A Deep Subsurface Ice Probe for Europa

A Lightning Talk

Brian.H.Wilcox@jpl.nasa.gov

California Institute of Technology

10 Oct 2017

Melt Probe Heat Leak

- The steady-state solution for a point source of heat in an infinite expanse of ice at temperature T_0 is of the form $T(r)=T_0+P/4\pi kr$ where P is the input power and k is the thermal conductivity in W/m*K.*
- To find the radius r_0 of the melt sphere, we set $T(r_0)=273K$ and that the ice body is originally at $T_0=100K$. So $P/4\pi kr_0=173$, or $r_0=P/692\pi k$. The value of k for pure water ice just below 0^oC is about 2.2 W/mK.
- So for $P=4783r_0$ in Watts for r_0 in meters. A 10 cm radius sphere requires 478.3 W just to heat the surface to melting, before any phase change is accomplished.

* See http://www.ewp.rpi.edu/hartford/~ernesto/S2006/CHT/Notes/ch03.pdf case 1 page 3.

Planetary Protection

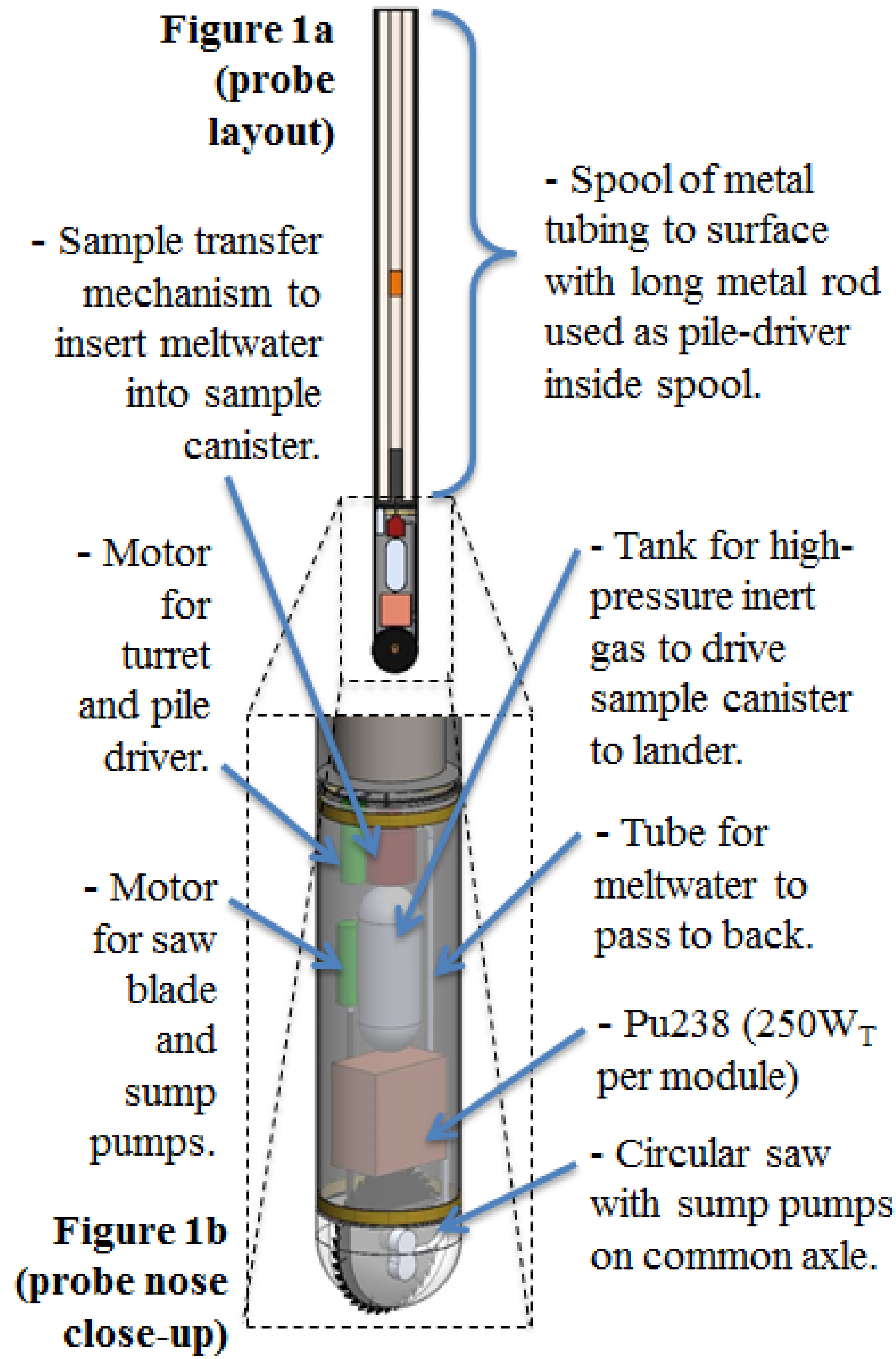
- Any Earth organism that accompanies a radioisotope heat source into the ice may flourish in the "oasis".
- Therefore we must sterilize anything going down-hole beyond debate.
- Any DNA or RNA (including fragments) that gets to a hydrothermal vent may reproduce every time it is cycled above 95C.
- Therefore all Earth DNA and RNA must be totally destroyed.
- Therefore all equipment must be sterilized by extreme temperatures - we picked 500C for an "extended" period.

Background

- NASA Space Technology Mission Directorate (STMD) funded task Ocean Worlds Mobility and Sensing FY' 15-16.
- Task took "blank sheet of paper" approach and surveyed scientists about what they wanted "independent of engineering feasibility".
- Task ultimately focused on developing a concept that could penetrate 10 or more km through the ice, returning samples to the surface all along the way, within a budget of ~100 kg and ~100 W_{elec}, with all downhole equipment heat sterilized beyond debate.
- Downhole assembly has only two brush-type motors with no electronics and so can survive long-duration heat sterilization at 500C.

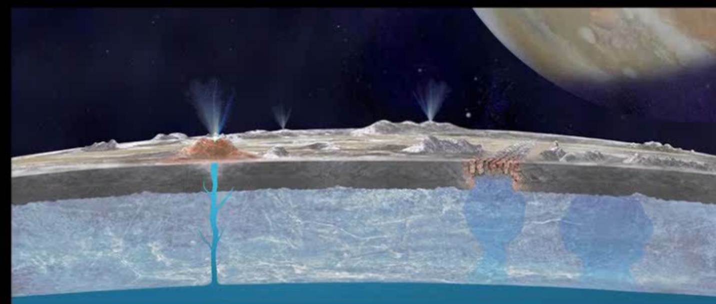
Selected Configuration

- Uses Pu238 General Purpose Heat Sources inside a Dewar to prevent heat leakage laterally into ice.
- Saw blade sticks through slot in "turret dome" at bottom nose of probe, cutting ice and throwing chips inside where they can be melted by Pu238.
- Sump pumps move meltwater to rear of probe where it refreezes.
- Thin aluminum tubing paid out from spool in probe all the way back to lander for pneumatic sample canister transport.



Saw Cutting Ice at -86C

Europa Lander



Planar Face Cutting, 350 rpm
6 mm trench, 6.25 mm/sec
Freshwater Ice

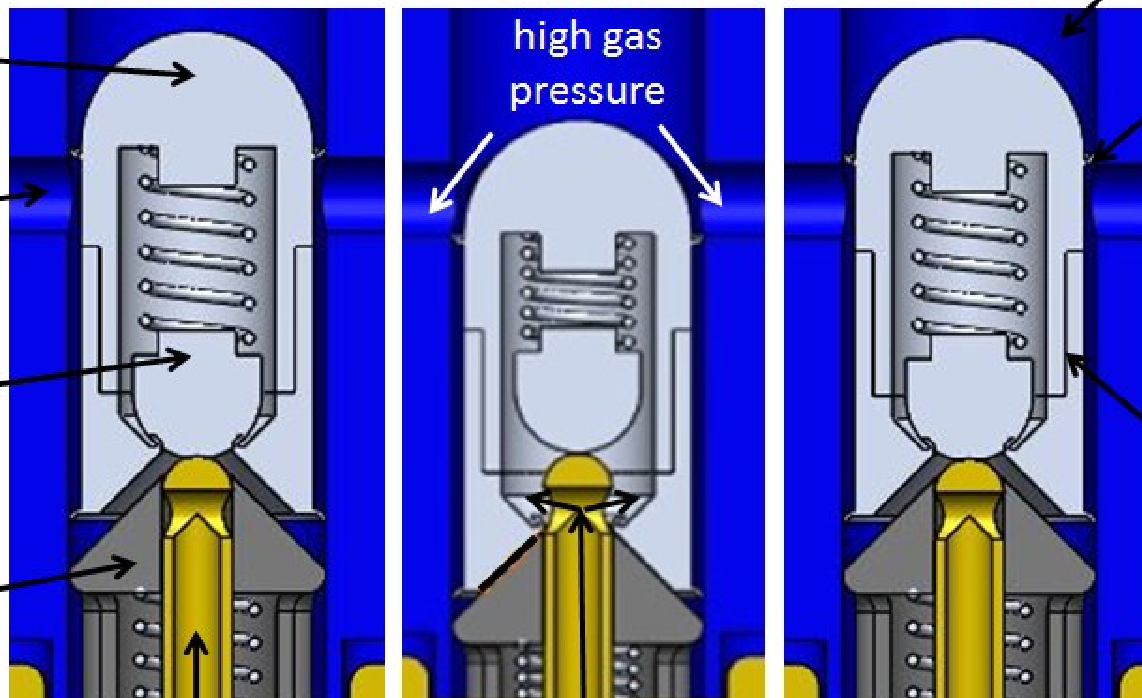
Recorded: 1000 fps
Playback: 30 fps

Testbed

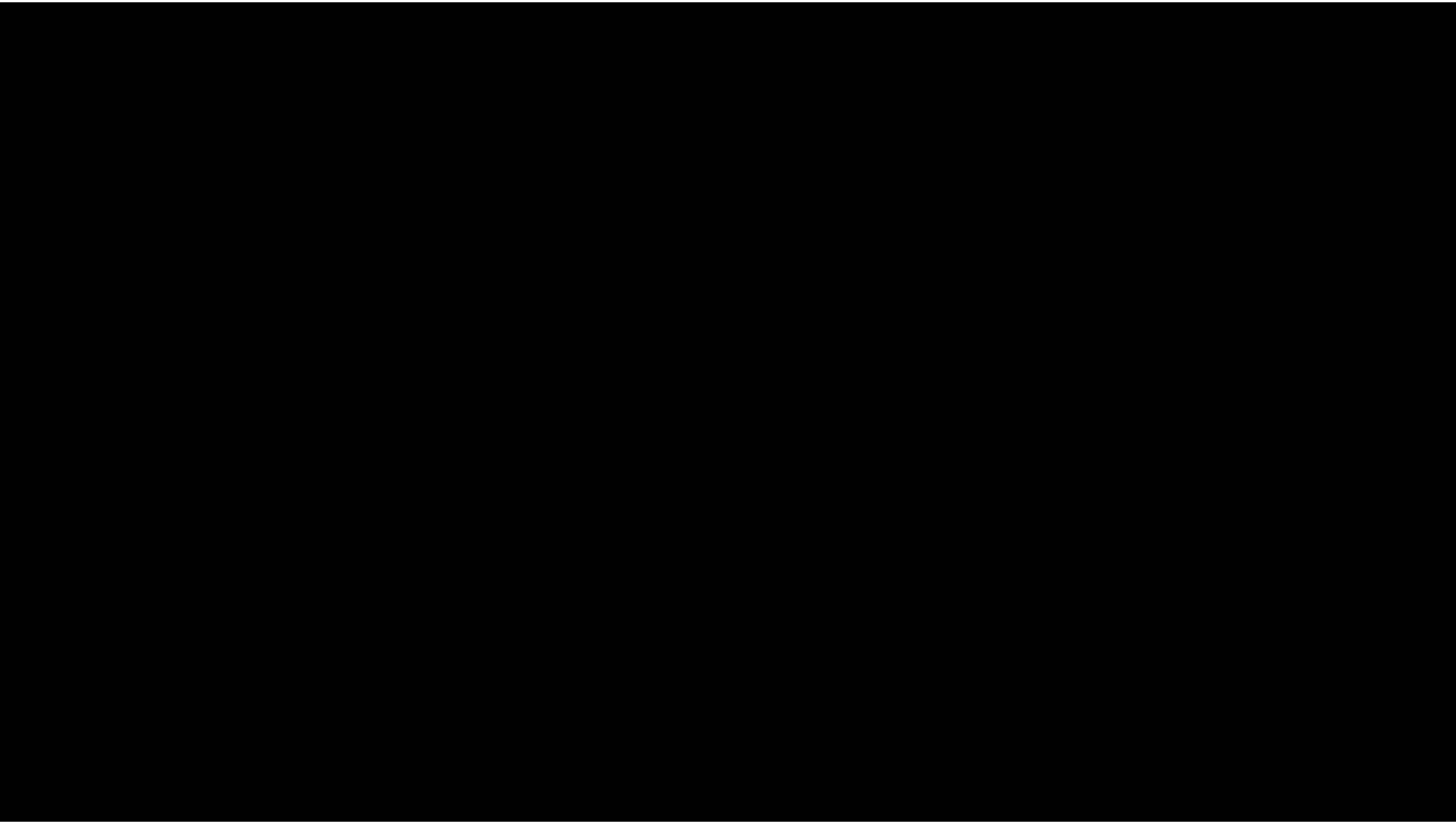
- A small amount of testing was completed in FY'17 before the STMD funds ran out.
- Seemed to work fine.

BACKUP CHARTS

Pneumatic Sample Transfer Mechanism

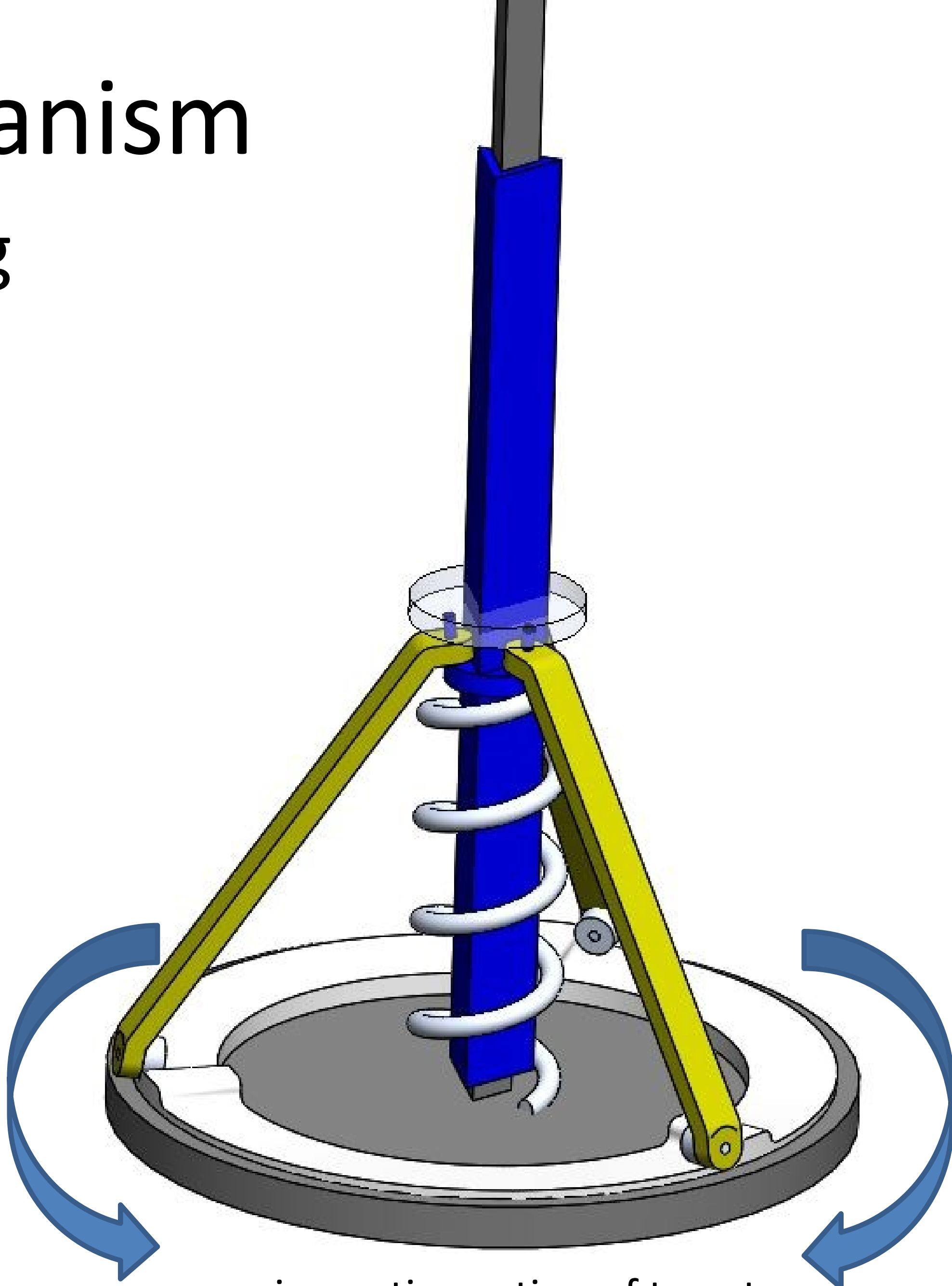


10X-Scale Sample Transfer Demo



Pile Driver Mechanism

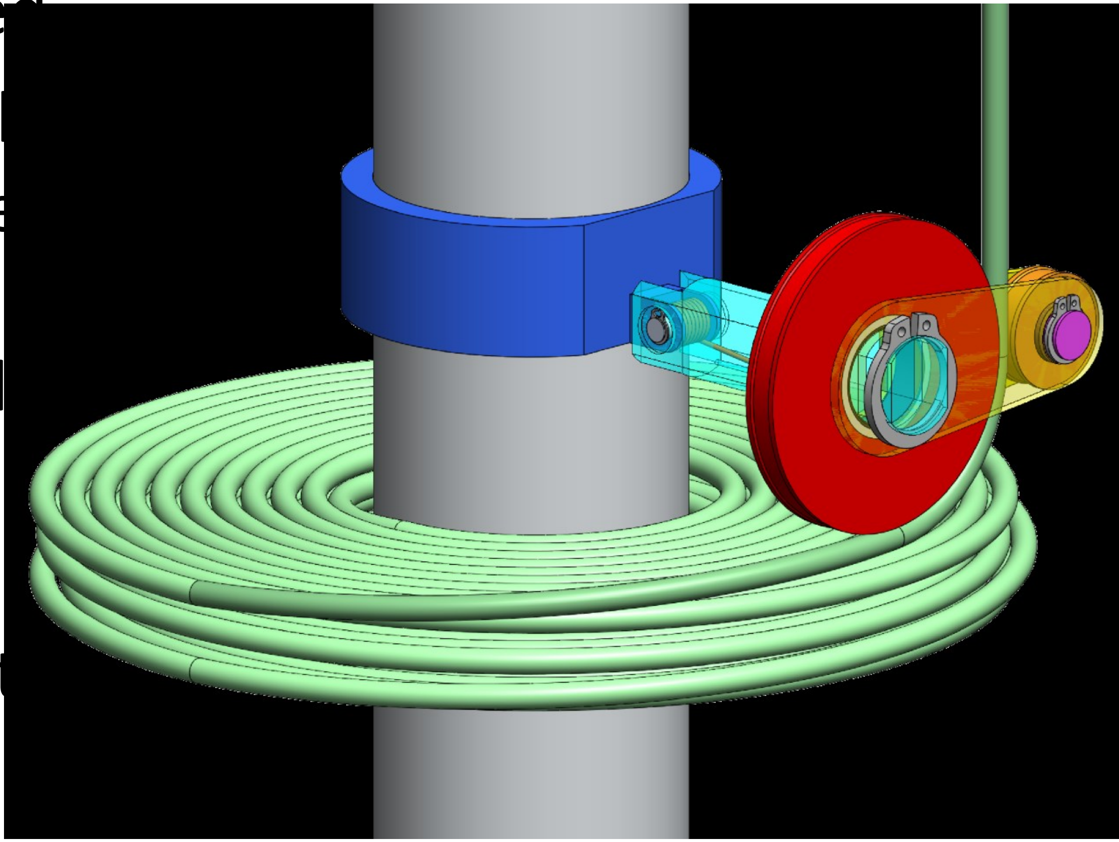
- Driven by reciprocating turret action
- Ensures one hammer blow each time turret changes direction
- Allow hammer to fall freely after being lifted up against spring
- See paper for detailed description of operation



reciprocating action of turret

Aluminum Tube Unwinding Mechanism

- Red and orange rollers capture tube so that it cannot become tangled
- As tube is pulled out th back as probe advance (by pile driver), blue ri rotates around central post, advancing radial arm with rollers.
- Rollers slide in and out on arm to stay on the current wrap of tube.



Spreadsheet Model

- 4 GPHS modules provide 1000 W_T
- Lander provides 165 W_e
- Tubing 0.53 mm OD allows one canister to be exchanged with lander each day
- 815 days to reach 10 km depth

GPHS thermal power		1000	Watts
Number of GPHS bricks		4	
Thickness of Dewar		0.02	m
Outside radius of Dewar		0.07494	m
Energy density for sawing		2.11E+07	J/m3
Outside radius of tubing		0.000529	m
Inside to outside ratio		0.44	
Inside radius of tubing		0.000233	m
Depth at bottom of ice		10,000	m
Mass of tubing (aluminum)		19.22	kg
Starting temperature of ice		100	K
Depth for half the delta-T across ice		2000	m
Thermal gradient in rigid layer		0.0433	K/m
Thermal gradient in convecting layer		0.0108	K/m
Volume of tubing and power tether		0.0180	m3
Length of tubing storage in probe		1.903	m
Time to reach depth		814.9	days
Misc. power needed down hole		10	W
Electrical power needed by saw		72.73	W
Voltage on saw tether at lander		578.11	V
Efficiency of saw power tether		50%	
Mass of tether wires		9.27	kg
Total elec. power needed at top of hole		165.47	W

Summary and Conclusions

- Surprisingly, it appears possible to make a system that can penetrate 10+ km through cryogenic ice, returning 100s of samples to the lander for analysis, within ~100W_e and ~100 kg budgets, all within constraint that all downhole equipment can be heat-sterilized at 500C for extended periods.
- This STMD effort was transformed into an SMD COLDTech proposal ranked "selectable".