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Surface and Subsurface Sampling Drills for Life Detection on Ocean Worlds

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Image courtesy NASA

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1. COLD (Concepts for Oceanworlds Life Detection) Technologies
2. SLUSH (Search for Life Using Submersible Heated) Drill SBIR

The Challenge

- The search for life beyond Earth is a search for similar or analogous environmental conditions, including abundant liquid water.
- Recent discoveries of water on ocean worlds including Titan and Europa have piqued interest in these destinations but liquid water is buried kilometers deep beneath an icy crust.
- State-of-the-art in ultra-deep drilling on Earth
  - Kola Superdeep Borehole: 23 cm diameter, 12 km deep, 19 years (1970-1989)
  - Vostok Hole: 13.7-16.5 cm diameter, 4 km deep, 22 years (1990-2012)
- State-of-the-art in deep drilling on the Moon.
  - Apollo Lunar Surface Drill: 2 cm diameter, 3 m deep, 1 cm/sec
- New planetary drilling methods are needed to reach subsurface water on ocean worlds. Drilling will take time and plenty of power.
- In the meantime, surface sampling at sites of scientific interest could take advantage of natural transport and preservation processes to collect early data more quickly and easily.

Planetary Excavation Methods

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Method	Material Strength	Sample Alteration	Ease of Delivery	Max. Depth	Power*
Scooping	Loose, unconsolidated surface material	No heating	Can be problematic with sticky material (e.g., Phoenix) and highly variegated particle size	~10 cm	0 W
Rasping, Abrading	Hard rock and ice	Minimal heating, generates small particles	Cuttings scattered	~1 cm	~30 W
Sawing	Hard rock and ice	Minimal heating, generates small particles	Cuttings scattered	~10 cm	~100 W
Coring	Soft surface material	Minimal heating, preserves stratigraphy	Removing core can be difficult	~10 cm	~100 W
Drilling	Hard rock and ice	Minimal heating, generates small particles	Cuttings deposited around bit	>10 m	~100 W - 1 kW
Melting	Hard ice	Release of volatiles, possible chemical alteration	Liquid water or slush can be easily pumped	>10 m	~10 kW

Drilling is suitable for both surface and deep cryogenic sample acquisition with minimal risk of sample alteration.

* note: estimates do not include power consumed by deployment system (e.g., robotic arm, etc.)

Extrapolation Based on Field Tests

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Arctic: water-ice and permafrost at 265K

- 1300 Watt, 6 inch (15.2 cm), rotary-only
- ROP: 50 cm in 4 min = 7.5 m/hr
- Energy: 173 Whr/m
- Specific Energy: 10 kWhr/m^3

Extrapolate to 90K (ROP drop by 50%)

- 1300 Watt, 6 inch (15.2 cm), rotary-only
- ROP: 50 cm in 2 min = 3.6 m/hr
- Energy: 320 Whr/m
- Specific Energy: 20 kWhr/m^3

Greenland: water-ice at 260K

- 1400 Watt, 4 inch (10 cm), rotary-percussive
- ROP: 1 ft in 1 min = 18 m/hr
- Energy: 78 Whr/m
- Specific Energy: 10 kWhr/m^3

Extrapolate to 90K (ROP drop by 50%)

- 1400 Watt, 4 inch (10 cm), rotary-percussive
- ROP: 6 inch in 1 min = 9 m/hr
- Energy: 156 Whr/m
- Specific Energy: 20 kWhr/m^3

Instrumented Drilling Testbed

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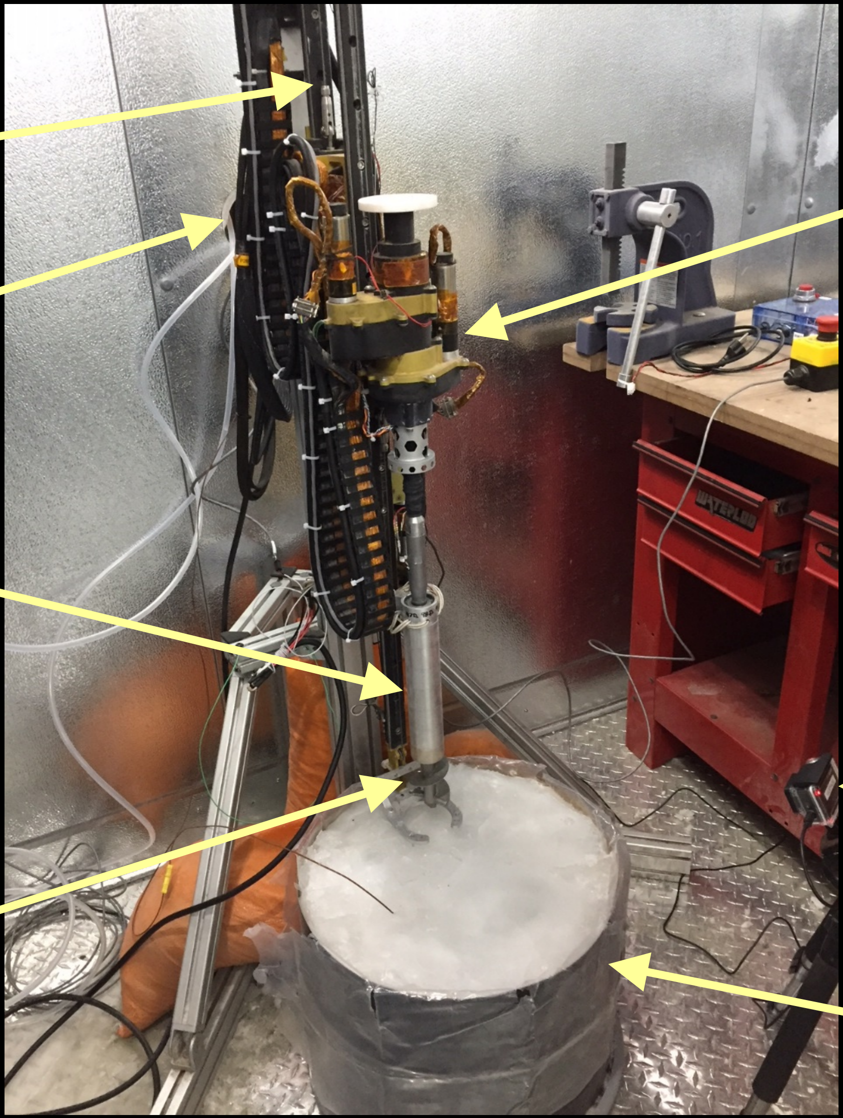
Drill Feed Stage

Freezer Feed-Thru

Heated Probe Body (Non-Rotating)

Heated Bit (Rotating)



Rotary Percussive Drill

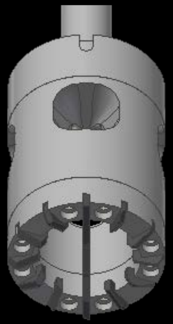
Go-Pro Camera

Water Ice Sample

Heated Bits (6.2cm Dia)

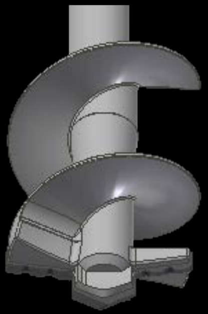
Full-face

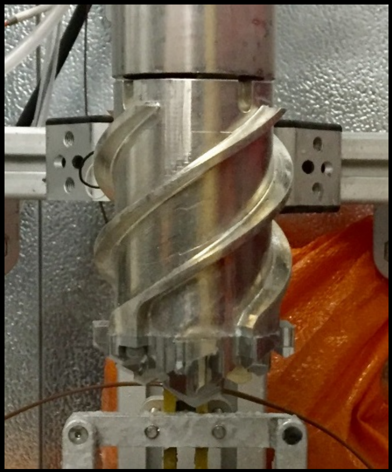
Peripheral Heating

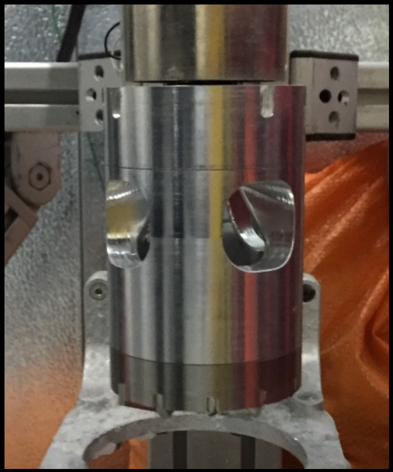


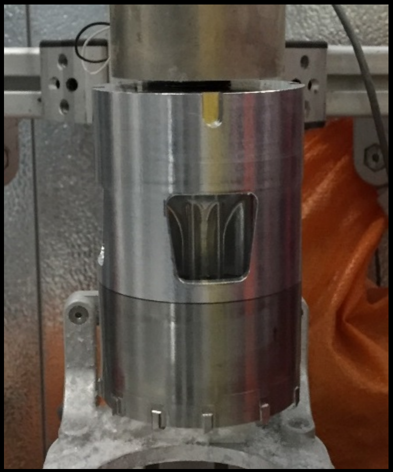
Central Heating

Auger









Drilling Modes Comparison (240K)

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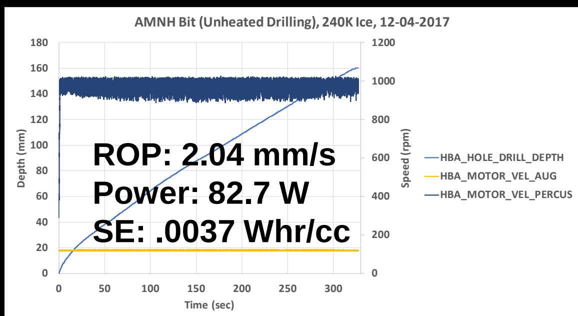
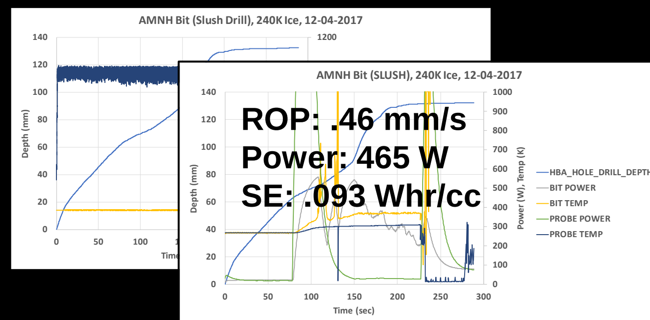
Drilling, Melting and Slushing (WOB controlled to 100N)

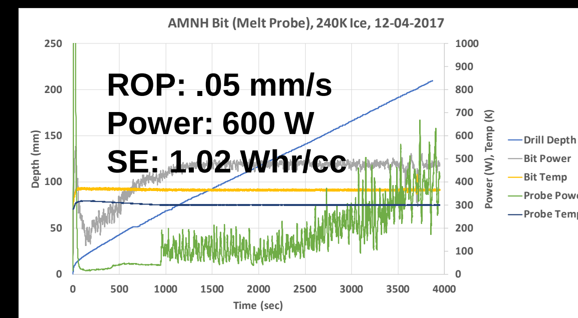
Baselined with full-face bit in 240K water ice to compare power consumption.



Drilling



Slushing



Melting

Test Results (log scale Y-axis)

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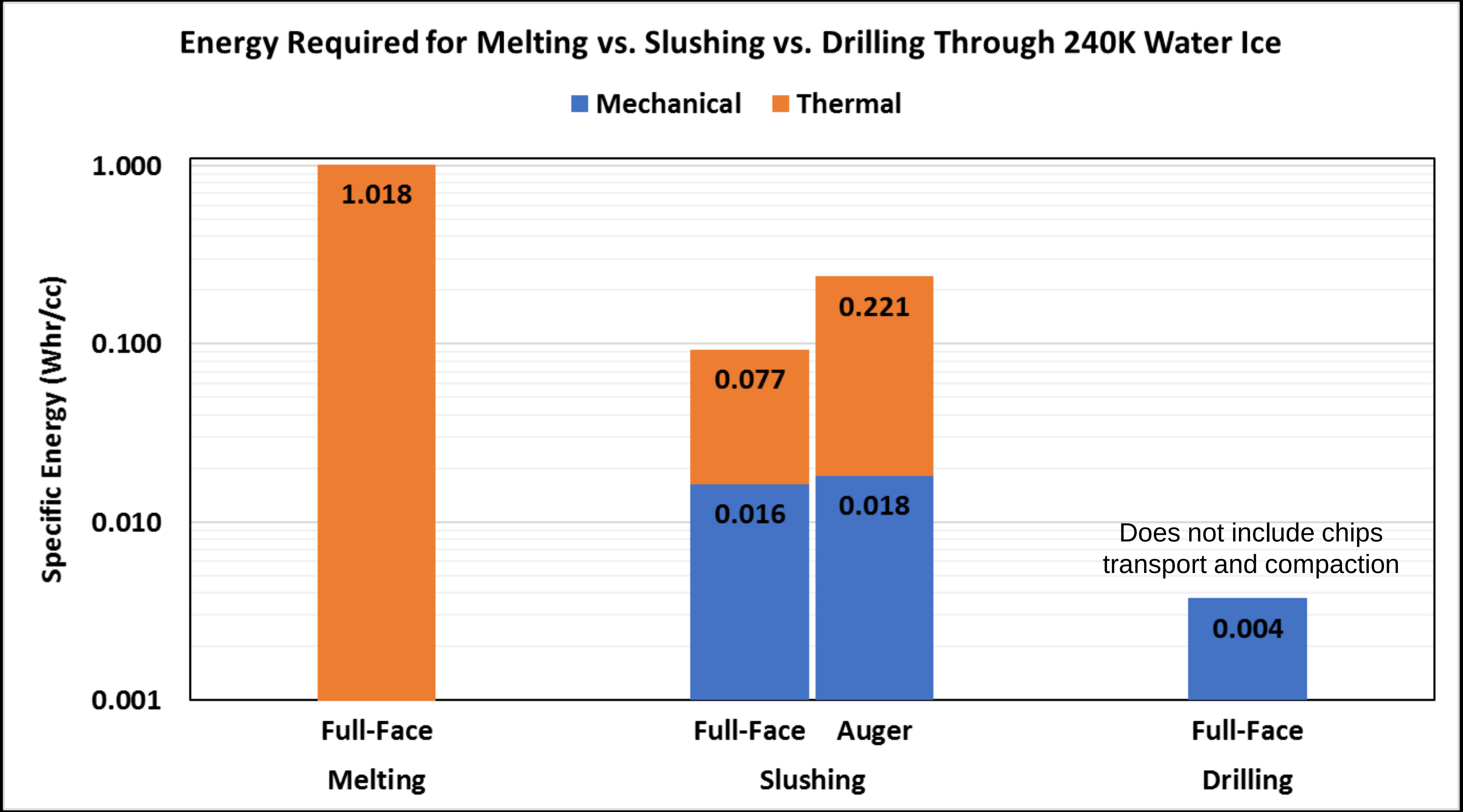
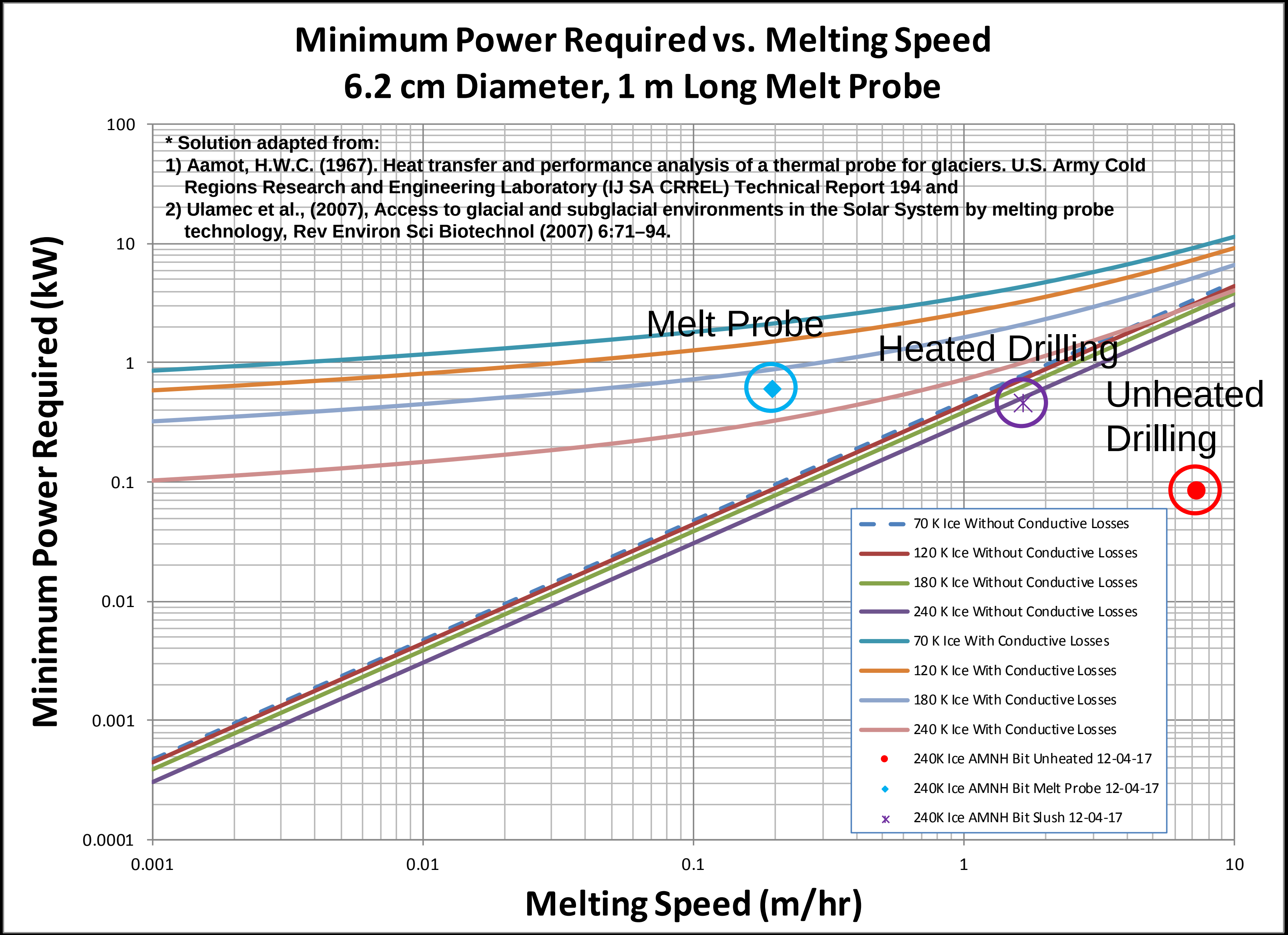
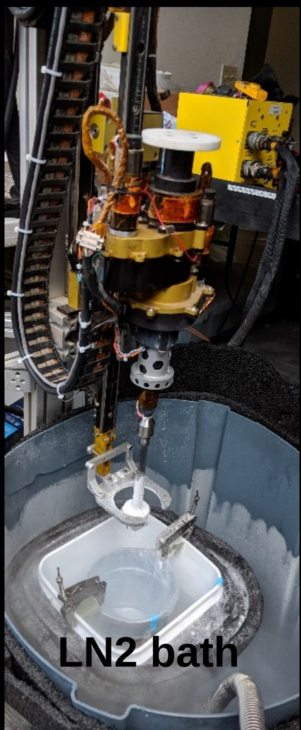
Goal: Repeat test with each prototype bit and cryogenic simulants.

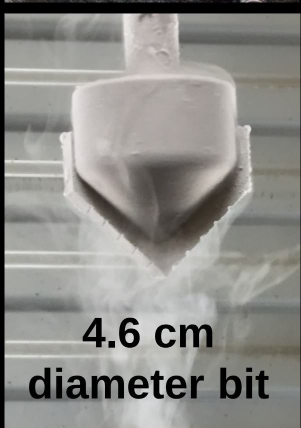


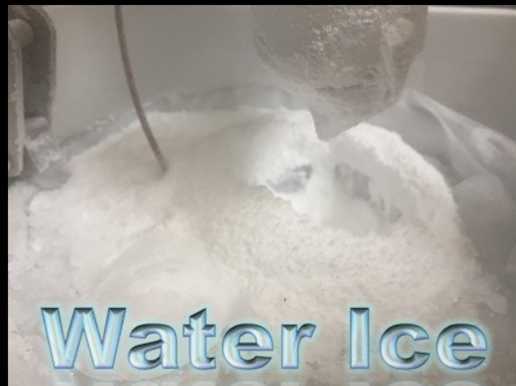
Theoretical Melting Speed*

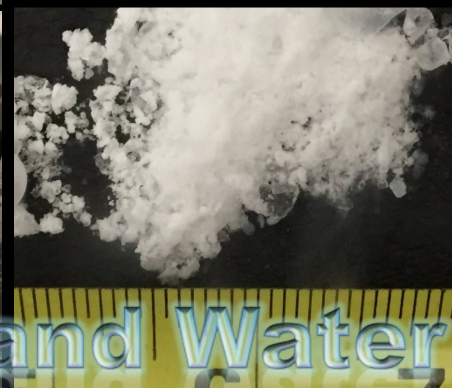


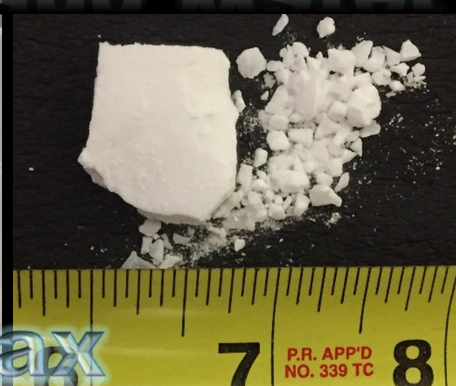
Drilling in Cryogenic Simulants (77K)

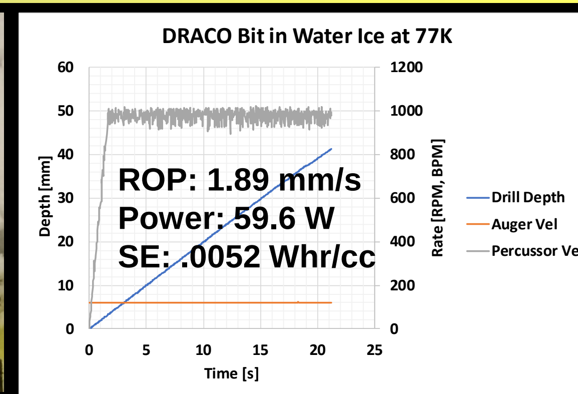


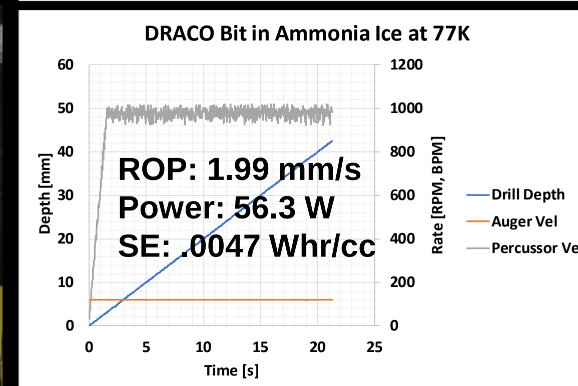


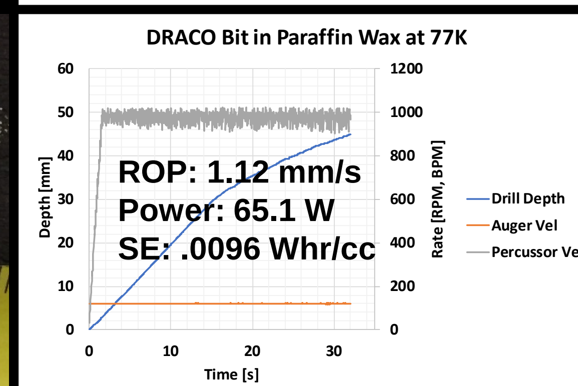












Conclusions

- **Deep Drilling (Melting vs. Slushing vs. Unheated Drilling):**
  - Melt probe is at a disadvantage in cryogenic water ice due to enhanced thermal conductivity
  - Energy required for unheated drilling is least but depth is limited by risk of ice melting and re-freezing around bit, causing it to get stuck
  - For deep drilling, slushing avoids sticking and facilitates transport of cuttings away from drill bit however tether management is still a complication
- **Surface Drilling (Cryogenic Material):**
  - Minimizing temperature rise of sample preserves volatiles and makes fines easier to transport
  - Depending on the hardness and brittleness of the sample, rotary-only mode may avoid cracking sample into large chunks that cannot be further reduced in size for easy transport

Future Work

- Combine drill with pneumatic transport and sample delivery subsystems for end-to-end testing of the entire sampling chain at 100K

Acknowledgements

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- We owe our sincere thanks and appreciation to the COLDTech program director Ryan Stephan (NASA HQ) and the SBIR COTR Juergen Mueller (JPL/Caltech).

Questions

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