	Dar Gibson, Terry Benson	Closed	01/20/22
LR11	Drilling activities should include some buffer time to allow for inefficiencies experienced at shift changes and mid-day breaks.	Dar Gibson, Terry Benson	Closed	01/20/22

Brief Bio

Terry Benson – UW Physical Sciences Lab (PSL)

- PSL Instrumentation Manager, mechanical engineer
- IceCube Upgrade Drill Systems Engineer
- Nearly 20 years hot water drill experience – joined IceCube EHWD team in 2003
- Drilling shift lead in the field
- 9 trips to South Pole for hot water drilling projects

PSL Team:
EHWD experience from IceCube Gen1 has become concentrated at PSL, and joined by a younger generation of skilled, enthusiastic engineers that are firmly engaged in Upgrade.