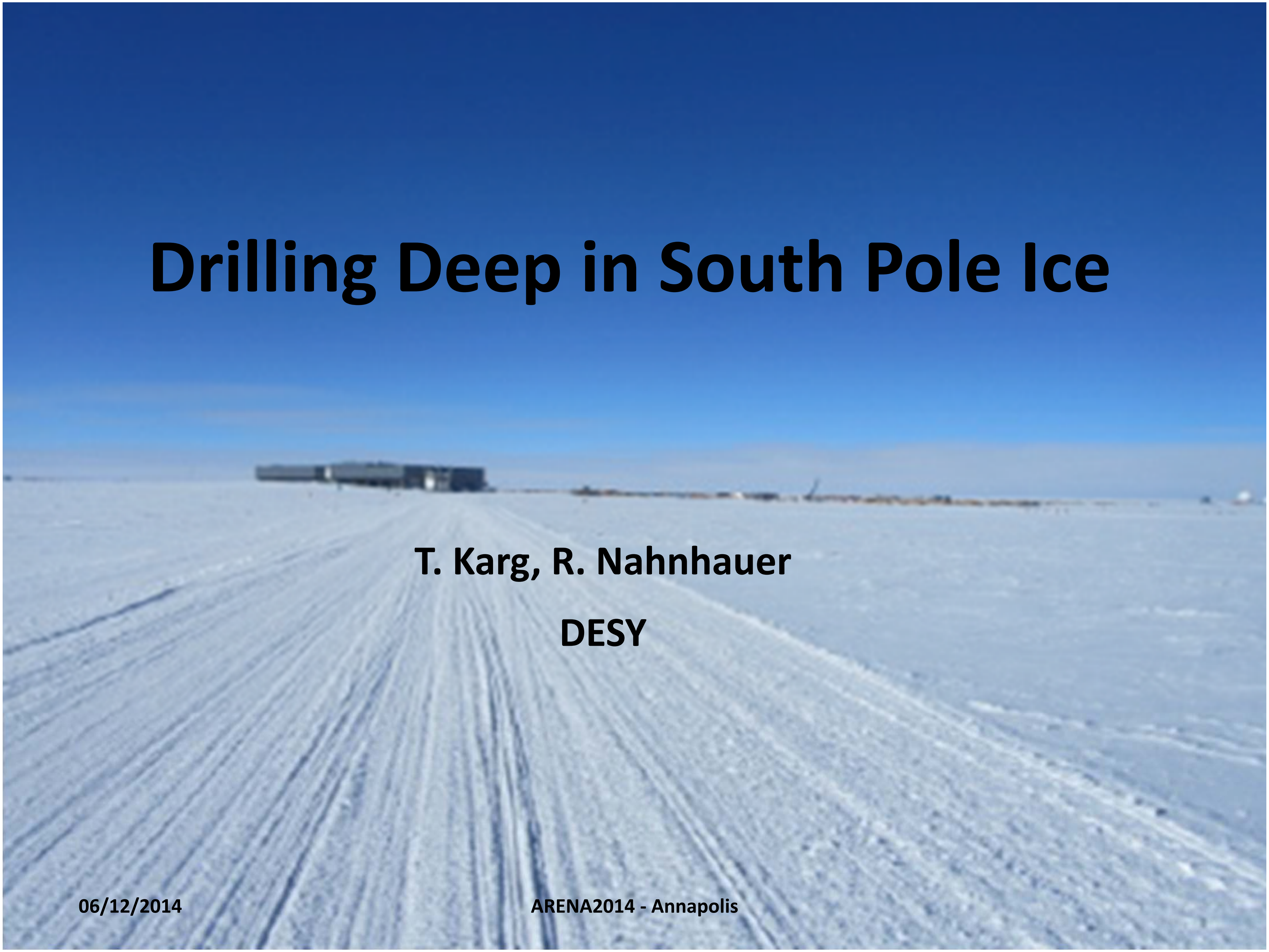
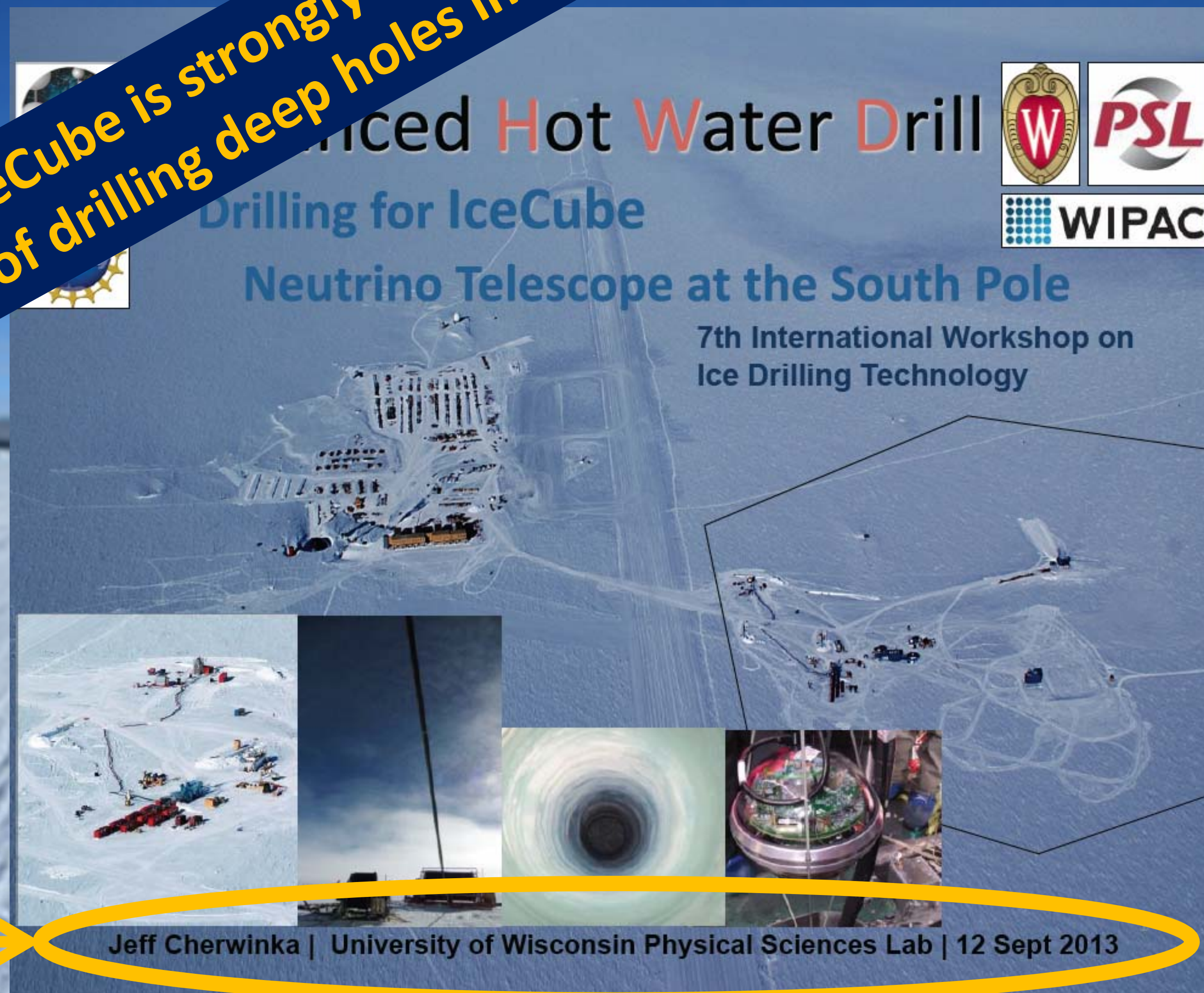


Drilling Deep in South Pole Ice

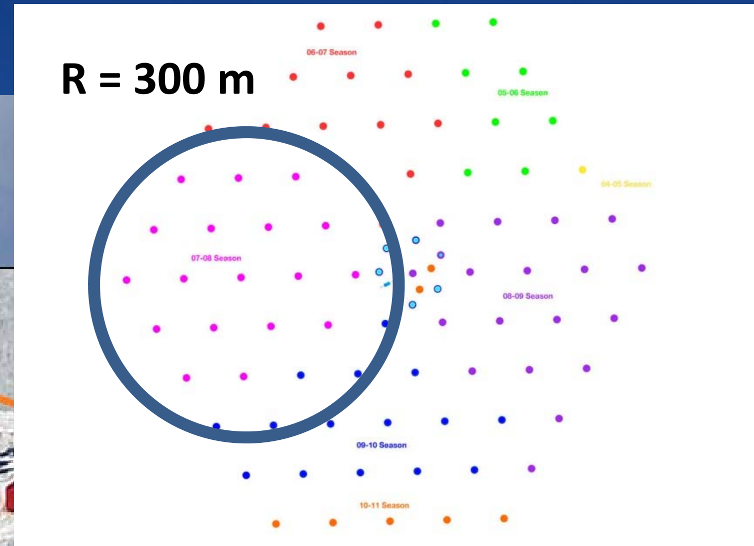
T. Karg, R. Nahnhauer

DESY

The success of IceCube is strongly connected with the success of drilling deep holes in the ice



Enhanced Hot Water Drill (EHWD)
From the Top



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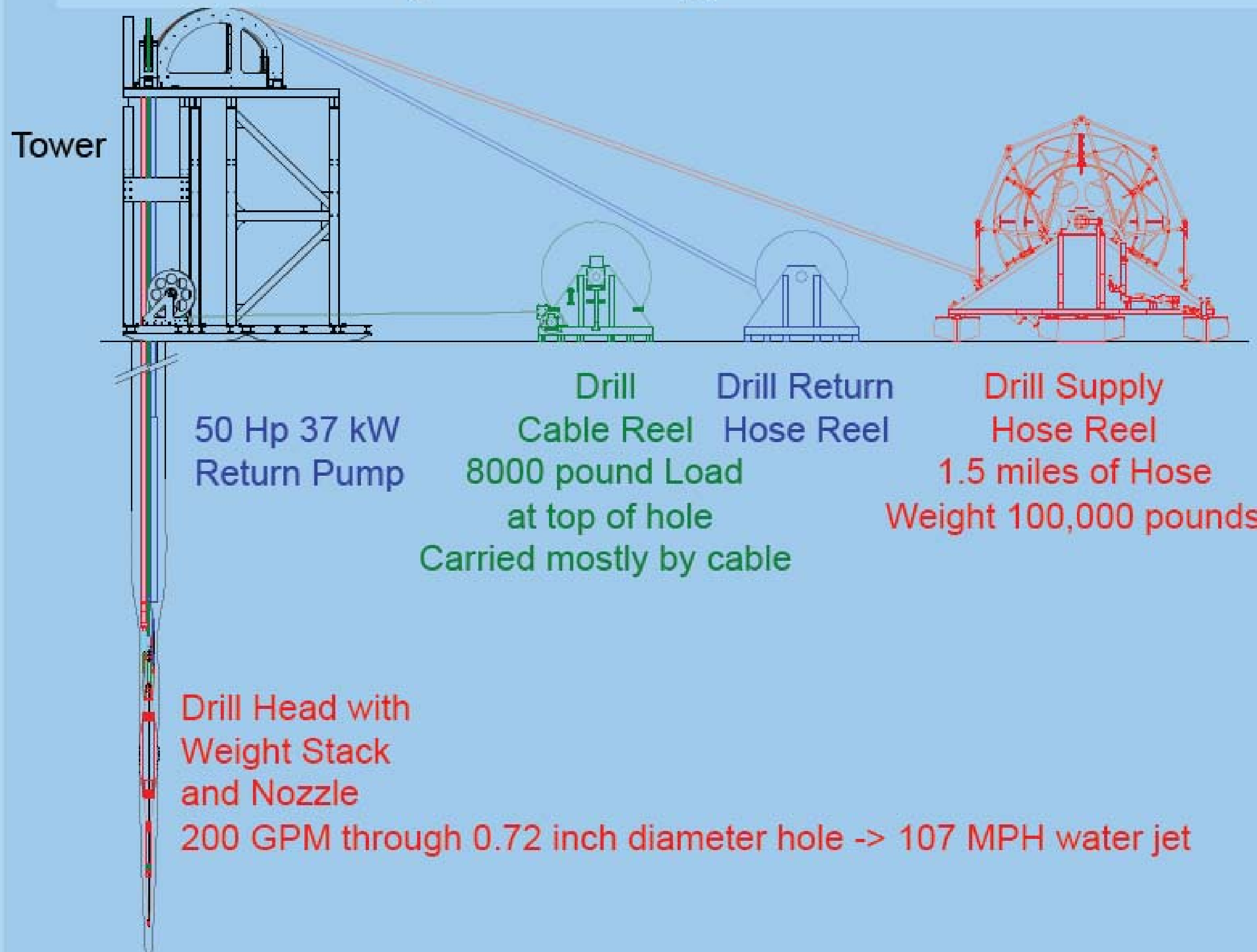
Deep Drilling Illustration



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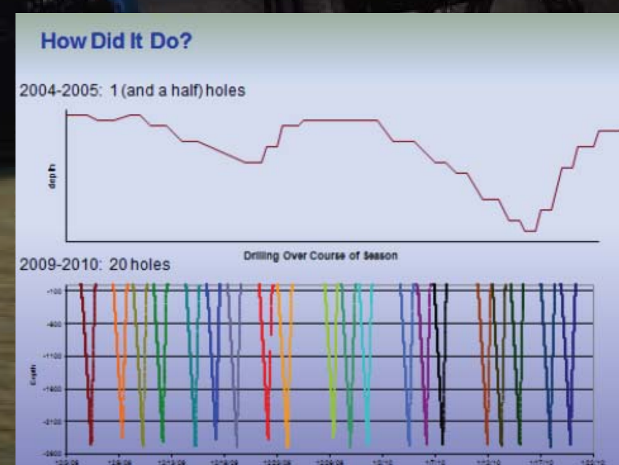
EHWD Stats and Specs

from J. Cherwinka

- IceCube has delivered ~9.5 million lbs to SPole, half of which is fuel
- 4.7 MW of thermal power output
  - That's 6300 horsepower
  - Equivalent to a locomotive at full power, or…
  - 8 Nascars racing at full speed
  - All this shot out of a ¾" nozzle!
- Mileage = 1400 gallons of fuel per mile
- Each hole requires 3 Herc flights
- We have drilled 86 holes, and have melted enough ice for 794 million cocktails!

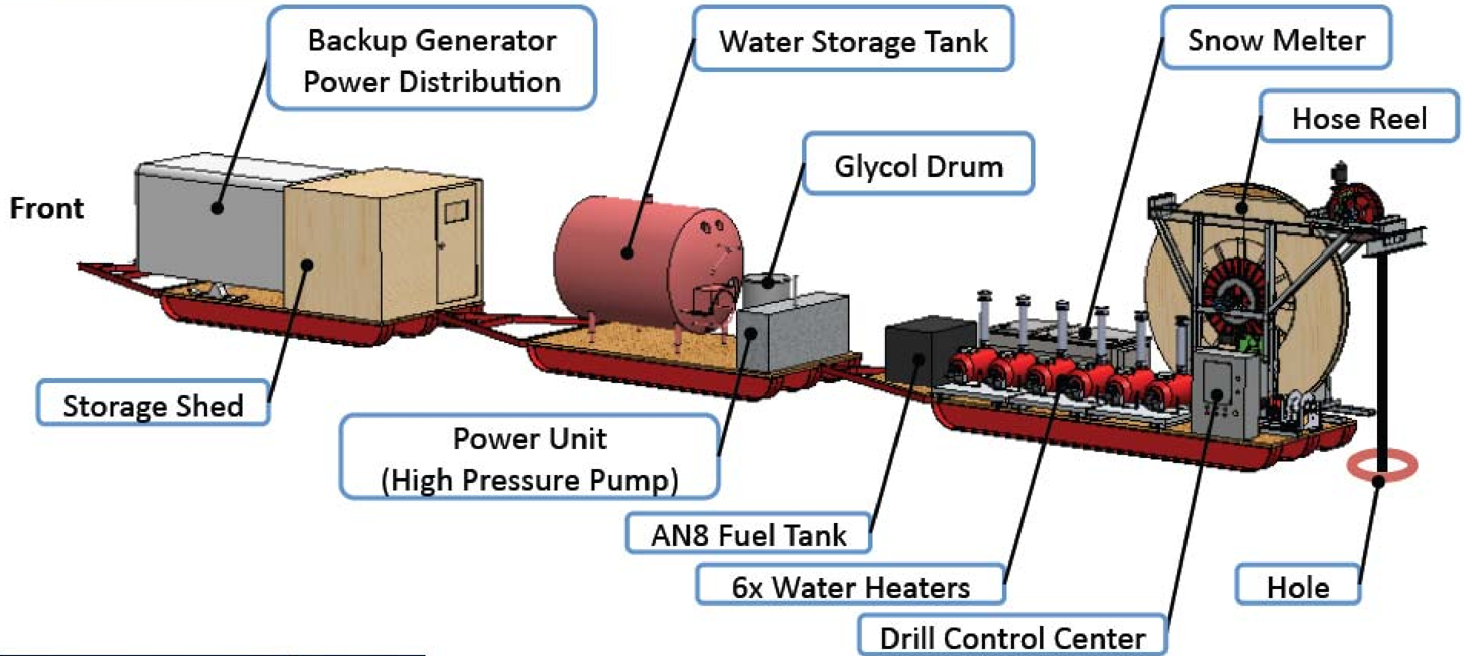
SPECS

- 5 MW (4.7 MW thermal, 300 kW elec)
- 200 GPM, 88°C, 1000 psi
- 1.4 million lb
- 2.1 m/min max drill speed
- ϕ60cm x 2500m hole
  - 31 hr drill
  - 48 hr turnover
  - 4500 gal fuel
- 24/7 operation, total crew of 30



Next step: movable drill for distances > 500 m

ARA Drill Train



+

2x 50kW Onan Generators

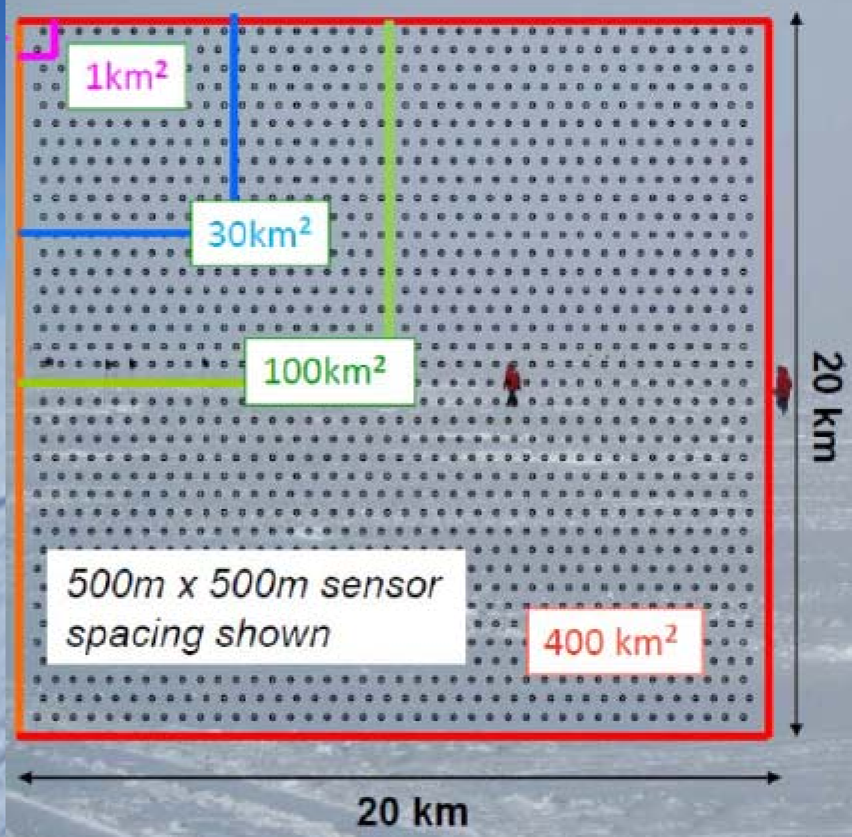
- Redundant
- Supplied by Support Contractor

9/12/2013 Terry Benson | Physical Sciences Lab | UW - Madison 6

Operations

- 5-person crew
  - 2-3 to drill
  - 4-5 to move
- Typical day = 12 hr (12-13 season), 10 hr target
  - De-pickle
  - Deep drill
  - Move
  - Firn drill
  - Pickle
- Not @ South Pole Station, but not "remote"
  - Sleep at South Pole Station
  - Eat at ARA site
- Checklists, safety meetings, and drill strategy tools (charts, etc.) commonplace
- Target Ops for future ARA drilling (80 holes/season)
  - 2 shifts + 1 skeleton shift
  - No pickling
  - Parallel firn drilling

What about very large, deep arrays with dense instrumentation ?



on same string:

- → optical modules (?)
- → radio antennas between 200-400m depth
- → acoustic antennas between 200-(400-1000m) deptl

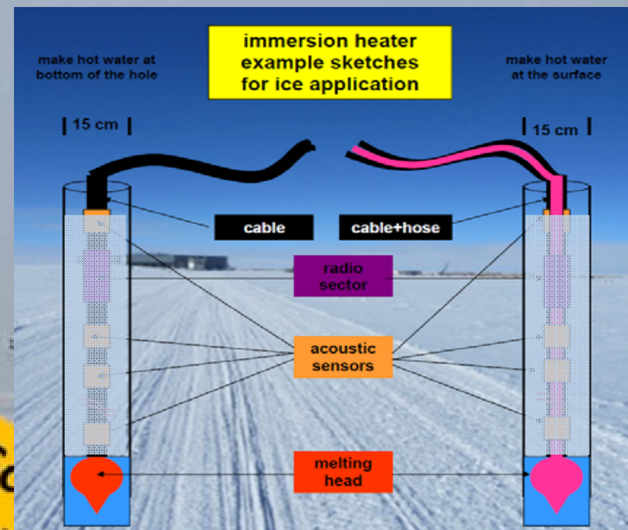
rely strongly on correlated hits from all technologies per event

ΔX	ΔY	#of holes
500	500	1600
333	333	3600

!

Detector deployment requirements

- instrumented area 100 -10000 km^2
- string distance 300 - 1500 m
- string depth 200 - 1200 m
- hole diameter 4 - 8 inch
- x00 – x000 strings
- in about 5 years (with only a 3-6 month per year available)

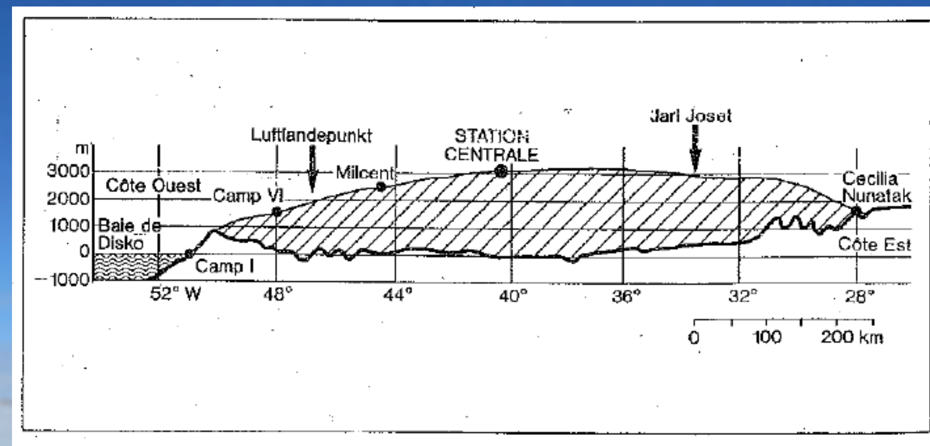


Fiction ?

robotic drilling + deployment scheme needed

Solution proposed and tested 50 years ago:

The Philberth Probe



Deployment of two autonomous thermal probes to a depth of 220 m and 1000 m by Karl Philberth and his team
Time: Summer 1968
Location: Jarl Josef glacier, Greenland
Firn temperature -28.5 °C
Height: 2850 m
Ice thickness: ~2500m

Probe size:
D=11 cm,
L = 280 cm,
wire length = 3000 m

Probe speed:
v = 50 m/day

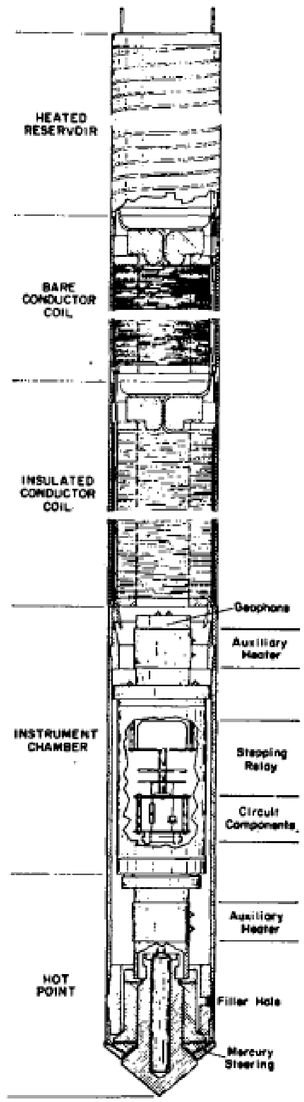
Power used:
P = 4 kW

Inclination:
vertical

Depth measurement:
by coil inductance

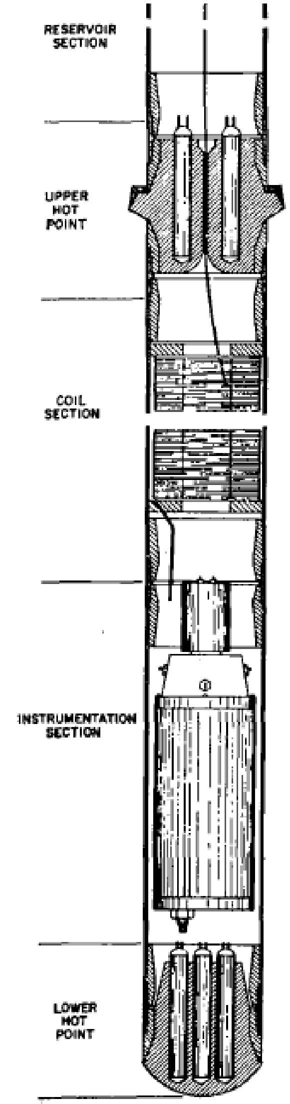
Temperature measurement:
T = -29.0 °C at 220 m
T = -29.3°C at 600 m !!
T= -30.0 °C at 1000m

original Philberth



THE PHILBERTH PROBE

Aamot



THE PENDULUM PROBE

	who	when	where	what	max depth
drill application	Philbert	1968	Greenland	thermal probe	220 m - 1000 m
	Aamot	1971	Antarctica	thermal probe	~100 m
	Hansen	1973	Antarctica	thermal probe	112 m
	Hansen	1979-1993	Lab tests	thermal probes	lab tests
	Hansen, Kelty	1993-1994	Greenland	thermal probe	7 m -135 m
	AWI	1995	Antarctica	thermal probe	
space application	NASA	2001	Lab tests (outdoor?)	thermal probe + water jet	5m (plan: 300 m ??)
	Dachwald (IceMole)	2010-2012	Alps	thermal probe (curvd pass)	5m
	Dachwald (Enceladus)	2012-2015	Alps, Antarctica	thermal probe (curved pass)	> 20 m ?
	Stone (Valkyrie)	2010-20xx	Lab tests	water jet (laser powered)	

First Philberth probe has shown best performance for deep drilling until today

A Thermal Probe for Melting Deep Holes in Antarctic Ice

Conceptual Design Report

A. Donat[1], T. Karg[1], H. Lüdecke[1], R. Nahnhauer[1], F. Tonisch[1], T. Ullmann[2]

[1]Deutsches Elektronen-Synchrotron
[2]Ferchau Engineering GmbH

Available at:
https://wiki.icecube.wisc.edu/index.php/IceCube_Extensions

ABSTRACT

After a review of the development of autonomous melting probes in the past, we discuss the requirements for a probe to be used at the South Pole to melt down to a depth of 2500 m within reasonable cost and time.

all references missed in the talk can be found here

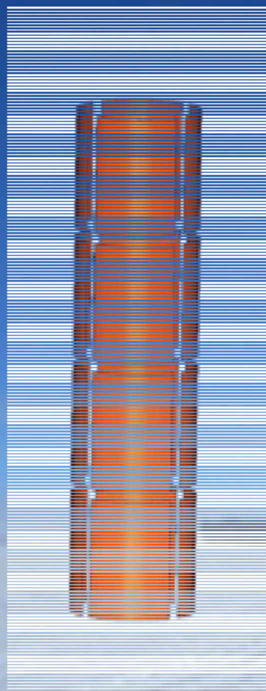
Try to design and build a "Philberth" probe for drilling application with up to date mechanical and electronic components

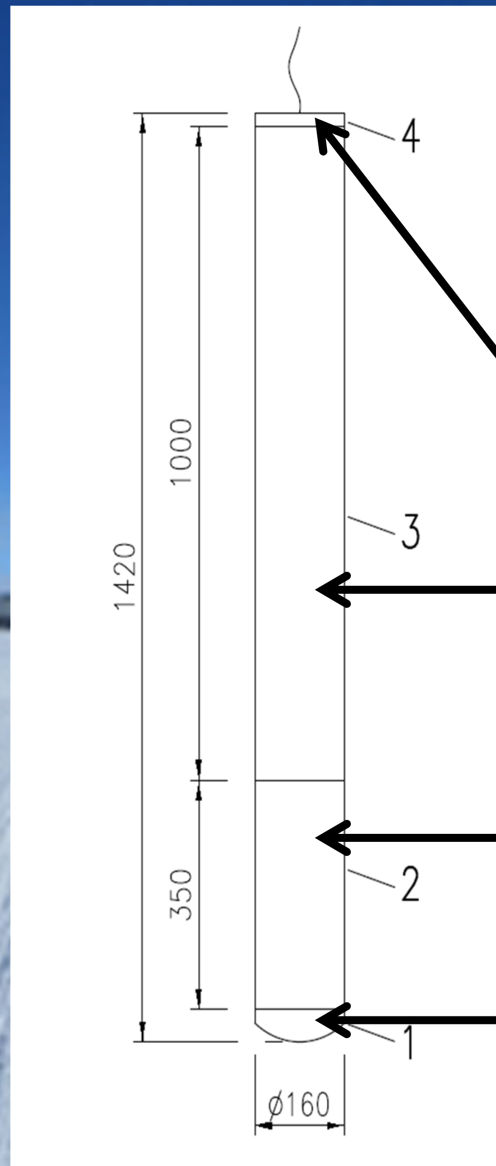
Second step:

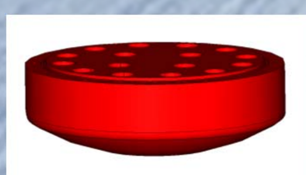
think about possible payload installation

- ➔ **for prototype testing**
- ➔ **for real detector installation**

Mechanical design







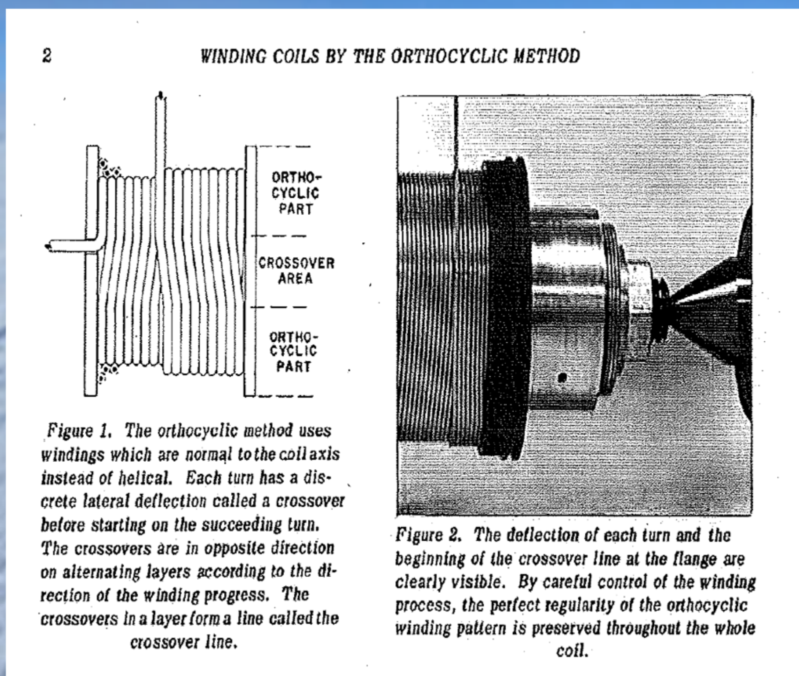
Segments:

4) Top cover with wire exit, heated
3) Coil chamber for 3000 m wire to surface, heated by segmented heater mats at wall (controllable)
2) Sensor and electronic container, pressure resistant
1) Head with heaters, single heater controllable

Mechanic details

Coil winding:

- ➔ probably most difficult part of construction
- ➔ use orthocyclic method (?)

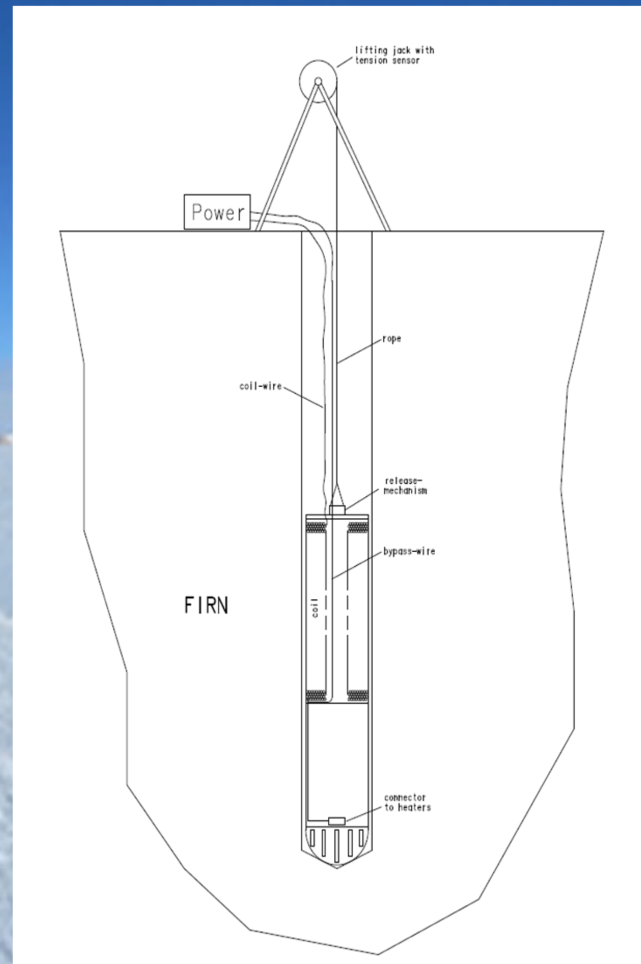


2 WINDING COILS BY THE ORTHOCYCLIC METHOD

Figure 1. The orthocyclic method uses windings which are normal to the coil axis instead of helical. Each turn has a discrete lateral deflection called a crossover before starting on the succeeding turn. The crossovers are in opposite direction on alternating layers according to the direction of the winding progress. The crossovers in a layer form a line called the crossover line.

Figure 2. The deflection of each turn and the beginning of the crossover line at the flange are clearly visible. By careful control of the winding process, the perfect regularity of the orthocyclic winding pattern is preserved throughout the whole coil.

Deployment startup phase:



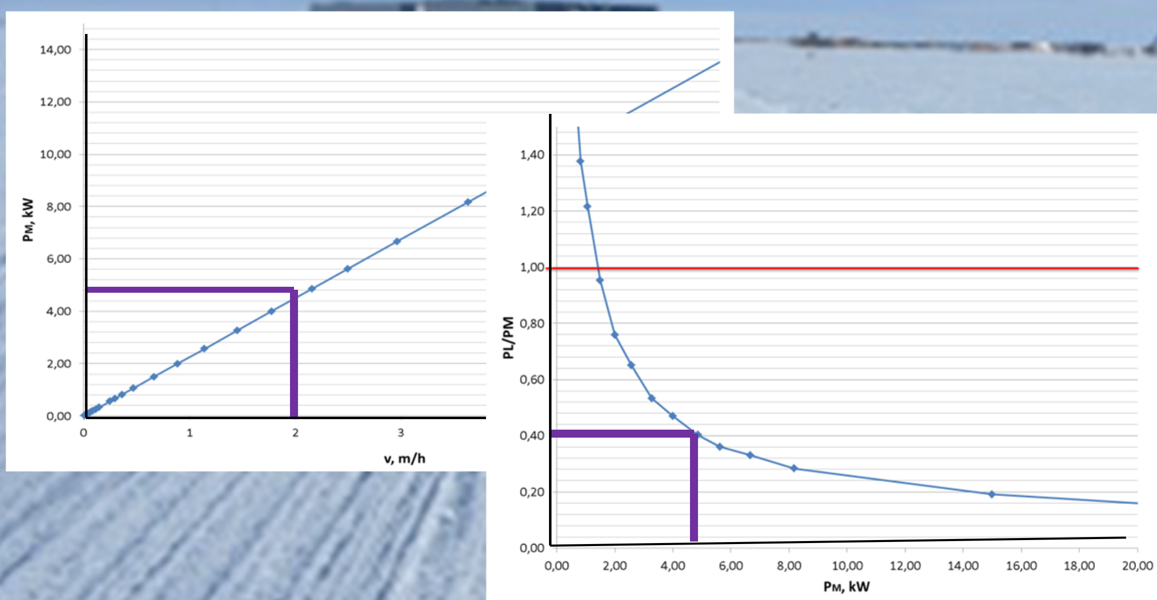
Power requirements for melting:

probe should go down in the ice with certain speed v:

➔ **need melting power** $P_m = \pi r^2 v q_m$, $q_m = \rho(H_m + c_p \Delta T)$

➔ **need lateral power to avoid re-freezing of walls**

$P_l = T v r^2 f(L/vr^2)$, $P_{tot} = P_m + P_l$



with $v = 2$ **m/s**

P_m = ~5 kW

P_{tot} = 7 kW

with

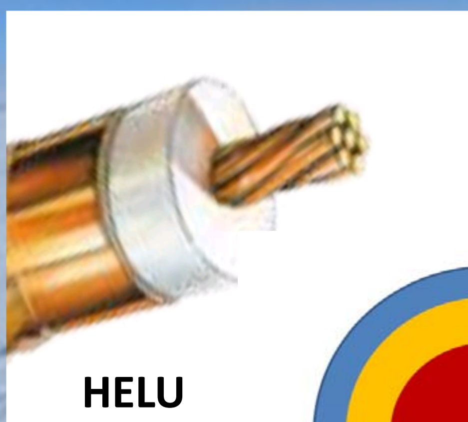
~15% contingency

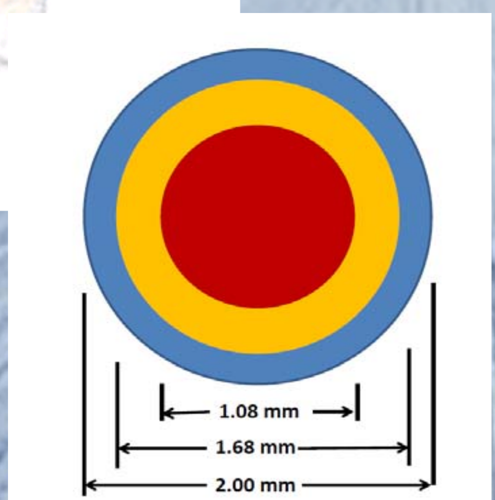
P_{tot} = 8 kW !

Electric power

assume surface generator
with 10 - 15 kW power
transformed to 2500 V DC
load of probe: 500 Ω

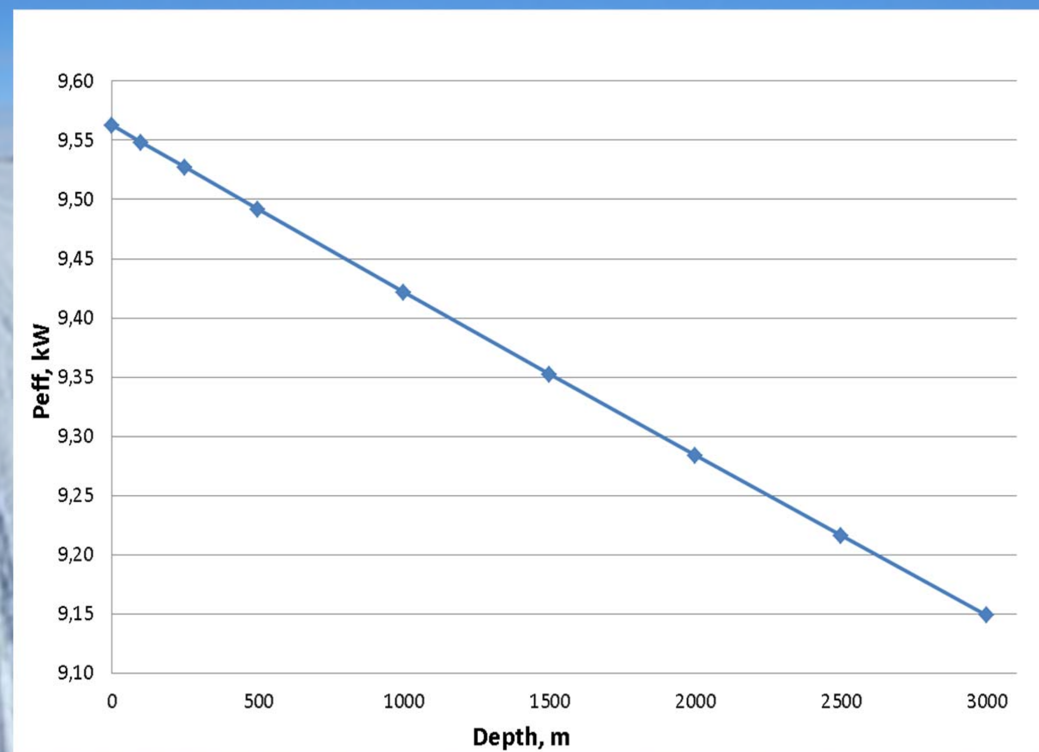
cable cross section:





resistance of cable is depth dependent

$$R_{wire} = \frac{l_{IC,hot} * \rho}{A_{IC}} * (1 + \alpha \Delta T_{hot}) + \frac{l_{IC,cold} * \rho}{A_{IC}} * (1 + \alpha \Delta T_{cold}) + \frac{l_{OC,cold} * \rho}{A_{OC}} * (1 + \alpha \Delta T_{cold})$$



Steering and data acquisition

Slow control

- ➔ Voltages and currents monitored for all subsystems
- ➔ Temperature measured at representative points
- ➔ Bearing measured by inclinometer
- ➔ Cable payout measure for depth determination
- ➔ Acoustic positioning system

Heater element steering

- ➔ water temperature 80 °C – 90 °C
- ➔ probe vertical
- ➔ foresee emergency procedure
- ➔ foresee in-ice re-start

Expected data rates :

Quantity	Rate (Hz)	Size (Bytes / reading)
Surface		
Voltage on cable (top end)	10	4
Current into cable (top end)	10	4
Probe		
Voltage on cable (bottom end)	10	4
Current out of cable (bottom end)	10	4
Voltages and currents at various points 20 test points to be defined, 4 bytes / pt.	1	80
Temperature at various points 10 test points to be defined, 4 bytes / pt.	1	40
Unspooled cable length	0.1	4
Inclinometer	0.1	8
Acoustic positioning	0.01	6152
Total data rate over cable:		**263 bytes / sec.**

Cost estimate

Surface equipment	Cost/€
Generator	5000.-
Transformer	3000.-
Rectifier	1000.-
PC + electronics	2000.-
Mechanics	1000.-
Total	12000.-
Total +20% cont.	14400.-

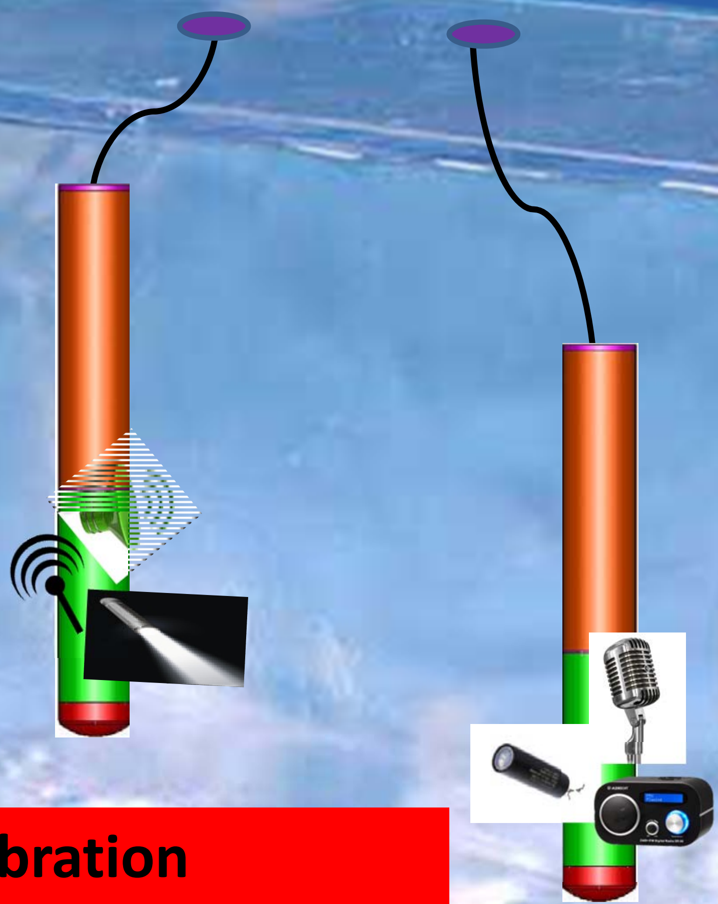
Probe equipment	Cost/€
Cable	6000.-
Mechanics	1000.-
Heating system	3000.-
Electronics	2000.-
Sensors	3000.-
Total	15000.-
Total +20% cont.	18000.-

Drilling fuel *)	Amount for 2500 m / l	Cost / €	+20% cont.
Kerosene	3250	1850.-	2200.-

*) cost without transport, 2.96 $/gal, 0.73€/$

Important: only 2-3 persons necessary for probe deployment

Possible first application(s)



Devices located in sensor chamber:

- radio sender
- loudspeaker
- light source
- radio antenna
- microphone
- photomultiplier

→ detector calibration
→ evaluation of ice properties

Summary

- ➔ It is possible to build an autonomous melting probe with modern technologies at reasonable cost
- ➔ It has to be evaluated if there is interest by other groups to start such a project as a common effort
- ➔ The next step could be the construction and test of a corresponding prototype following the Philberth concept
- ➔ In parallel alternative designs should be developed (water jet, heated wire from surface, ...)
- ➔ First applications could be the study of ice properties and the deployment of calibration sources at any wanted location