IceCube Hot Water Drilling

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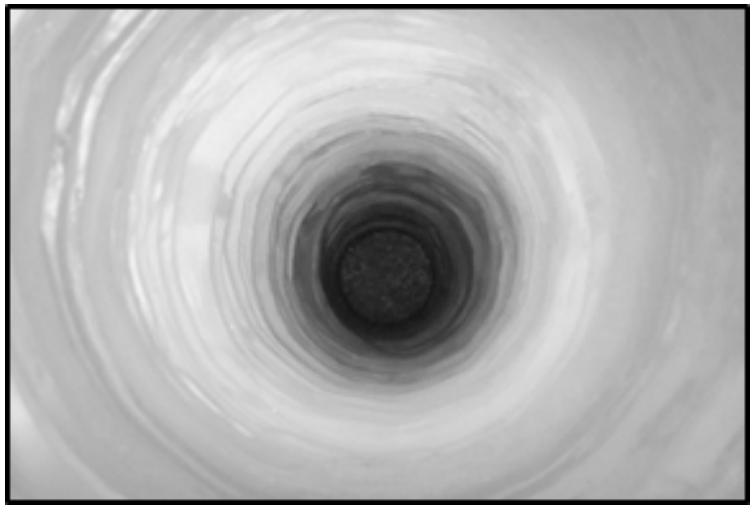
IceCube Polar Science Workshop
19 January, 2021

Scope

- Drilling holes for Optical Sensor Installation for IceCube
- IceCube Upgrade Drilling
- IceCube GEN2 Drilling
- Independent Firn Drill (IFD)
- Enhanced Hot Water Drill (EHWD)
- GEN2 Drill Plans
- ARA Hot Water Drill

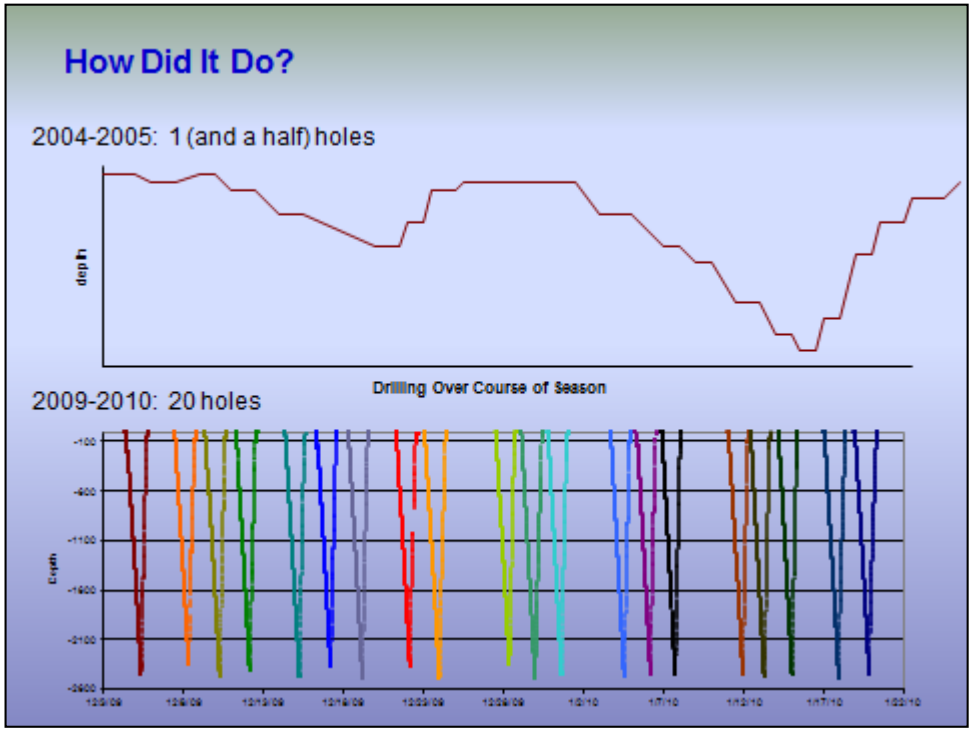
Optical Instrument Hole

- IceCube Optical Instruments need to be in the deep clear ice below 1400 m and above the shear zone around 2600 m.
- The Instruments need to be optically coupled to the ice, so they need to freeze in.
- Hot Water Drilling keeps the hole full of water allowing for this freeze in and provides counter pressure to keep the hole from closing.
- IceCube holes were drilled about 60 cm (24 in) diameter to provide time for deploying the 45 cm (18 in) instrumentation (includes cable). Upgrade will require 52 cm (20 in)
- The time from end of drilling to when the hole is no longer “safe” for deployment is called the lifetime. For IceCube this varied from 24 hrs to 40 hrs. Longer lifetime means larger initial hole, more fuel use, and more time. Upgrade will require 45 to 55 hr.

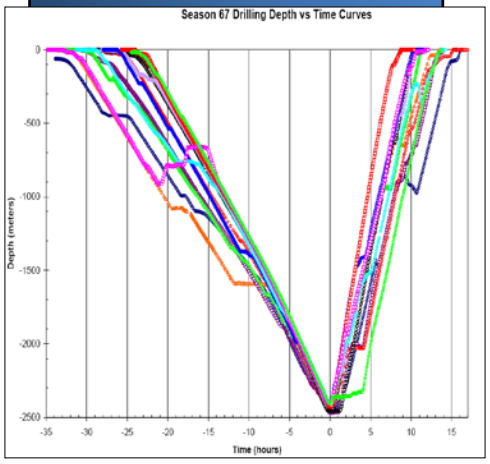


Hot Water Drill Goals

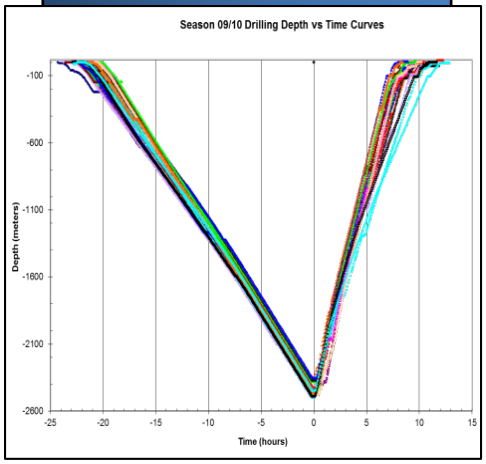
- The Main Goal is to maximize the number of good holes per season.
  - Minimize drill set up and take down time
  - Min drilling time (~34 hrs)
  - Min hole to hole time (~48 hrs)
- Make every hole useable, known good
  - Measure on ream, and ream to lifetime shape
  - Freezeback has been modeled and measured
- Minimize fuel usage (~5300 gal)
- **SAFE**
- Predictable
- Reliable



2006-07: 13 holes

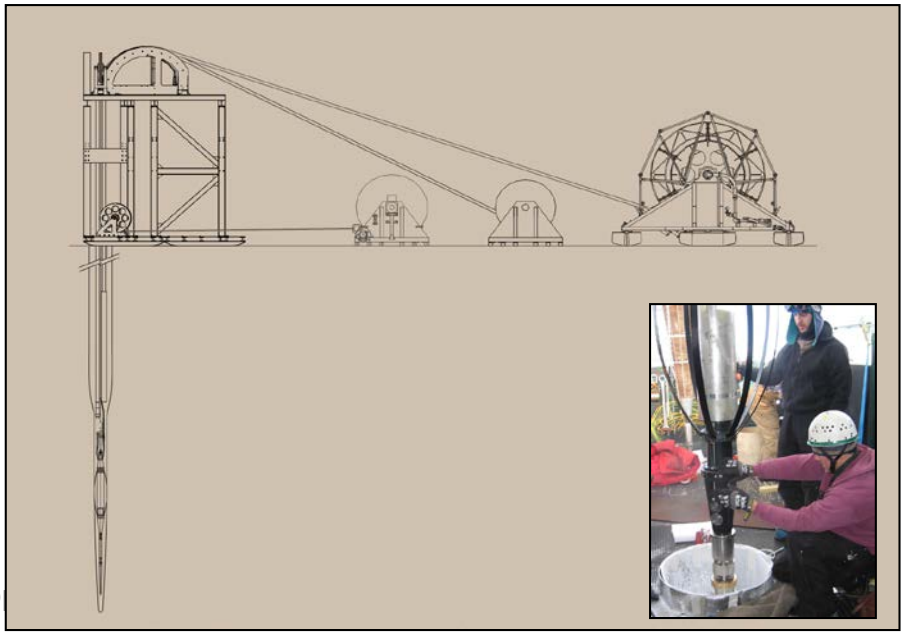


2009-10: 20 holes

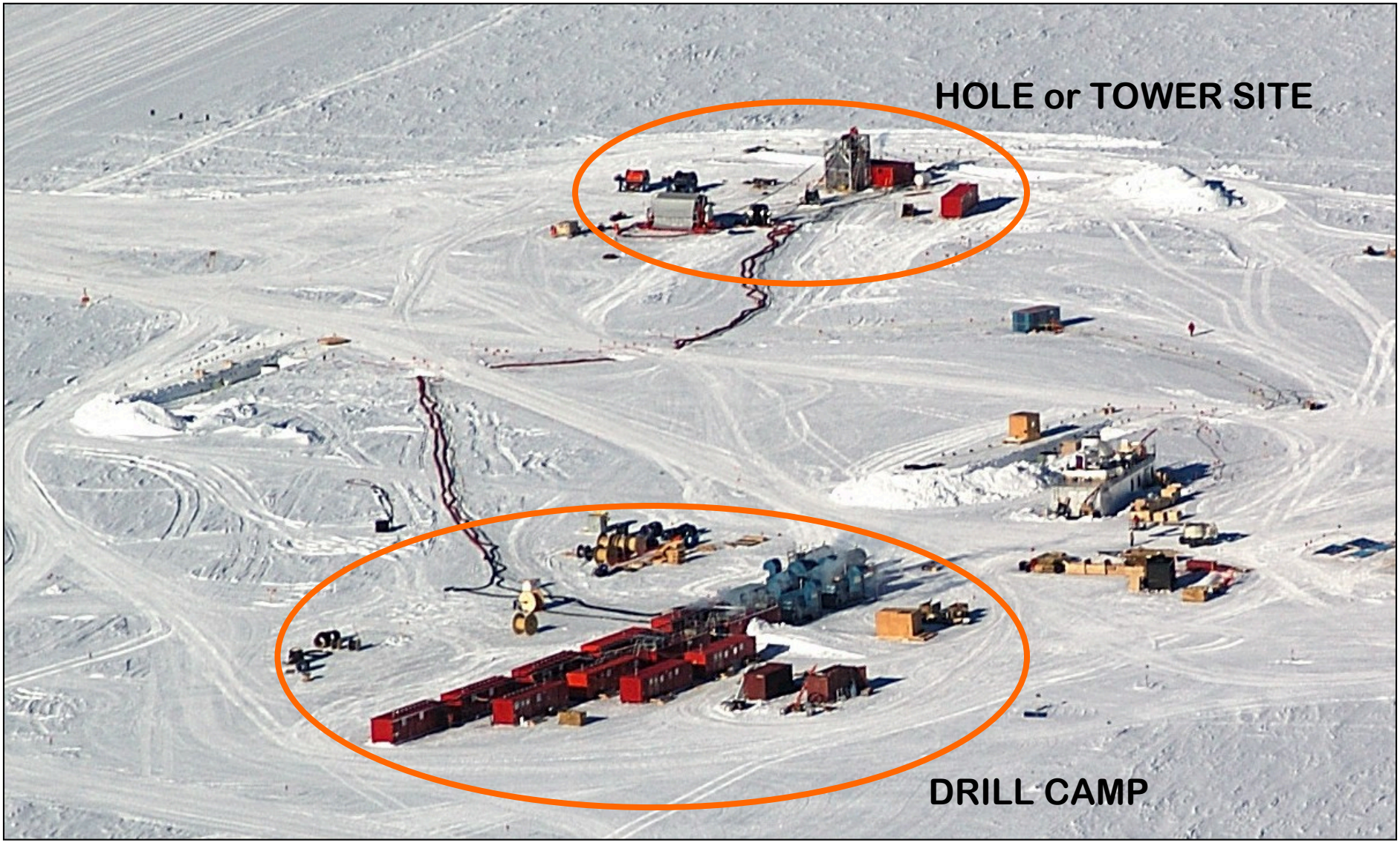


Enhanced Hot Water Drill (EHWD)
Modules fit in LC130, Conventional Gens, Heaters, Pumps

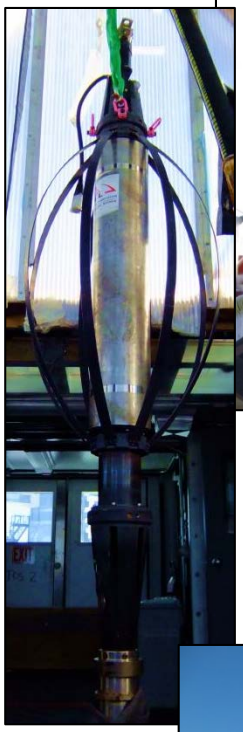
WATER RESERVOIR → PUMP → HEAT → SHOOT OUT NOZZLE → RECIRCULATE

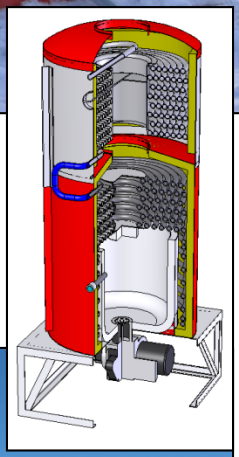


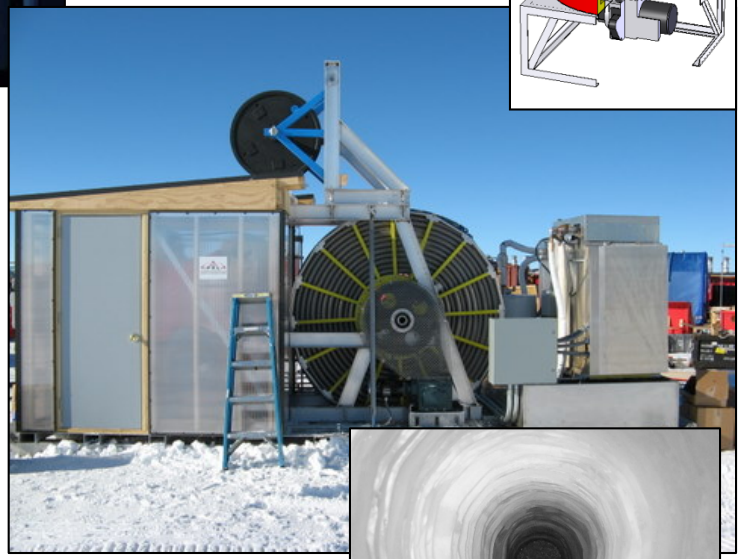
Enhanced Hot Water Drill (EHWD)
Seasonal Equipment Site Stationary, 2 Tower Sites Leapfrog

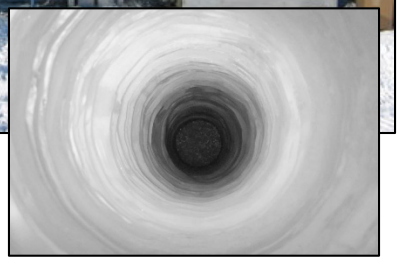


Enhanced Hot Water Drill (EHWD) Notables and Takeaways









Notables

- Advanced computer control system
- High-efficiency water heaters, 92% HHV
- Instrumented drillhead
- Thermal modeling and drill strategy
- Giant hose reel with continuous custom hose
- Independent firn drill

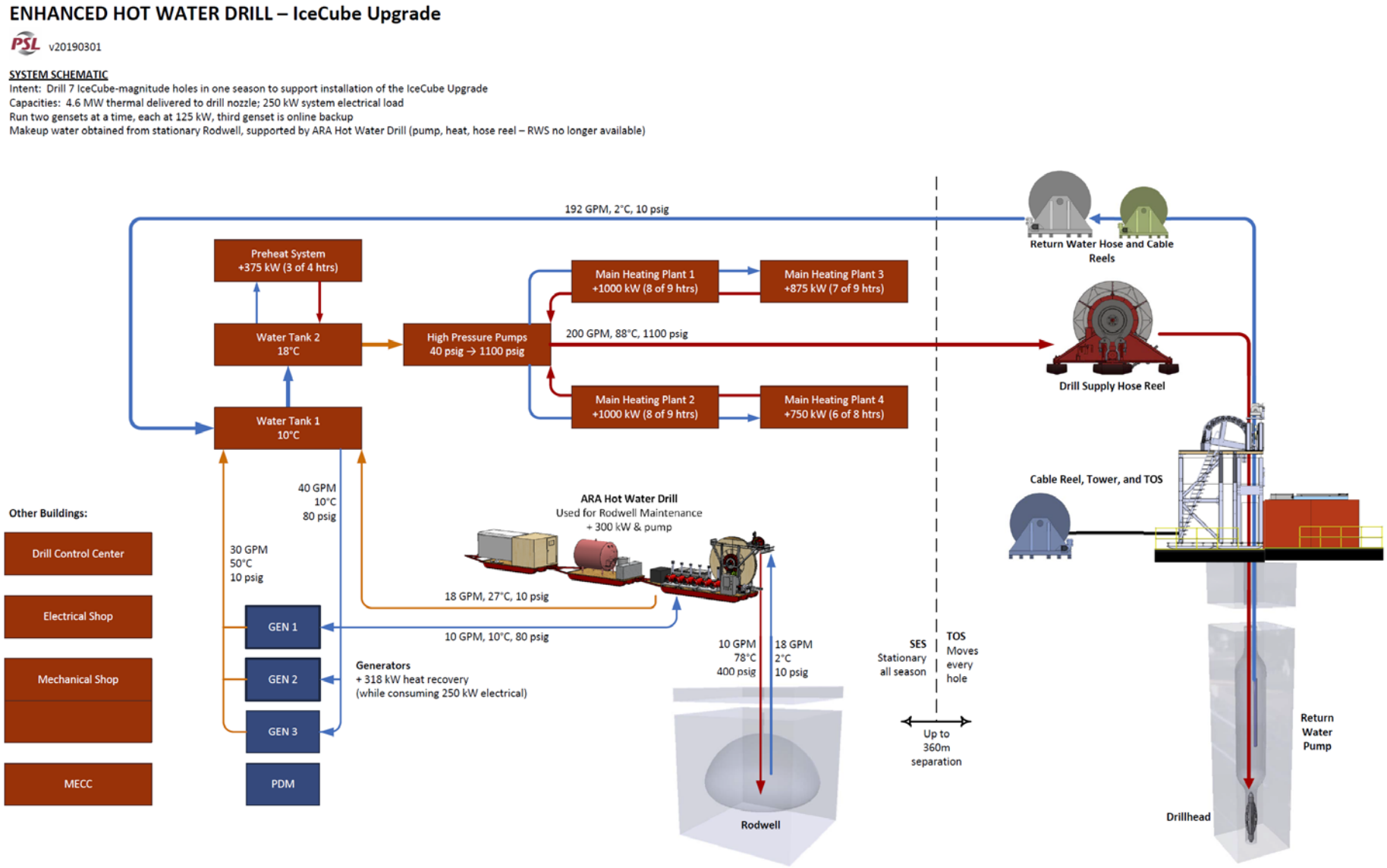
Takeaways

- Wide range of electric and mechanical systems implemented at South Pole
- Hole modeling and freeze back tools
- Hose and its challenges
- Nozzle velocity very important
- Independent firn drill incredibly valuable
- Generator heat recovery
- Rodwell strategies
- Strong safety and fuel-conservation cultures make a difference
- Staffing – RETAIN EXPERIENCE

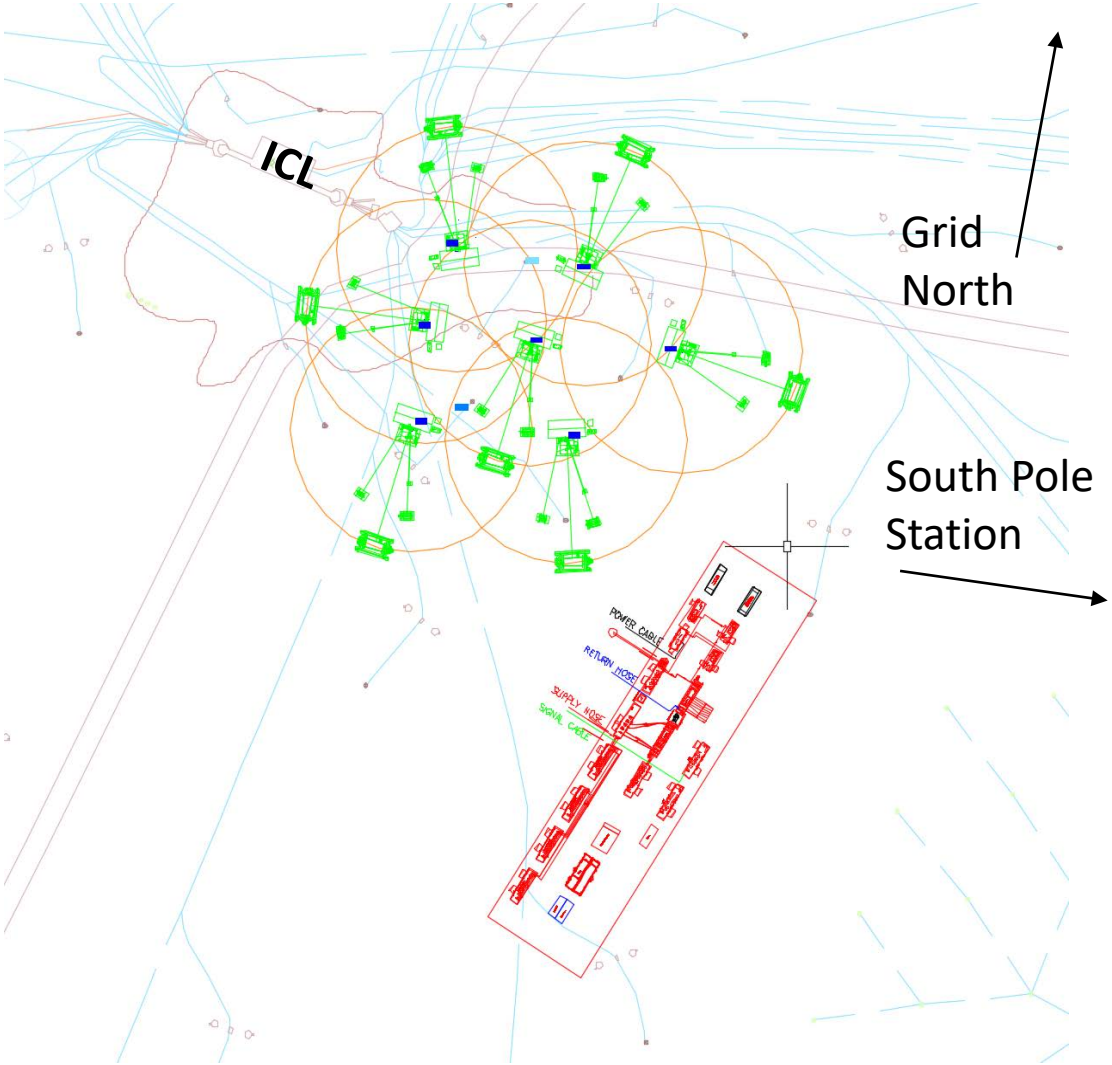
Parts Used to Enable WISSARD
Now Recovered for Upgrade EHWD

Papers can be found in Annals of Glaciology 55(68) 2014

Upgrade EHWD System Schematic



Upgrade Drilling Plan



- 7 Holes near the center of the existing IceCube Array.
- Closest Holes 22 m apart
- 2600 m deep instruments Drill to ~2650 m ~108 instruments per hole
- 52 cm target lifetime diameter 50 hr lifetime Drill to ~70 cm
- Estimate 7000 gal of fuel
- Improve Water Quality
  - No Condensate
  - Degas physics region for 5 of 7 holes

Upgrade Drilling Uses Refurbished EHWD

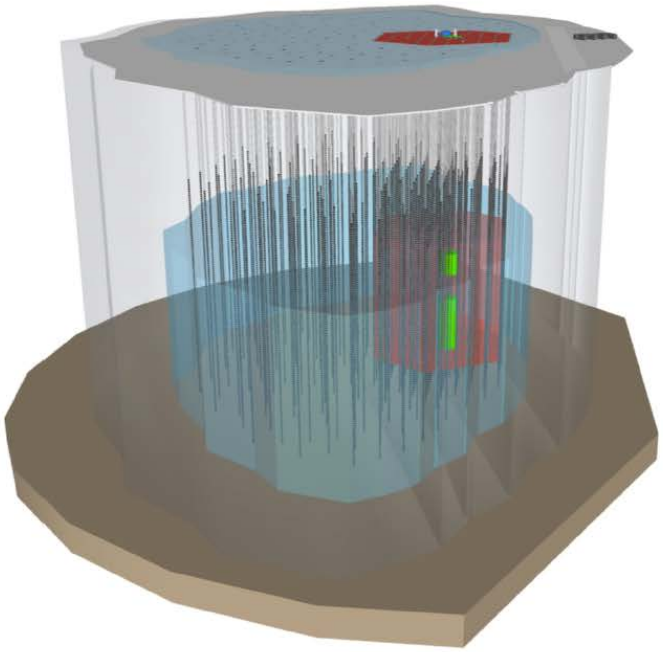
- The IceCube Upgrade will drill holes with the EHWD. Every system of EHWD has been investigated and restored or improved.
- Generators have been rebuilt. 2x by WISSARD and 1x IceCube. They are all in McMurdo now. Testing was done last season running and syncing with the Power Distribution Module (PDM). The PDM was moved to Pole.
- All 42x Model 75 heaters have been turned on at the South Pole and repaired as needed. Burners and controla refurbished but haven't flowed hot water yet.
- The control system is being upgraded to modern hardware including new drives and Programmable Logic Controller (PLC) plus Ethernet based control
- New Yellow Stripped Low density hose has been ordered and is at Port Hueneme.
- The Independent Firn Drill (IFD) has been rebuilt and is in McMurdo
- The Drill Cable Reel is being rebuilt at UW-PSL
- Many former IceCube driller have returned to work on Upgrade Drilling; Terry Benson, Dar Gibson, Darrell Hamilton, Dennis Duling, Jeanne Edwards, Jonas Kalin
- We also have new younger engineers working on the Upgrade and getting experience with the drill and drillers from other programs joining IceCube.

Equipment Status

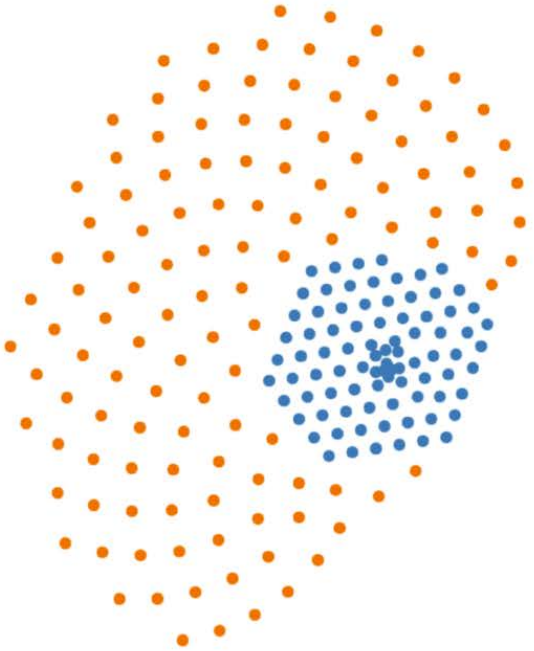
Subsystem	Status	NPX	MCM	Port H	PSL	NEW	
Water Tanks	90	X					Refurb underway
Preheat	90	X					Refurb underway
Makeup Water	75	X			X		Under development
Filter & Degas	50				X	X	Under development
High Pressure Pumps	90	X			X		Final details
Heating	90	X			X		Refurb underway
Surface Hose	100			X			Shipped
Hose Reel	75	X					Refurb underway
Deep Hose	100			X			Shipped
Tower	90	X					Final details
TOS	50	X					Final details
Cable Reel	50				X		Refurb underway
Drill Cable	75					X	Procured
Return Water System	75	X					Final details
Drill Control	50	X			X	X	Integration underway
Generators	75		X	X			Final details
Independent Firn Drill	90		X				Shipped

IceCube GEN2

- 120 Strings of Optical Sensors at 240 m spacing



Artist's conception
120 strings at 240 m spacing

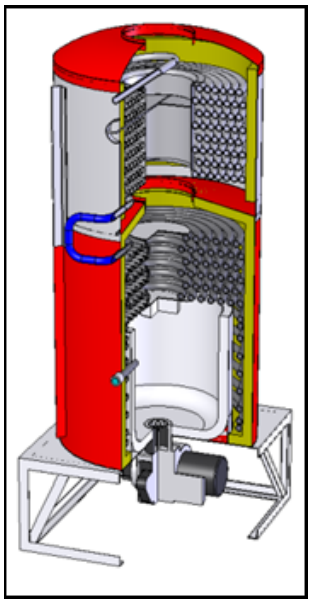


120 strings
surface detectors

GEN2 Hot Water Drill Requirements

- Meet or exceed thermal performance of EHWD
  - 4.7MW thermal delivery to drill nozzle
  - 48 hour hole production rate
  - 90% thermal efficiency
- Compatible with trending logistics -> From LC 130 to Traverse. Larger modules
  - Equipment and fuel delivered to Pole via traverse
  - Reduced logistical footprint at Pole ->Smaller crew
- G2 improvements
  - Safety
  - Mobility -> Farther between holes and less grooming
  - Reliability -> Microturbines have high reliability. ->Reduce sensitivity to failure
  - Reduced setup and decommission time -> More integrated module
  - Reduced Manpower -> Possible with better reliability and more automation
  - Cleaner drill water

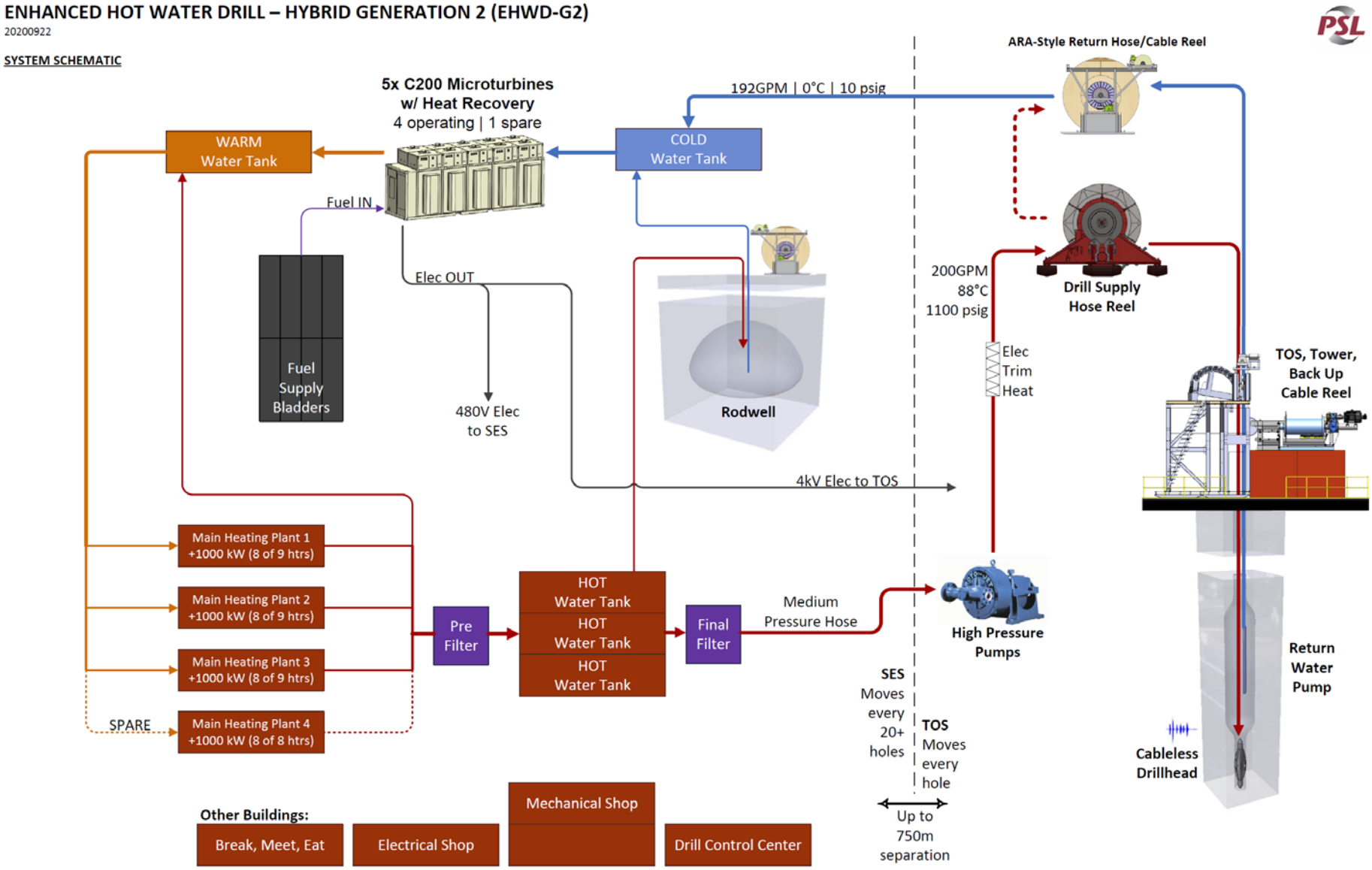
Hybrid GEN2



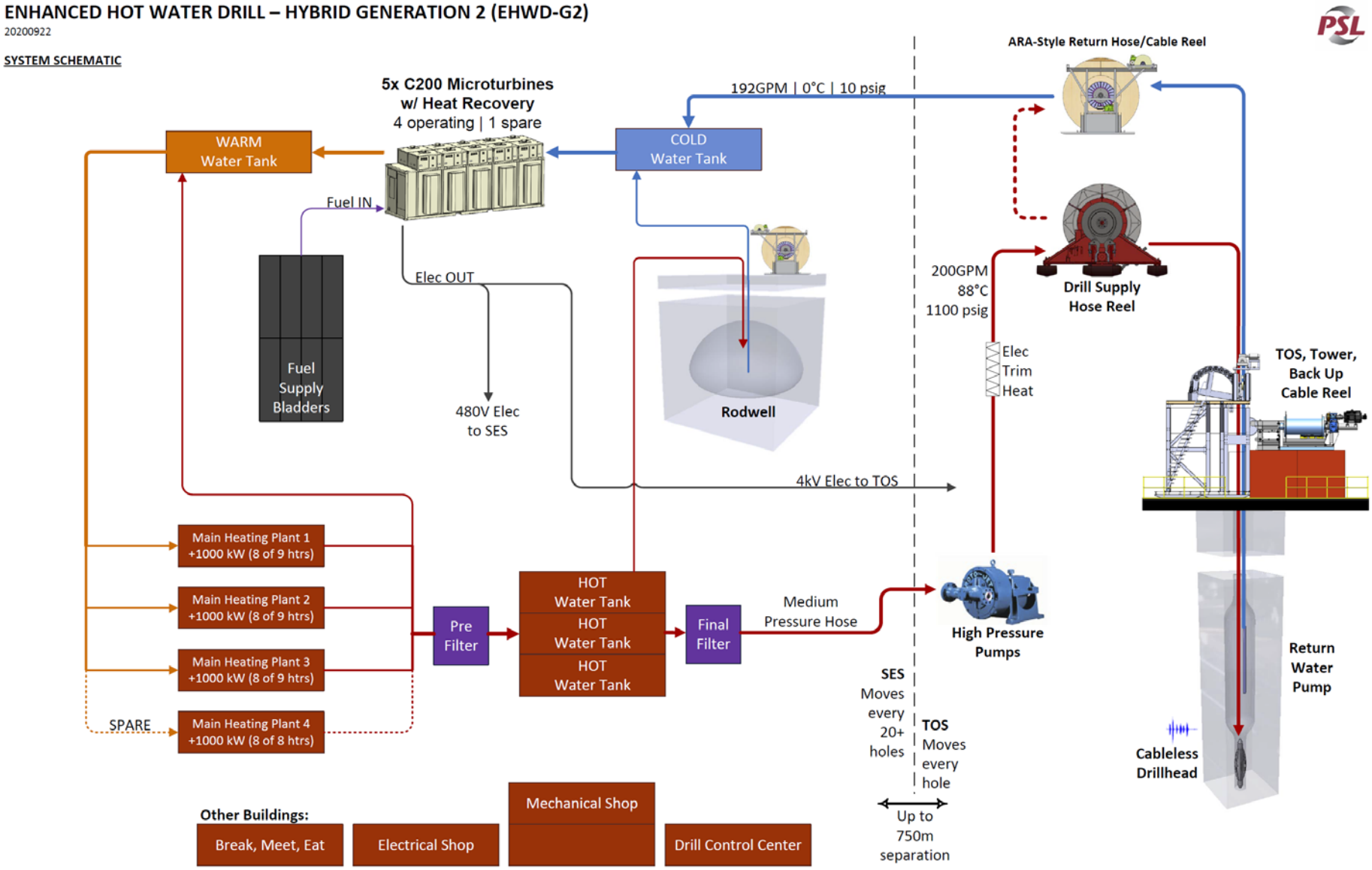
- Reuse of MHPs (Model 75s) is possible at low pressure
  - Refurbishment of MHPs done by Upgrade
  - Save money – 15 -> 5 microturbines at $0.5 M each ~$5 M
  - Save schedule – less items to purchase, prepare, and ship
  - Save Logistics
  - Reliability and maintenance are still issues
- Drill all holes in a season from one SES location
  - Medium pressure water transfer hose with hot pump at TOS
  - Medium voltage electrical transfer system
  - Enable one rod well for season

- Elimination of load carrying drill cable simplifies operation
  - Low Density Hose with vertical traction drive
  - Save people – no taping and untaping
  - Simplified hole set up and operations
  - Cableless drill head
- Hot water tanks on surface provides operational flexibility
  - Less vulnerable to heater failures or other failures
  - Enables effective use of solar panels

Hybrid GEN2 System Schematic



Hybrid GEN2 System Schematic

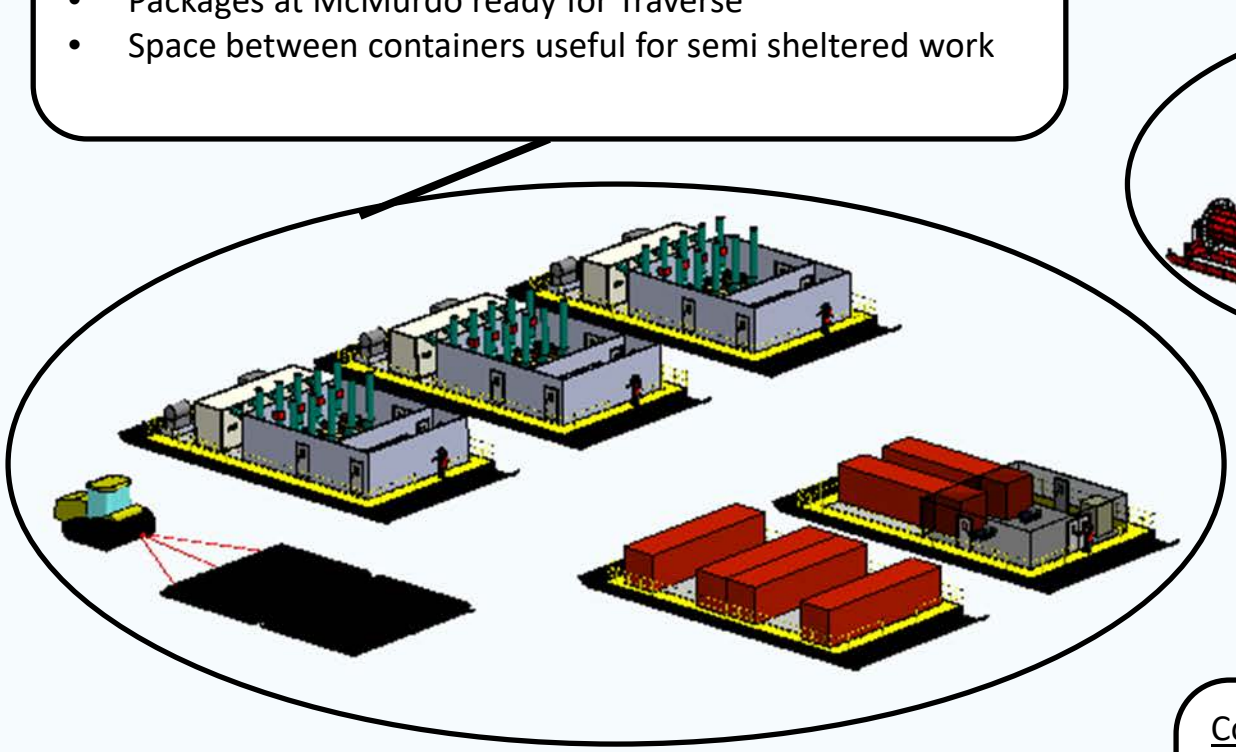


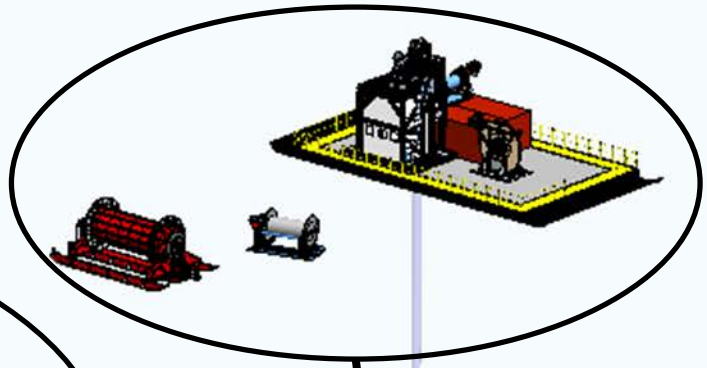
Large Sled Modules Important -> Traversable

Seasonal Equipment Site (SES)

Water Heating, Electricity Generation, Water Storage, Rod Well

- Large Modules still valuable for season to season move
- Packages at McMurdo ready for Traverse
- Space between containers useful for semi sheltered work





Condensed Tower Operations Site (TOS)

- Deep drilling ops
- Deployment ops
- 1 big hose reel
- 2 sets of tower and reel assemblies
- Moves every hole

EHWD-G2: Air-Ride Cargo Sleds (ARCS)

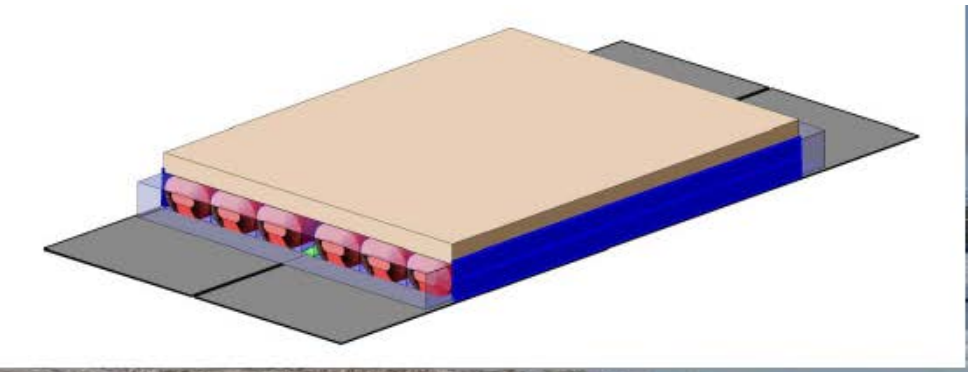


Figure from *Lightweight Cargo Sleds for Polar Traverses; Lever, Song, Weale; Polar Technology Conference 2014*

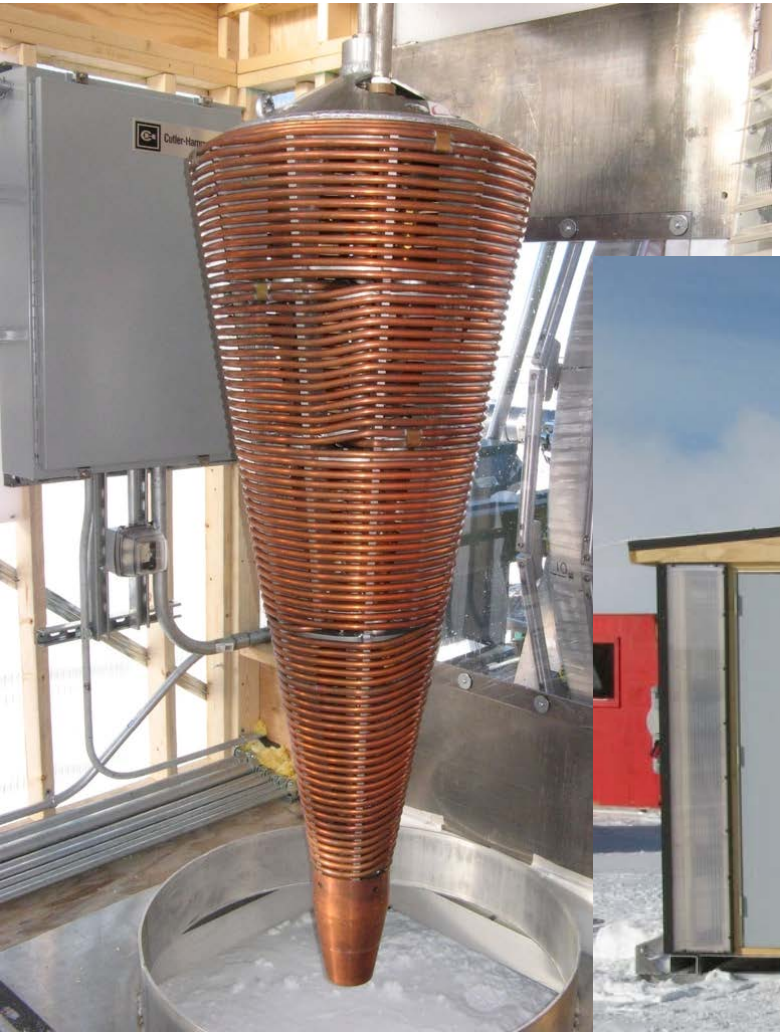
- Rigid deck on top of air bladders on top of PE panels
- Far superior to ski-based traverse designs
- In active development for high-payload traverses in Antarctic and Greenland
- Consult with expert Jim Lever, CRREL: EHWD-G2 ARCS-based concept is within feasible envelope and a “good idea”

Preliminary Design Underway

- We had a “Kickoff” meeting Nov 10 on Zoom. The people working on the Upgrade are busy with it an other tasks, but we have asked many people to look into on eor more GEN2 issues.
- Meetings each week with a small group to start developing a cost and schedule
- There are periodic technical meetings to talk about design issues
- A C200 Micro Turbine (MT) has been ordered from Capstone. It had acceptance tests in California Dec 28. It will ship to UW-PSL this week.
- The Drill Test Area at UW-PSL is being reconfigured to allow upgrade work with the control system development, Meyers High Pressure Pump, and Model 75 in parallel with MT commissioning and characterization.
- We plan to purchase a hot water tank, a hot water high pressure pump (RotoJet), and high pressure electric hot water heaters (Durex) for the test bed to allow further development and testing of the GEN2 concept.

Independent Firn Drill

Electrically Heated Recirculating Glycol Drill
150 kW, 61 cm diameter, 45 m in ~30 hrs
1 person crew, single spiral reel



Recirculating Glycol Drill Performance

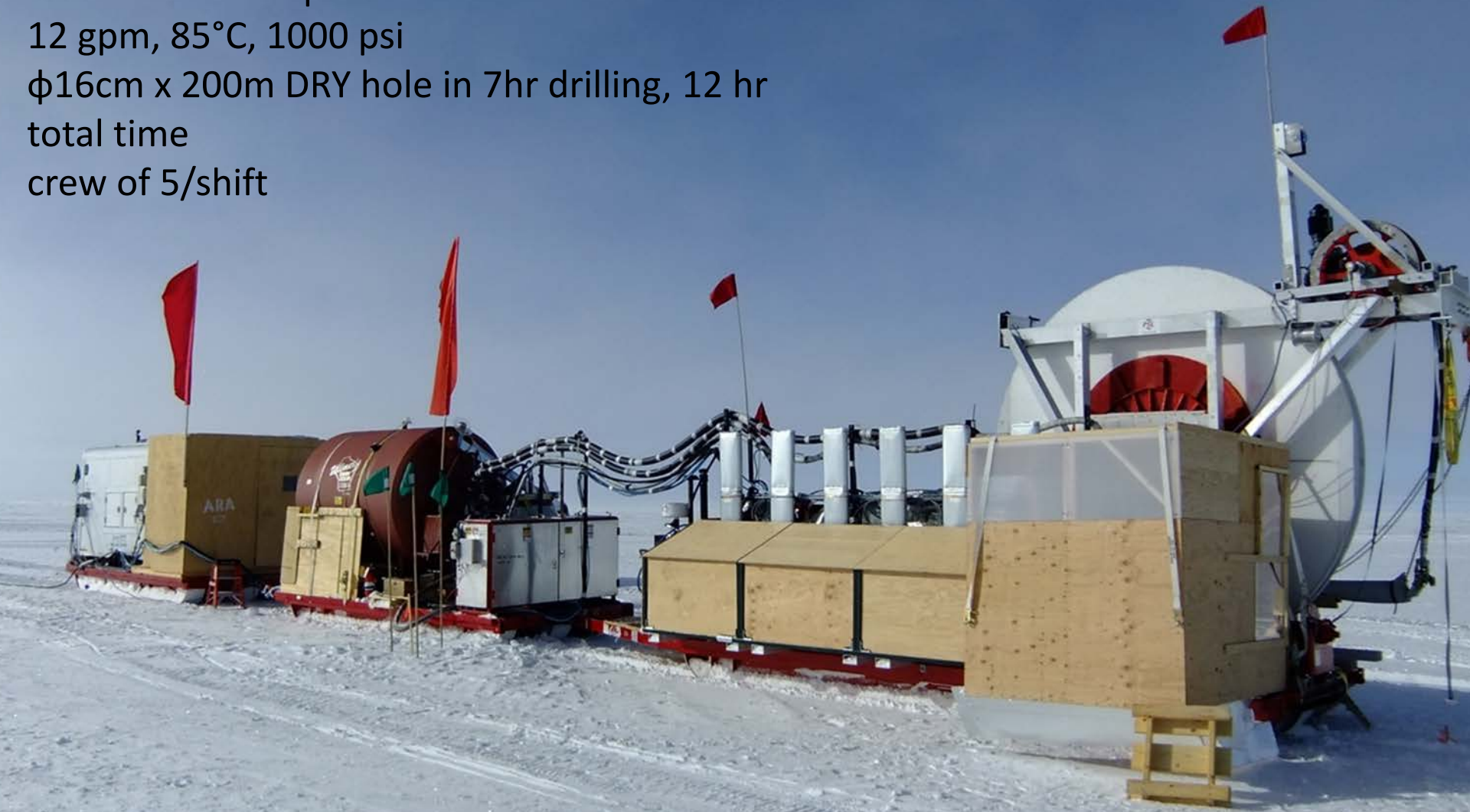
- Drill rates went from 0 to 3+ m/hr with recirculating glycol drilling. 24” hole size.
- Low speeds need surface were due to debris in the snow. We had to stop, pull up the drill head, and remove debris with ice pick and vacuum cleaner.
- Above 2 m/hr straightness can be an issue
- Ran at ~12 GPM

IFD was run unmanned with periodic checks.

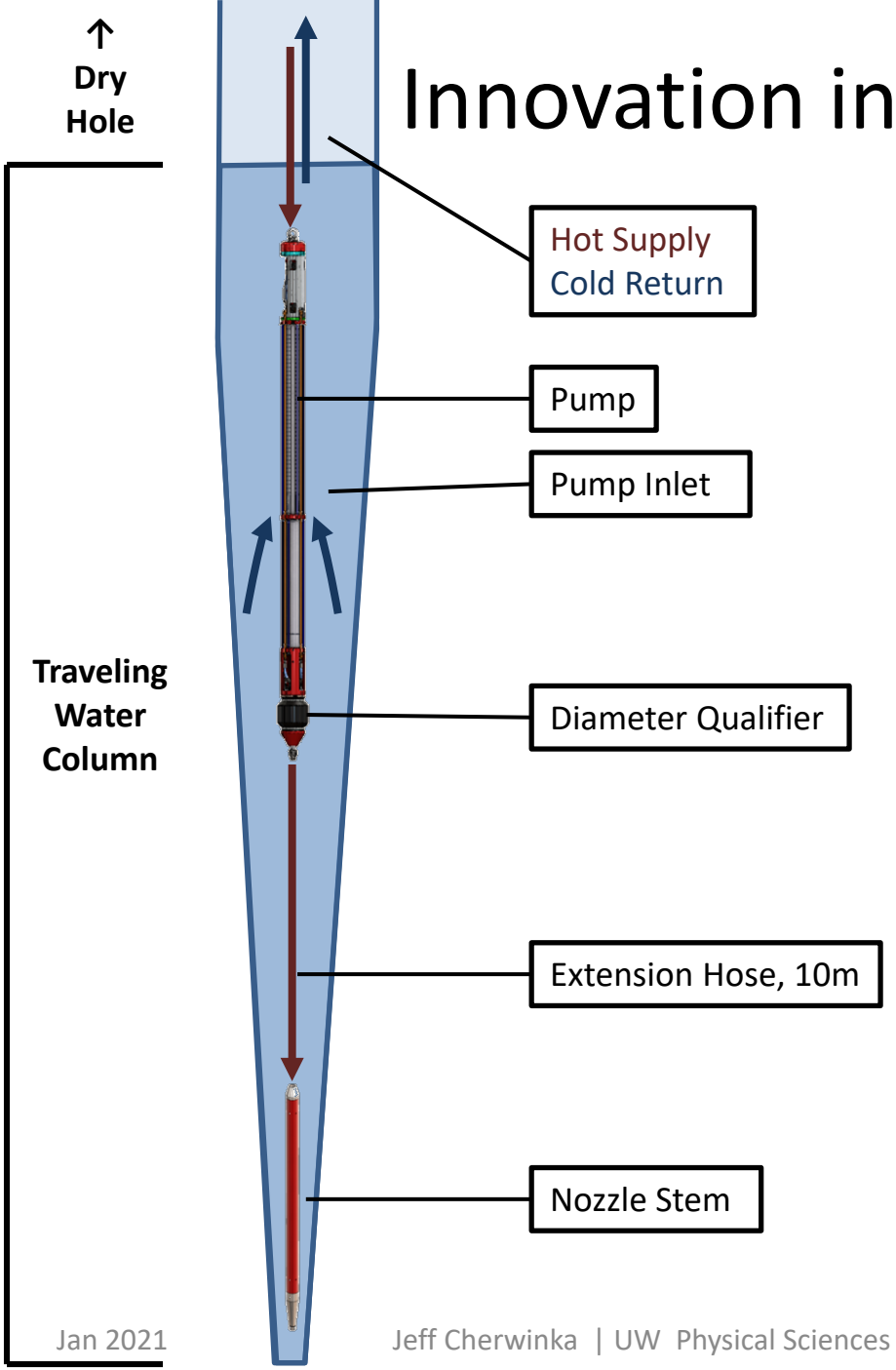
Firn holes was NOT in series with with Deep holes after second season

ARA Hot Water Drill (ARAHWD)

3 sled train configuration, 34k lb dry weight
300 kW thermal power
12 gpm, 85°C, 1000 psi
ϕ16cm x 200m DRY hole in 7hr drilling, 12 hr total time
crew of 5/shift



Innovation in Technique

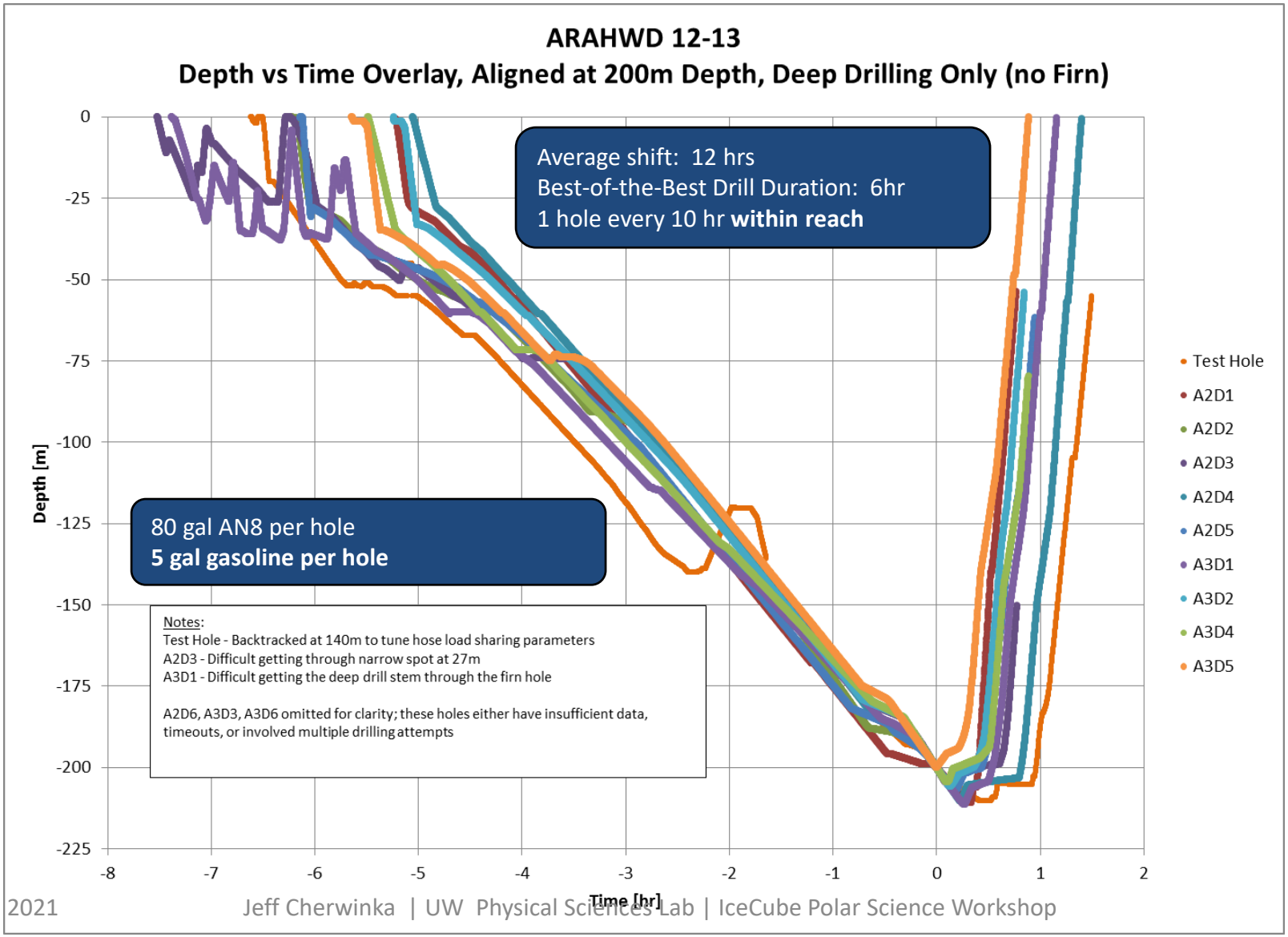


<u>New Drilling Method</u>:
PUMP/DRILL AT SAME TIME

Recirculated water column travels down with drillhead. Hot water sprays out nozzle and travels some distance back up the hole to the pump, where the water is pumped back to the surface. Hole diameter is developed between nozzle and pump.

- Closes loop and returns water during drilling
  - No snow melting, net water production
  - System capacity effectively doubled from lost water / snow melting method
- Leaves dry hole above
  - No freezeback!
  - 1 step = faster production rate

ARA Hot Water Drill (ARAHWD) Performance



Summary

- IceCube developed and used EHWD to drill 86x 2500 m deep holes. Drilling became reliable and efficient producing a complete hole every 48 hours with about 5000 gallons of fuel
- IceCube Upgrade drilling will produce 7x 2600 m deep holes in the center of the existing array and deploy dense instrumentation. Equipment transferred to WISSARD has been returned and is being refurbished. Improvements include an updated control system and low density hose.
- Preliminary design of a GEN2 Hot Water Drill that could make 120x holes at 240 m spacing is underway. The architecture of this drill will change to heating the water at low pressure and then pressurizing it hot. Electric generation is changing to more reliable MicrotTurbines. We hope to be able to take advantage of the lower density hose to simplify or eliminate the drill cable.
- Water quality will be improved by not using the condensate as drill water and adding additional filtration. We will try degassing water in the physics region in some upgrade holes to try and get clearer hole ice.