The Experience and Limitations of using Manganese Alkaline Primary Cells in a Large Operational AUV

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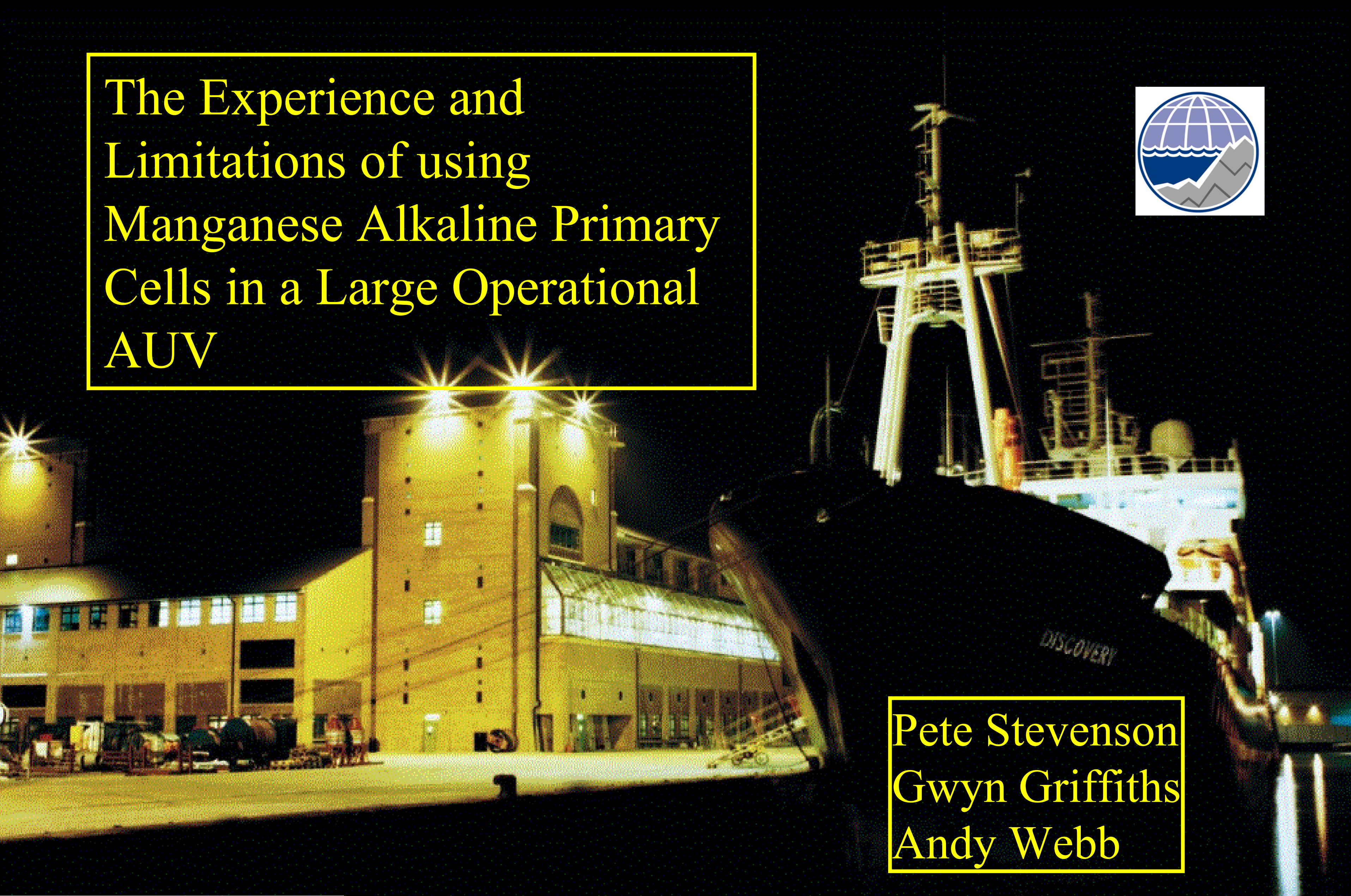

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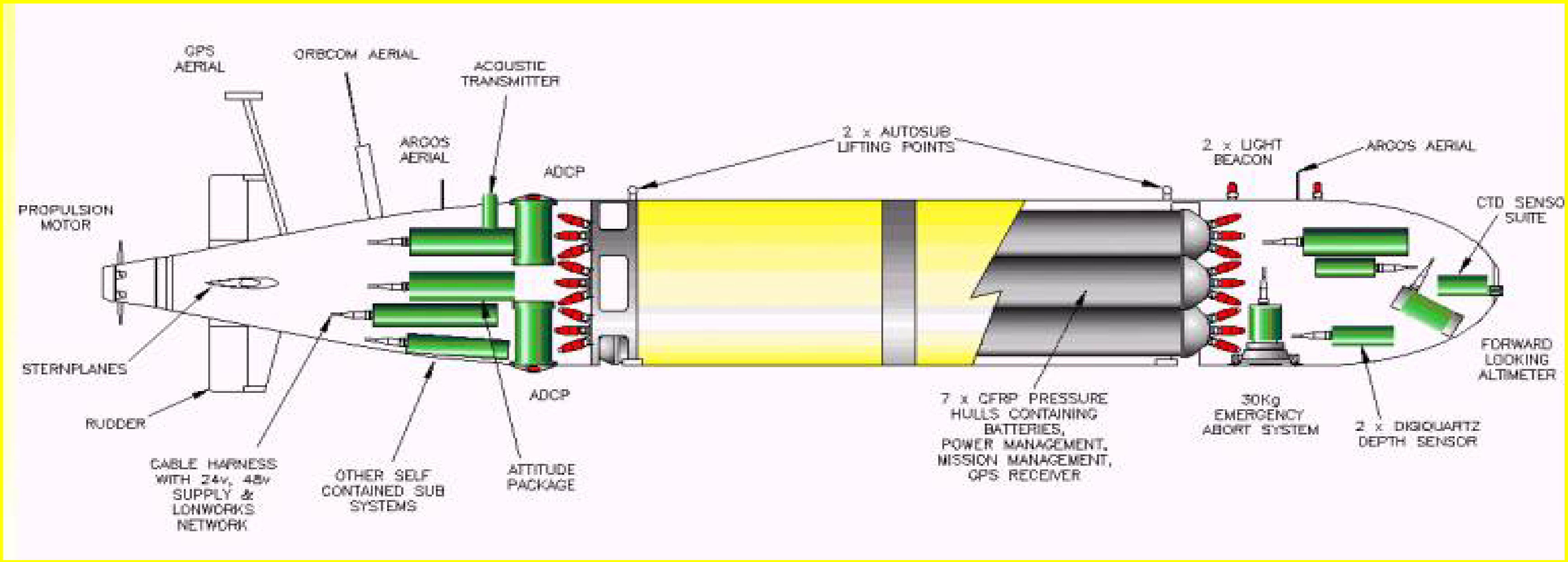
Autosub: Operational since 1996

7m long

0.9m diameter

2.3 Tonnes in air

3.5 Tonnes form displacement



Early trials in Empress dock,

84V Sealed lead acid cells

Cheap, practical, rugged.

Served to prove the vehicle would control and navigate.

NERC Science campaigns 1999-2001

Estimate stock levels of herring in the North Sea. Measure ice thickness and krill abundance in Antarctica

Map turbulence over sandbanks in the North Sea

Measure wave turbulence off the Atlantic coast of Scotland

Sample manganese and oxygen in Scottish sea lochs

Make oceanographic measurements in the Strait of Sicily

Particle analysis using flow cytometer in SW Approaches

The programme allowed money and effort to upgrade Autosub to provide a greater depth rating, endurance and space for electronic sub-systems. This lead to the development of CFRP pressure hulls to give a working depth of 1600m

…a new energy source.

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Battery Type	Specific Energy (kJ/kg)	Approx range/pack or charge (km)	Approx cost to equip Autosub (£k)	Minimum No. of cycles to break even with the cost of Manganese Alkaline
Manganese Alkaline	460 @21 C, 0.1W/cell	640	5	-
Sealed Lead Acid	110	150	14	12
Nickel Cadmium	140	190	40	24
Nickel Metal Hydride	330	430	90	26
Lithium Ion	470	610	170	34
Silver Zinc	580	750	170	29

Manganese Alkaline cells had the advantages of:-

•Minimum capital investment, reducing the value of the vehicle for high risk missions

•Low development effort.

•Enabled greater investment to be made in sensors and ship time.

Autosub:- Missions since launch

June ‘96 - May ‘01

271 Missions

3596 km

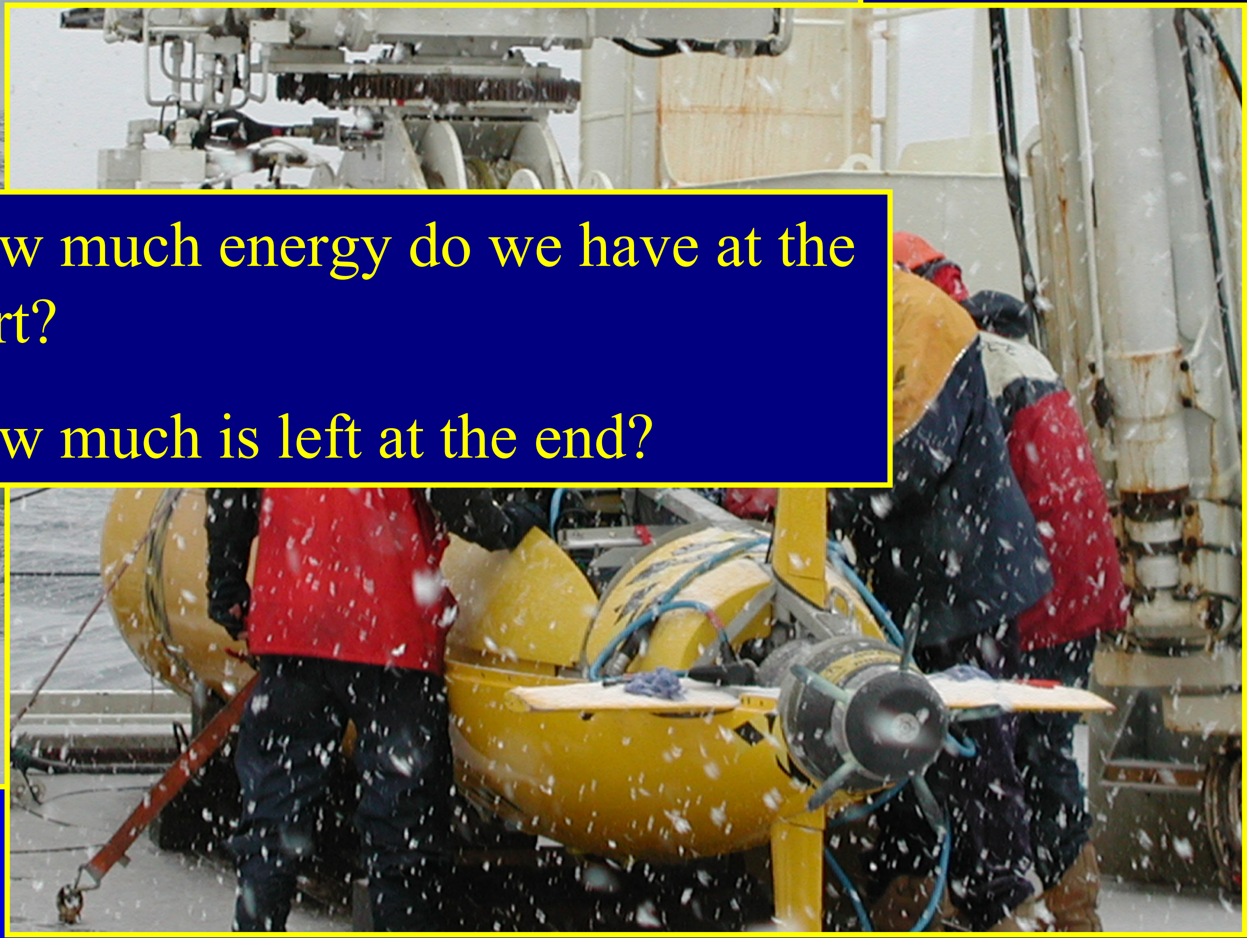
Science programme- Start July ‘99

89 Missions since July ‘99

6 different ships

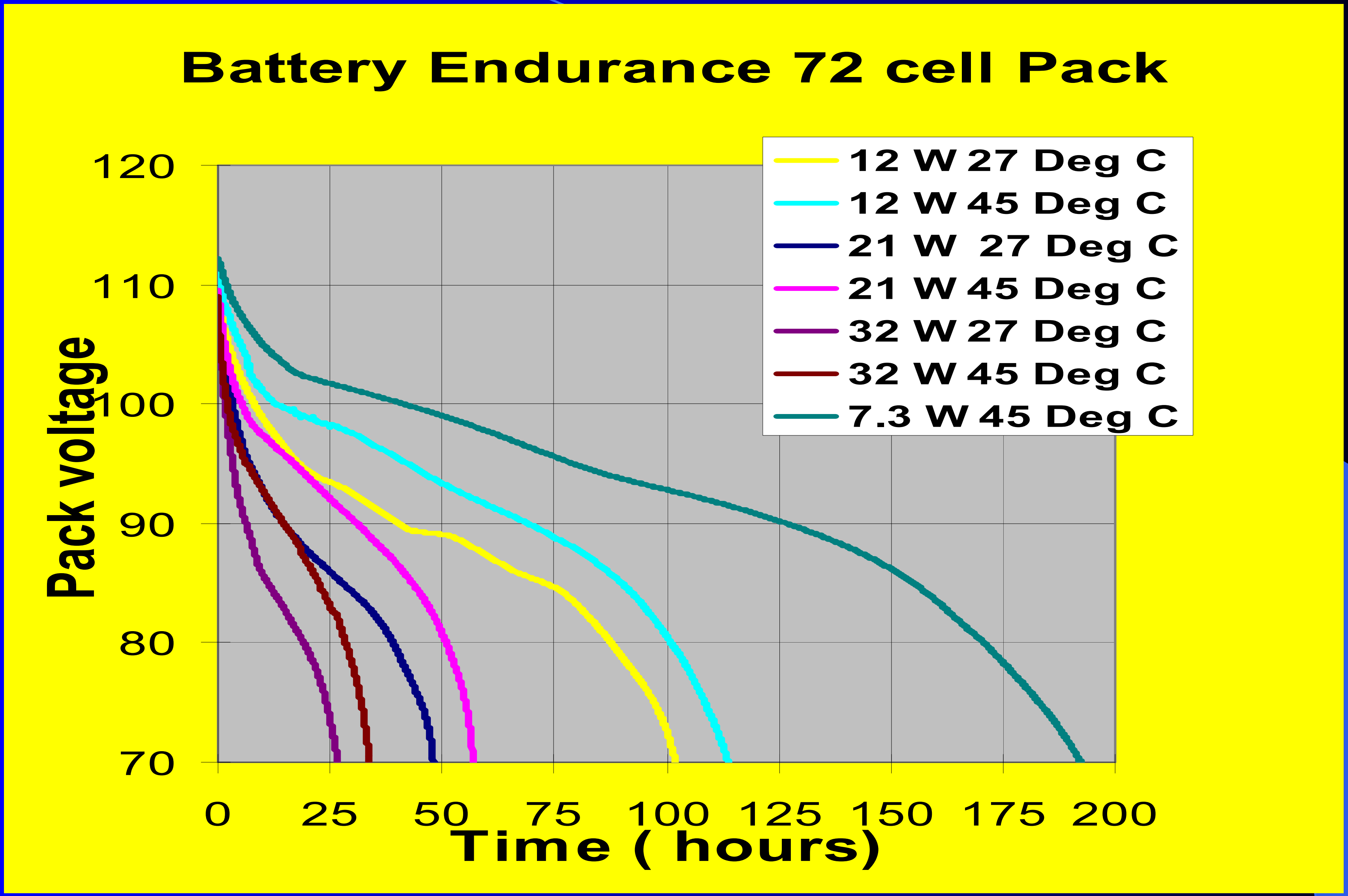
- 2502 km
- 550 hours mission time
- 1812 km unescorted

Autosub Under Ice (AUI) campaigns



How much energy do we have at the start?

How much is left at the end?



Battery Endurance 72 cell Pack
Pack voltage
Time (hours)
120
110
100
90
80
70
0
25
50
75
100
125
150
175
200
12 W 27 Deg C
12 W 45 Deg C
21 W 27 Deg C
21 W 45 Deg C
32 W 27 Deg C
32 W 45 Deg C
7.3 W 45 Deg C

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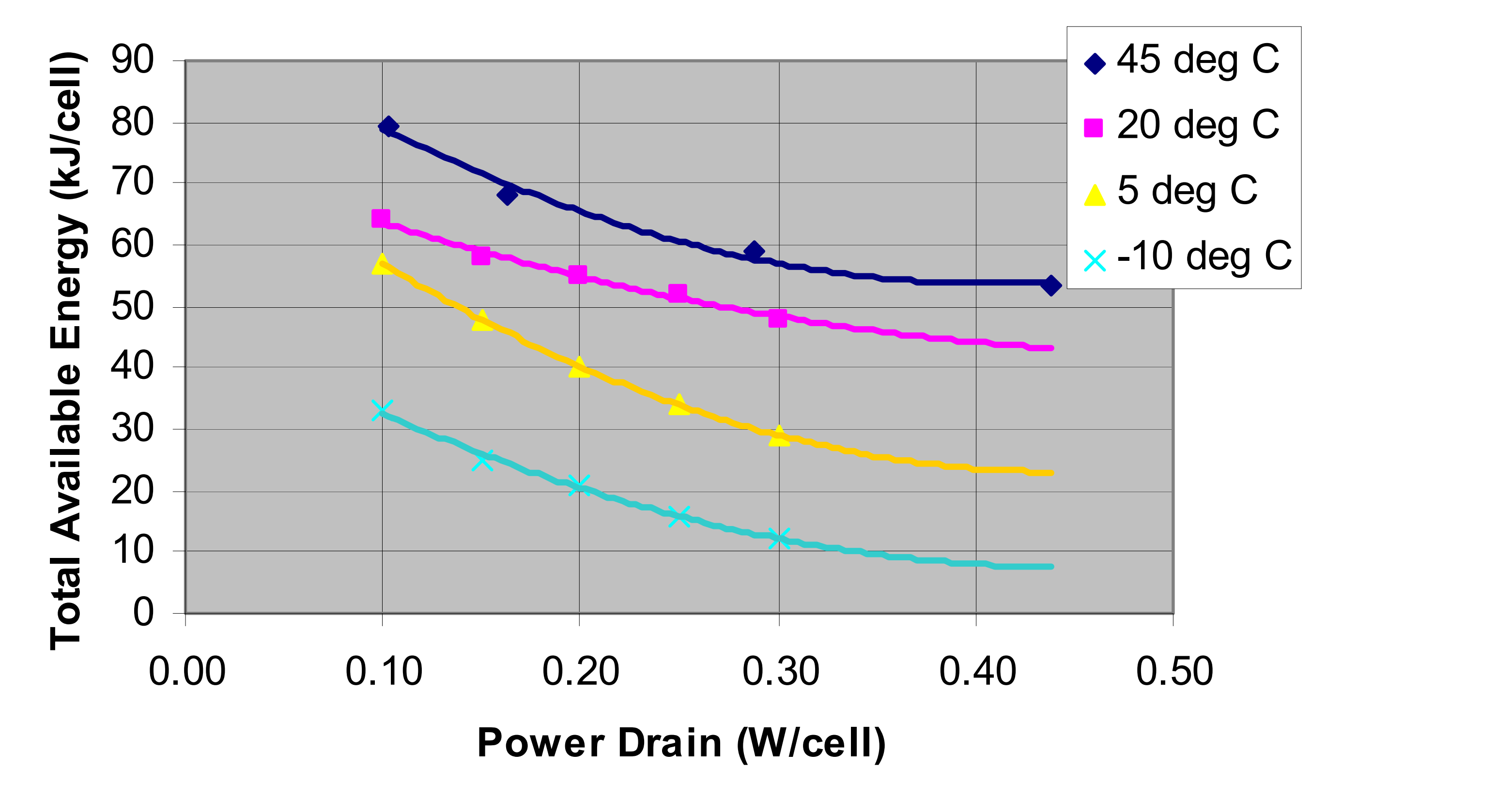
Illustration of drop in total energy available from a cell with increasing power drain and decreasing temperature.



Electro chemical basis for predicting voltage decay

$$V_t = V_h - \frac{\phi RT}{F}\ln\left(\frac{Q_t}{Q_r}\right) + \Delta\eta_c - \Delta\eta_a$$

V_t = Voltage decay

V_h = Cell voltage at half the useful life

F=Constant

R = Gas Constant

T = Absolute temp

F = Faradays Constant

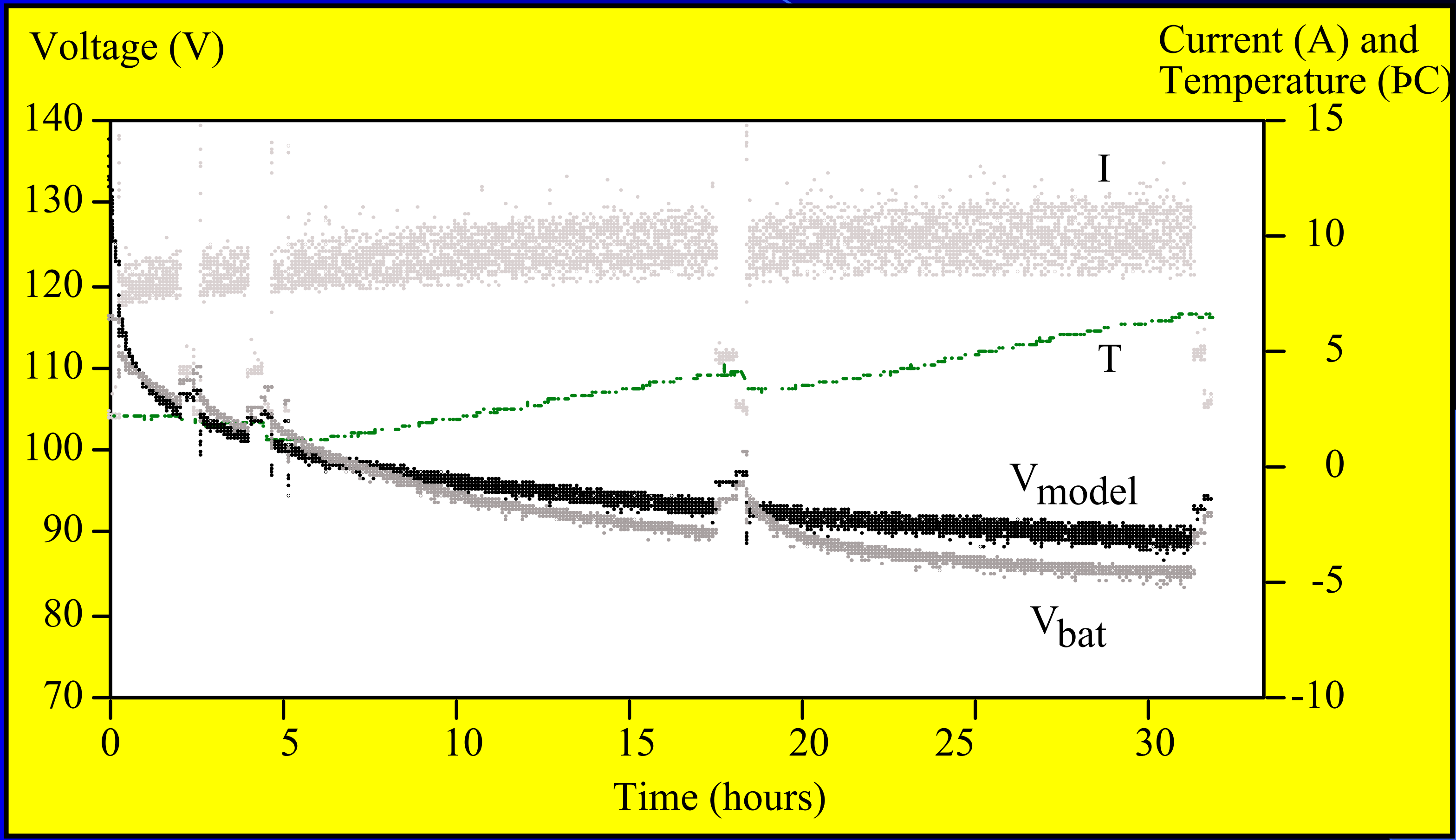
Q_t = Useful energy extracted to time t (measured on AUV or simulated)

Q_r = Useful energy remaining (estimated from total energy Q_T)

Dc = Cathodic overpotential (f [T,I,state of discharge])

Dh_a=Anodic overpotential (f [T,I,state of discharge])

Comparison of predicted battery voltage over a number of missions with recorded data.



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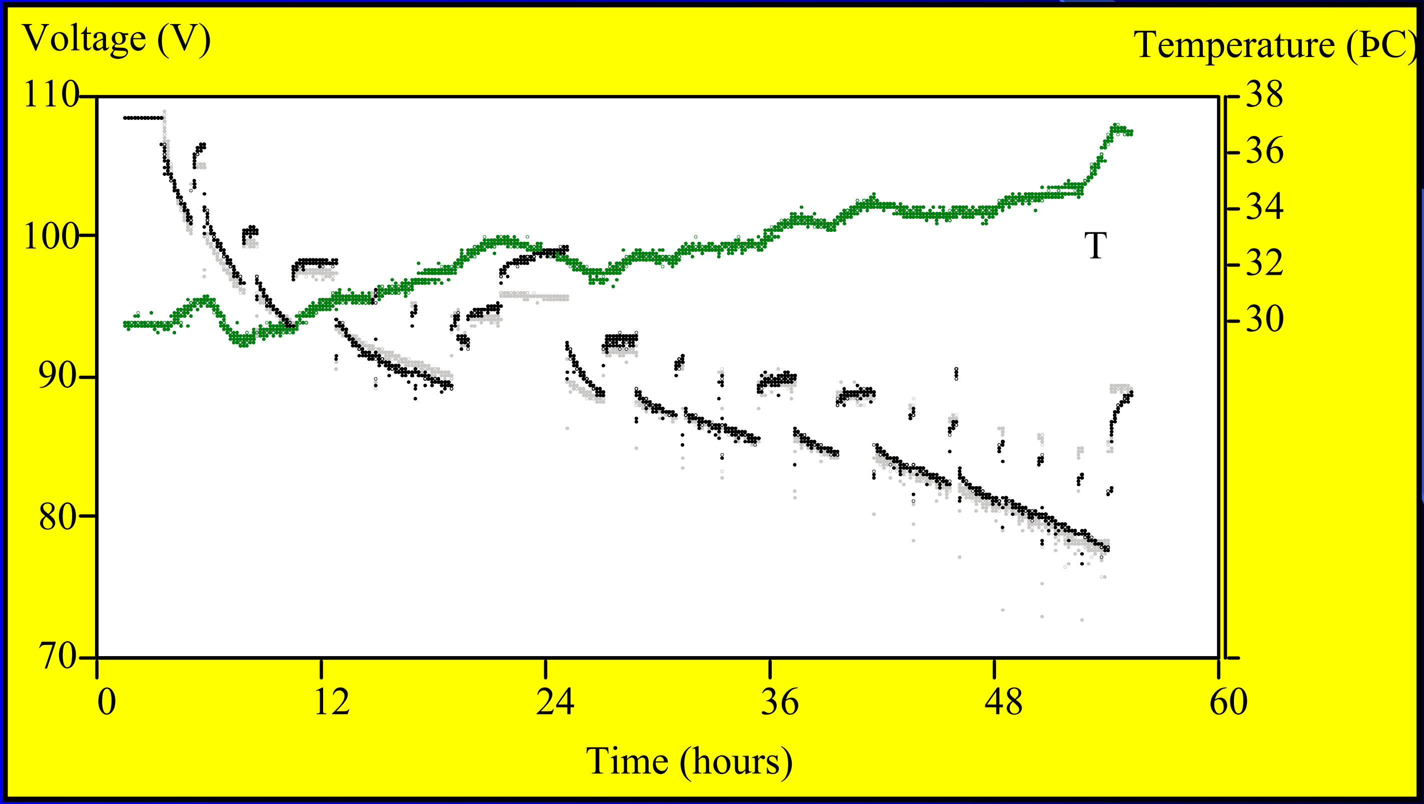
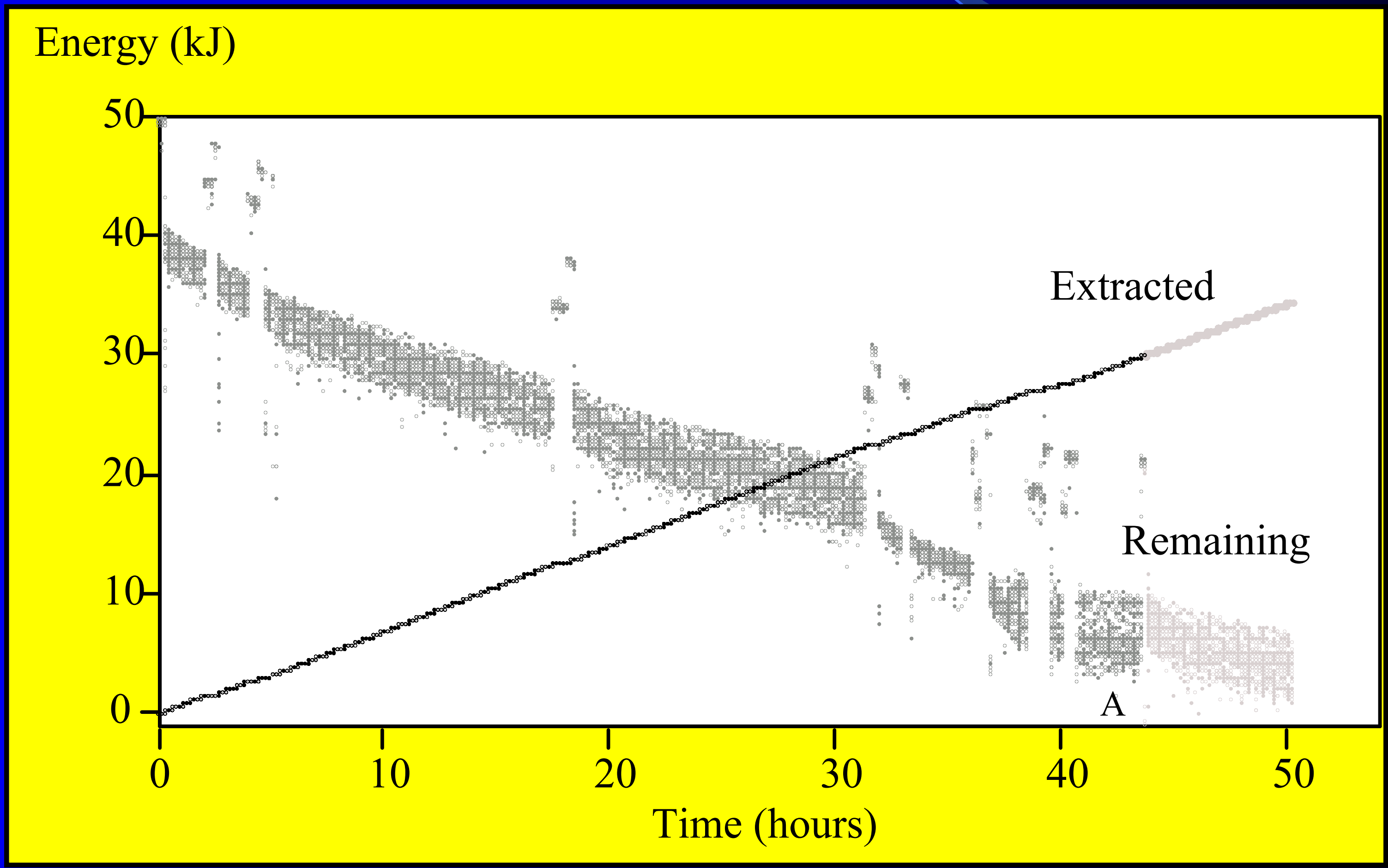
Comparison of the actual terminal voltage of the Autosub battery pack as measured during mission 145 (dark points) and the model results (light points) using the measured current consumption and the average temperature of the battery pack (T).



Actual and predicted Energy extracted/cell, using the model to predict performance with the remaining energy



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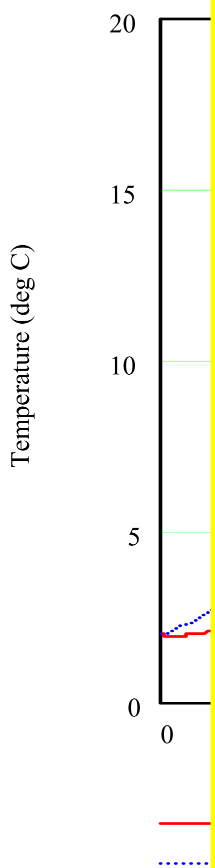
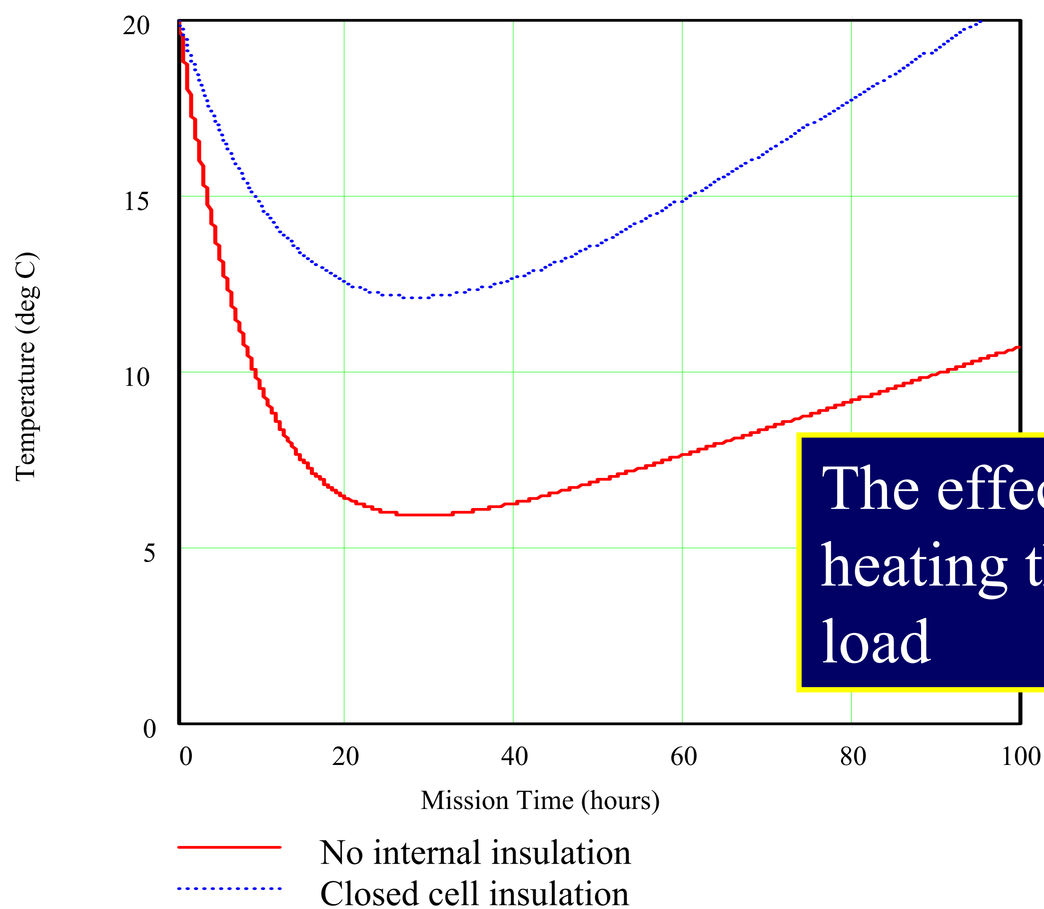
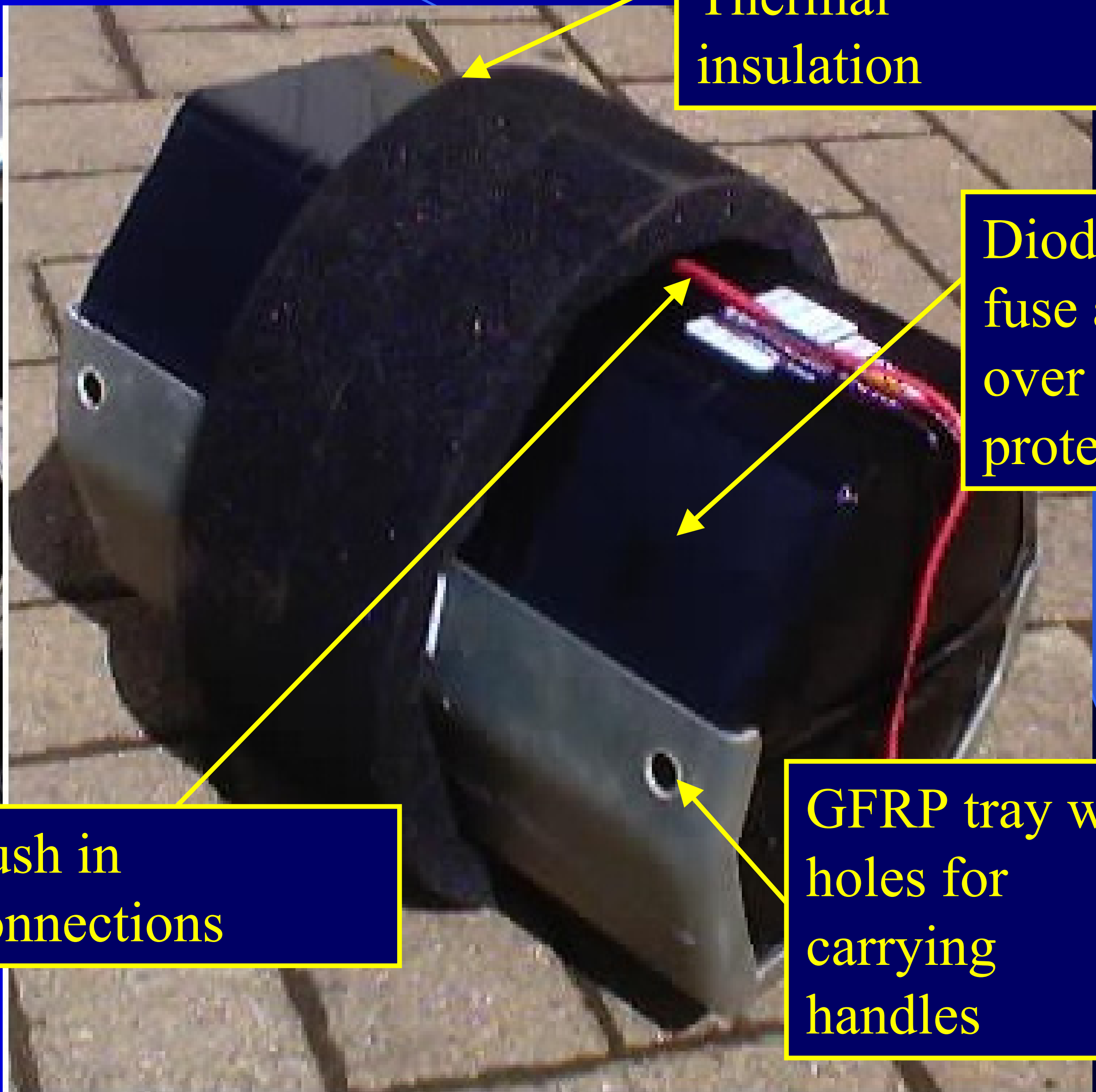
The effect of waste heat warming the battery pack. (based on sea temp of 0 degrees and no pre heating)





The effect of pre heating the battery load

Practical Design Features



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The Future of Primary Cells in AUVs?

The compromise of high consumable cost but low capital cost of primary cells will serve the present programme well. They may continue to be used in:-

- Small AUVs where the cost of primary batteries is low cost compared to the total cost of a deployment,
- Vehicles where ultimate energy density and reliability overrides the cost (due to the importance of the data and/or the survey speed and or endurance
- The development phase of new vehicles
- A lower cost purchase option for the customer with the possibility of upgrading to a secondary source

Present energy sources will undoubtedly improve but the overall effectiveness is moderated by the weight of the pressure proof housing and the efficiency of other sub systems (propulsion, pressure hulls, drag sensors).