RSN DISSUB TRIALS WITH PASSIVE CARBON DIOXIDE SCRUBBING

MAJ (Dr) Raymond Siew

Republic of Singapore Navy

DISSUB Concerns in Tropical/ Warm Water Environment

- Heat build-up within enclosed submarine compartments
  - Warmer sea-water temperatures (25-28^{o}C at surface, up to 28-29^{o}C at depth around equatorial South China Sea)
    - Less heat loss from DISSUB to surrounding waters
  - May be compounded by exothermic reaction of Sodalime & Lithium Hydroxide used in a DISSUB
  - Potential for heat stress and significant dehydration
    - Exacerbated by high humidity (96-100%) in the DISSUB as sweating becomes ineffective as a mechanism for heat loss from the body

DISSUB Concerns in Tropical/ Warm Water Environment

- Efficacy of passive carbon dioxide scrubbing technologies/ techniques
  - Sodalime granules spread on trays
  - Sodalime/LiOH granules in curtains (e.g. Battelle curtains)
  - Lithium Hydroxide curtains (ExtendAir®)
- Health effects and potential problems from exposure to Sodalime/ Lithium Hydroxide

DISSUB Concerns in Tropical/ Warm Water Environment

- Physiological challenges in a DISSUB
  - Restriction of calories (emergency rations) and water
  - Effects of dehydration and heat stress
  - Effects of raised carbon dioxide levels for prolonged periods

DISSUB Concerns in Tropical/ Warm Water Environment

- Logistical challenges for Diesel-Electric Submarines
  - Weight and space limitations for emergency water supplies, food, oxygen stores, and carbon dioxide absorbents
  - DISSUB survivors may be cramped into one compartment
    - Need for emergency stores to be distributed throughout the submarine in adequate quantities
  - Lack of ventilation
    - Potential pockets of dead space with low oxygen/ high carbon dioxide levels

RSN DISSUB TRIALS

- 2004
  - ❖48hrs in harbour
  - ❖Battelle curtains containing sodalime granules
- 2008
  - ❖48hrs in harbour
  - ❖Lithium Hydroxide curtains (ExtendAir)

2004 DISSUB Trial

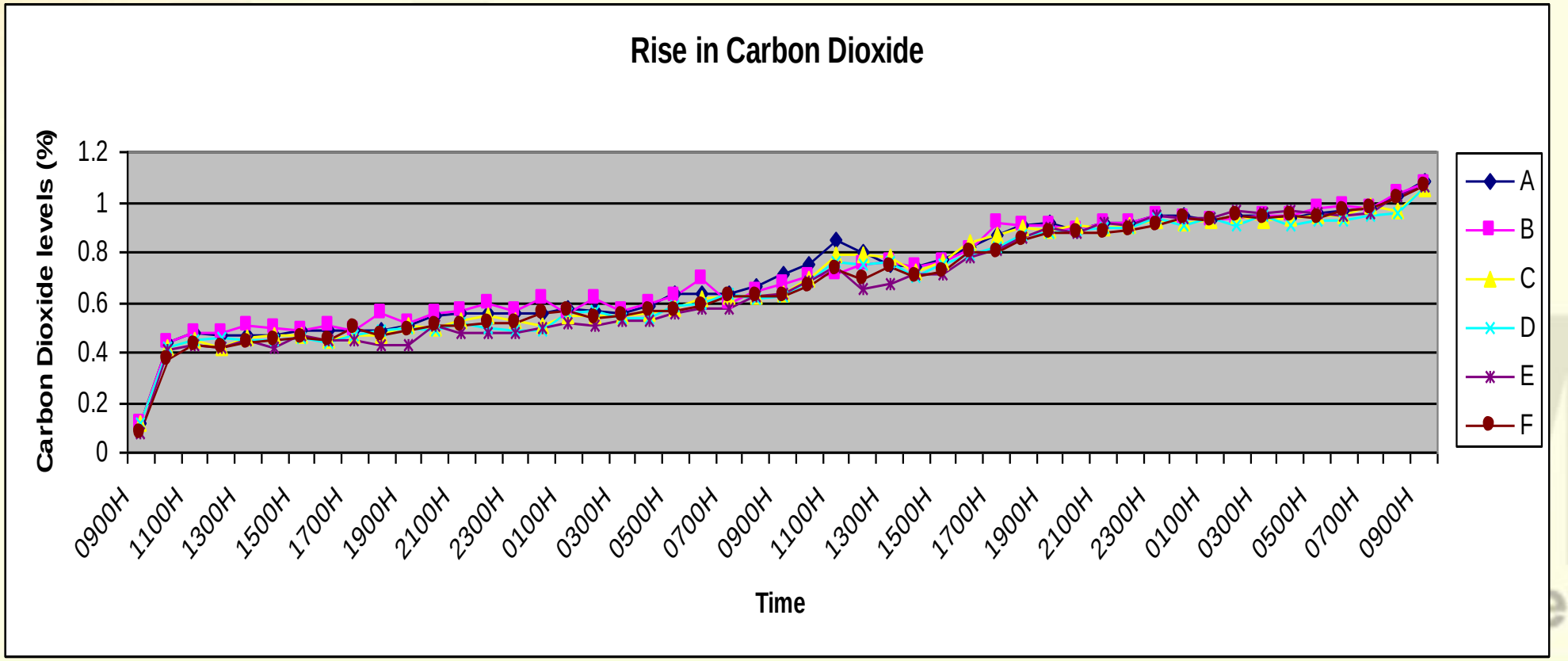
- Trial conducted in harbour due to safety concerns
- Measures taken to minimise radiant heat build-up
- Crew kept in forward compartment for 48hrs with no electrical power and ventilation
- DISSUB procedures adopted by crew

2004 DISSUB Trial

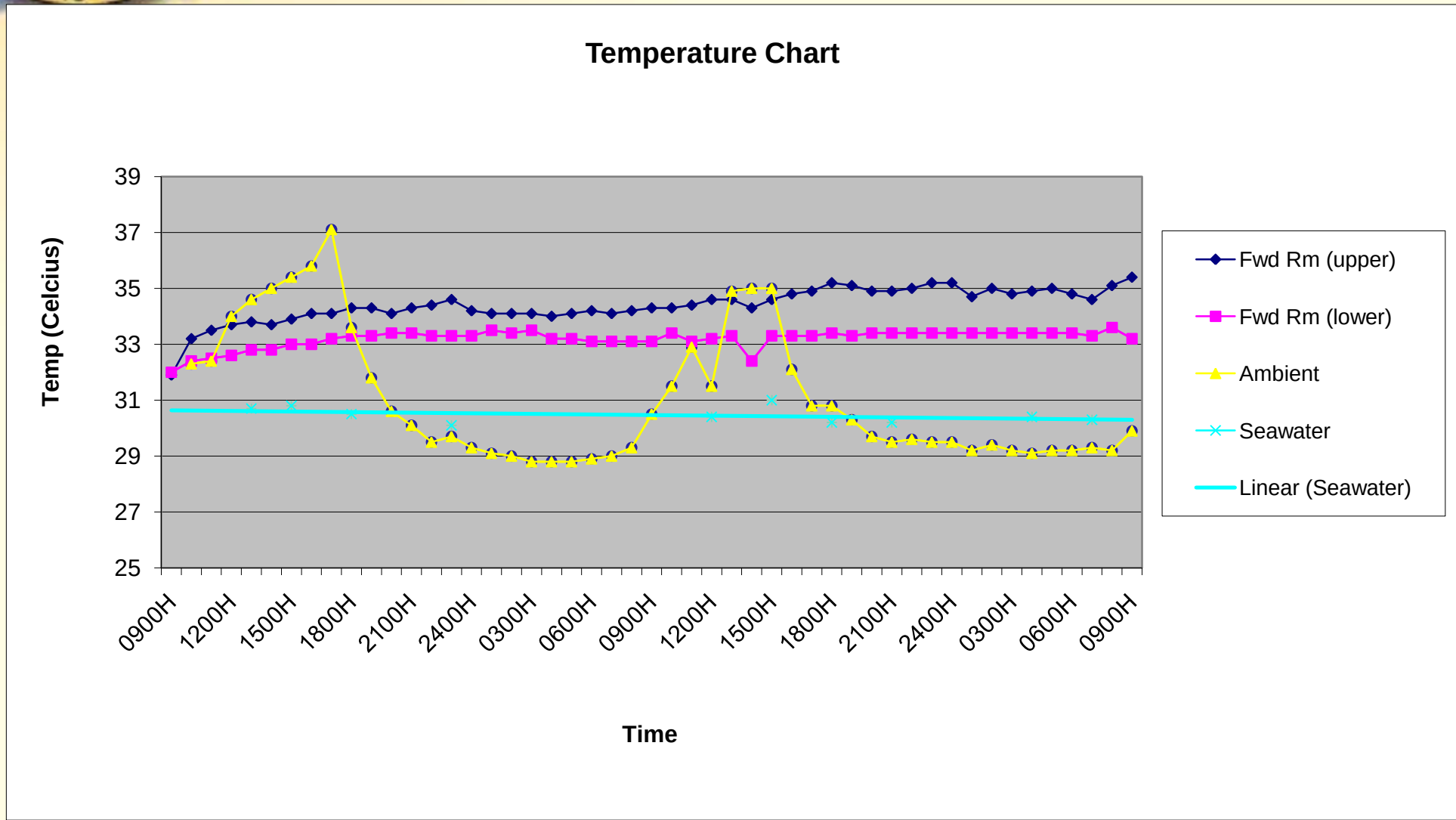
- Each Battelle curtain filled with 6kg of Sodalime granules
- All Battelle curtains deployed at the start of trial and left hanging for 48hrs
- Crew adopted DISSUB procedures
  - Emergency rations consumed
  - Encouraged to drink as much water as desired (Trial Safety)

2004 DISSUB Trial Results

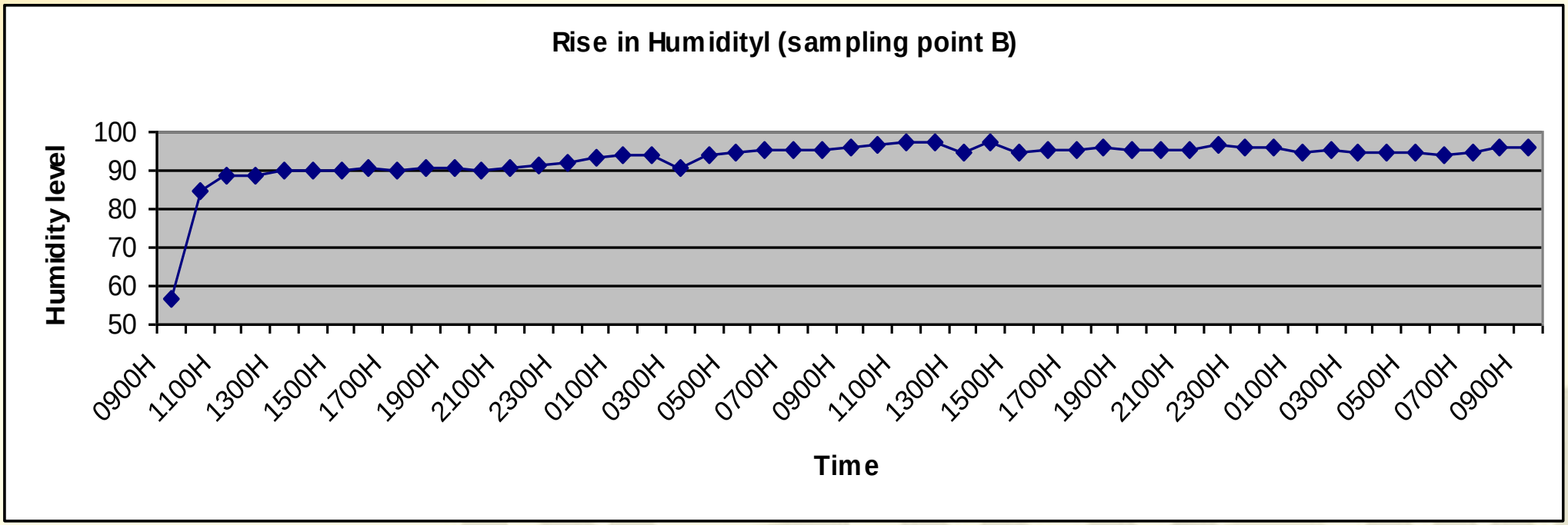
- 2.45kg of Sodalime per person per day sufficient to keep CO_2 levels <1.5%
- Compared to 4kg if using traditional method of spreading Sodalime on open trays



2004 DISSUB Trial Results



2004 DISSUB Trial Results



2004 DISSUB Trial Results – Physiological parameters

- Average weight loss: 1.5kg (0-5Kg)
- Average water intake: 7.4L (4-11.5L) over 48hrs
- Average urine output: 2.8L (0.7-5.4L) over 48hrs
- 15% of crew with >5% weight loss
- Average rise in body temperature: 0.6^{o}C; 10% of crew had body temperatures > 38^{o}C but < 38.5^{o}C
- Average increase in pulse rate: 25.7% from baseline

2004 DISSUB Trial
Significant Observations

- 90% of crew developed generalised rashes with itch; 25% had severe rashes with significant discomfort
- 50% of crew complained of eye irritation with discharge; a few complained of temporary visual blurring (reversible)
- 80% of crew complained of mild persistent headaches but were able to carry out assigned tasks
- 33% of crew complained of a subjective feeling of having difficulty in breathing

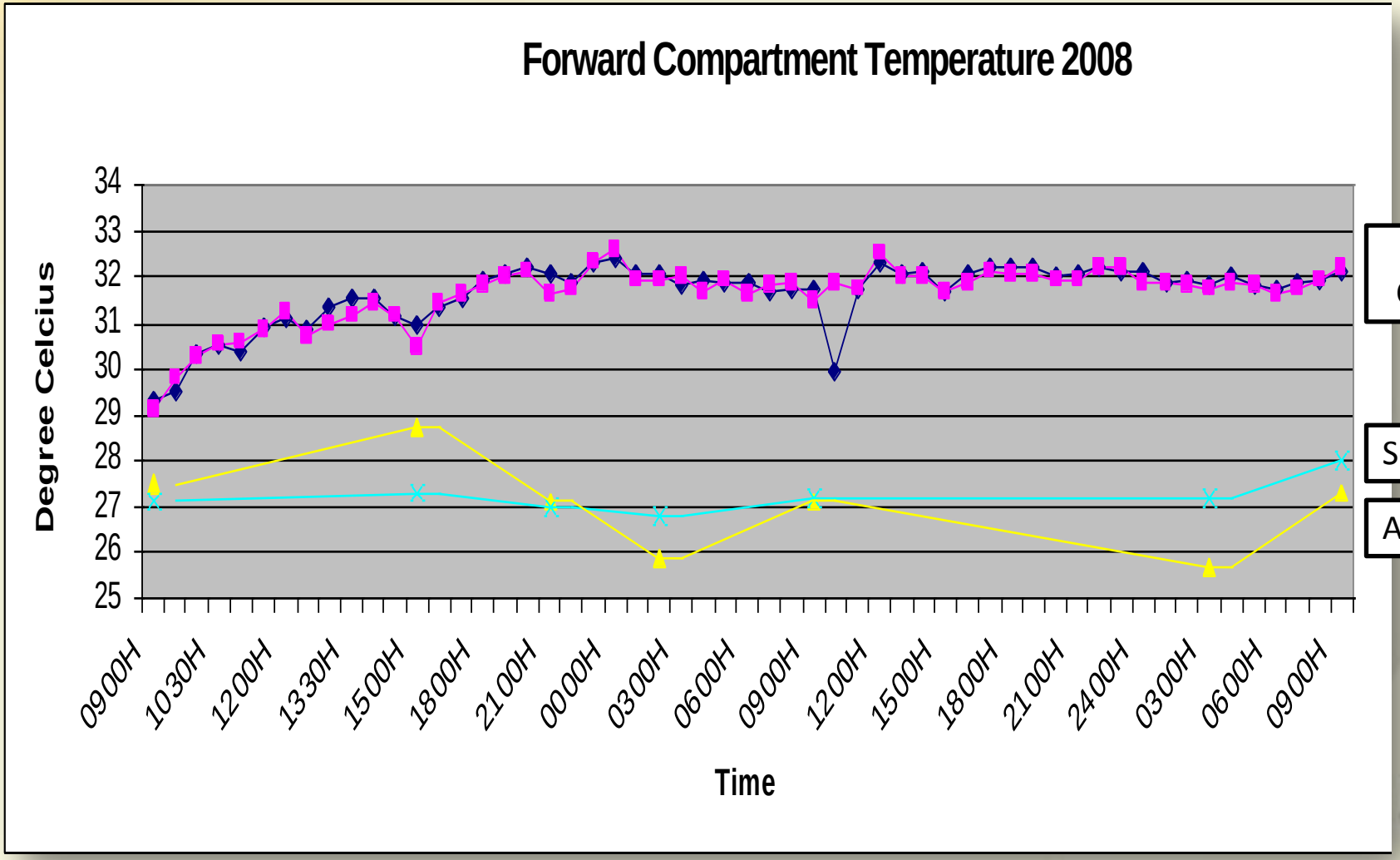
2004 DISSUB Trial
Significant Observations

- All complained of a lack of appetite
- Majority actually did not feel thirsty although they were mildly dehydrated
- Psychological screening done during and after the trial indicated that the majority were able to endure the trial as there was a definite end-point
  - Problems may arise in an actual DISSUB situation as survivors may have to remain in the DISSUB for days, especially when awaiting rescue

2008 DISSUB Trial

- 48hrs in harbour with submarine under shelter – excluded effects of radiant heat
- Lithium Hydroxide curtains from ExtendAir® used
- Crew kept in forward compartment with no power or ventilation
- Adopted DISSUB procedures
  - Emergency rations consumed
  - Each pax required to drink >2L water per day

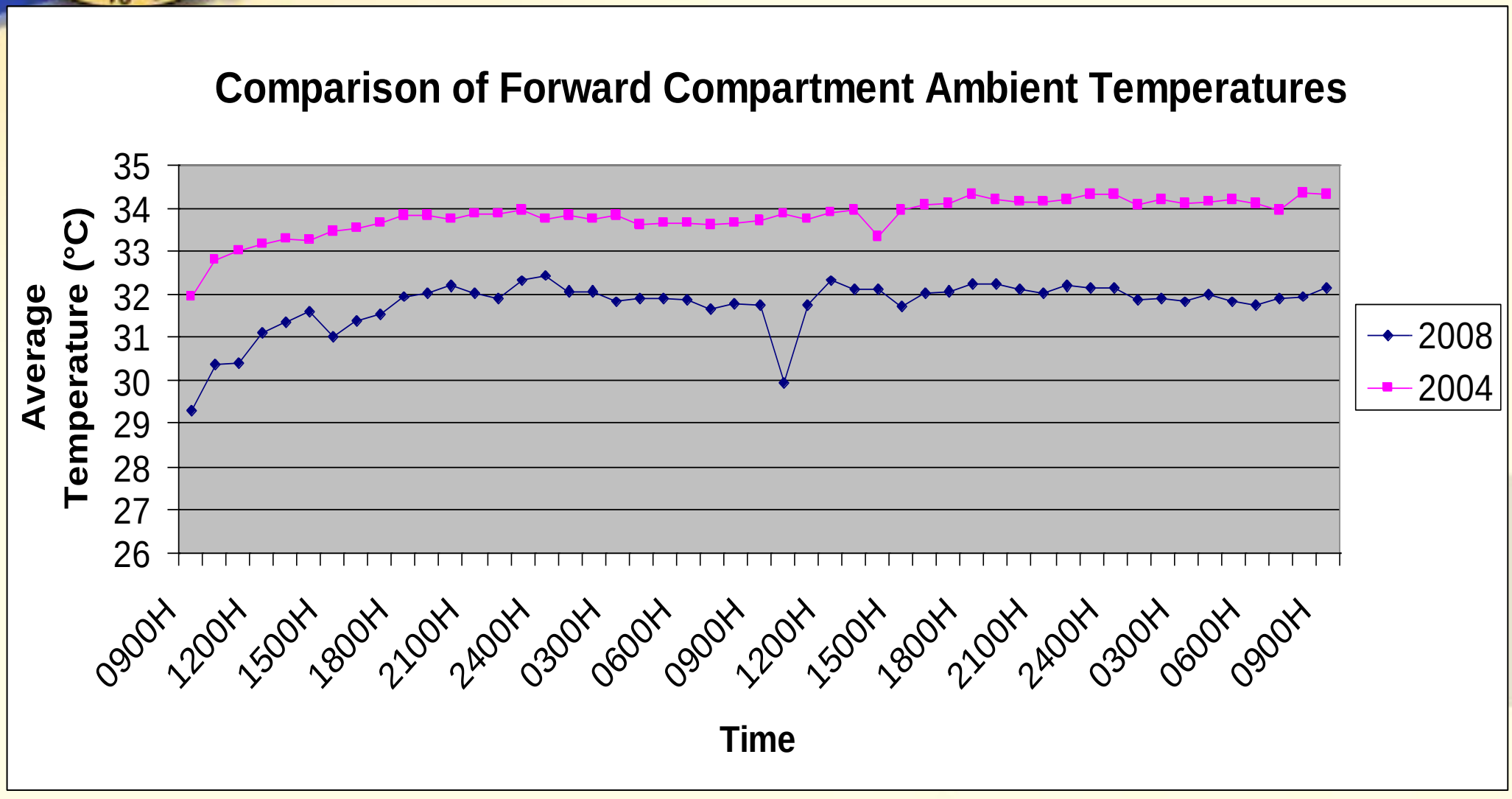
2008 DISSUB Trial Results



2008 DISSUB Trial Results

- Average forward compartment temperature at steady state was 31.8^{o}C (from 29.3^{o}C to 32.4^{o}C).
- Temperature rose gradually by about 1^{o}C very 4 hours from baseline of 29^{o}C, before reaching steady state of about 32.0^{o}C.
- Average ambient temperature was 27.0^{o}C and seawater was 27.2^{o}C.

2008 DISSUB Trial Results



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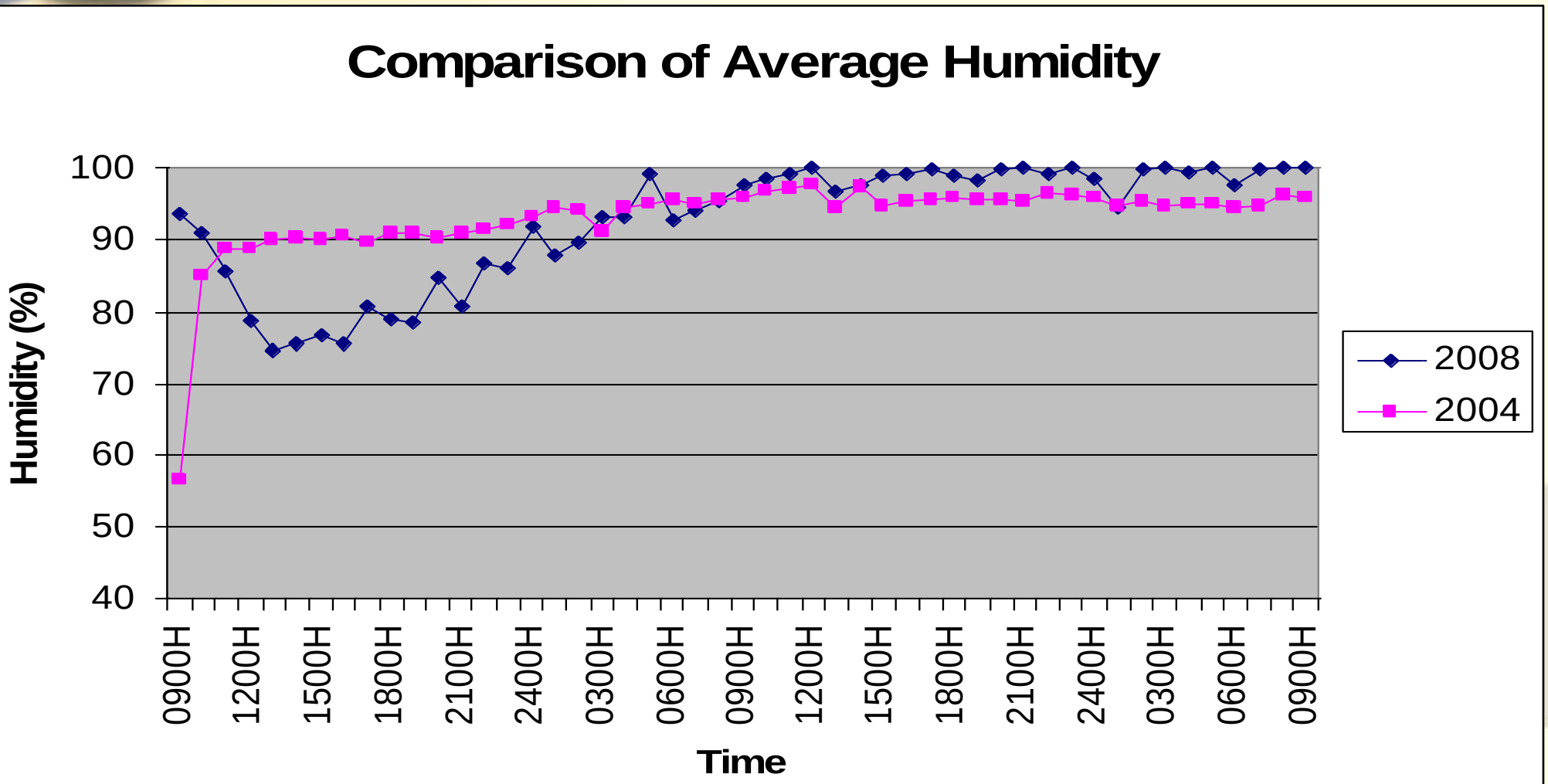

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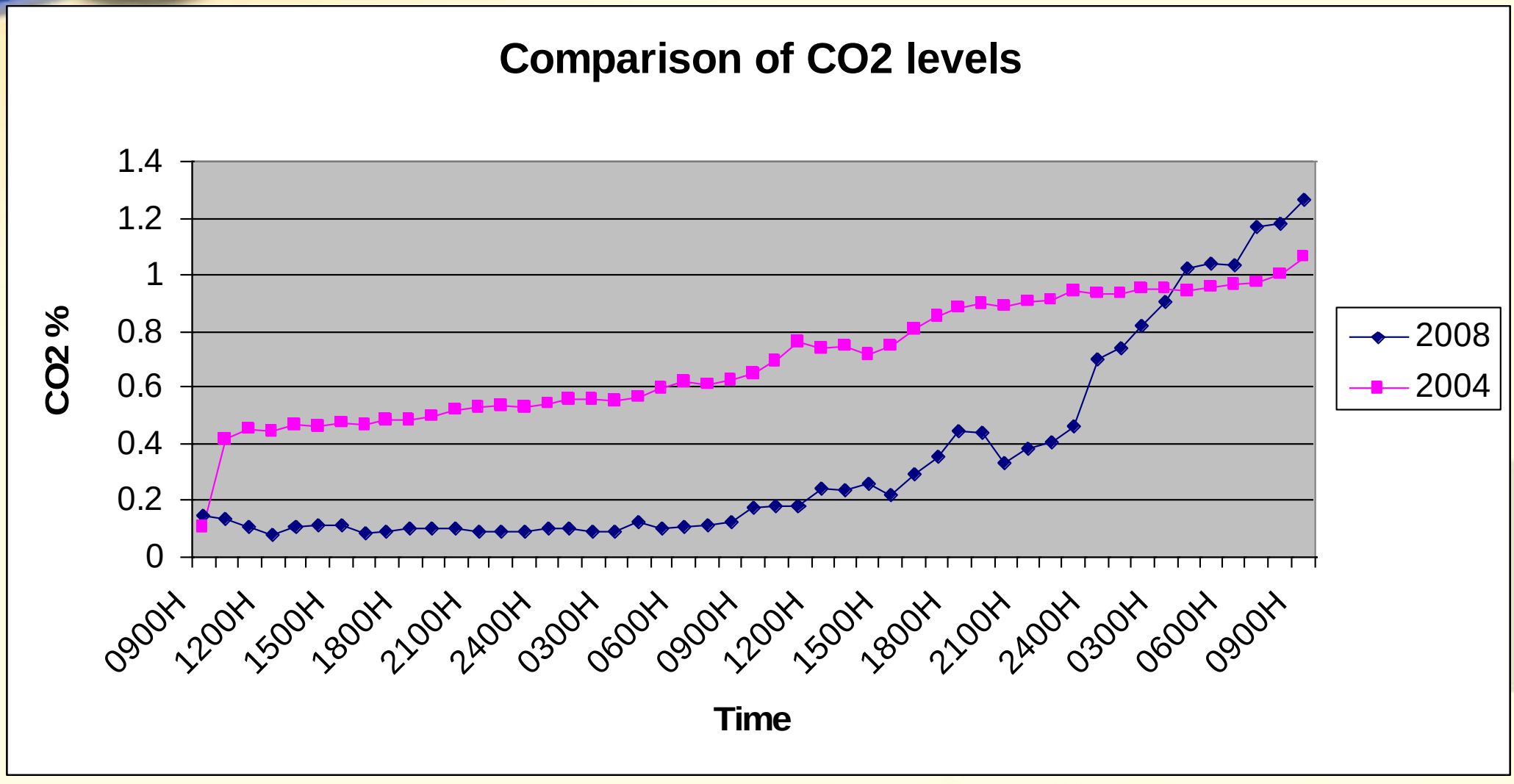
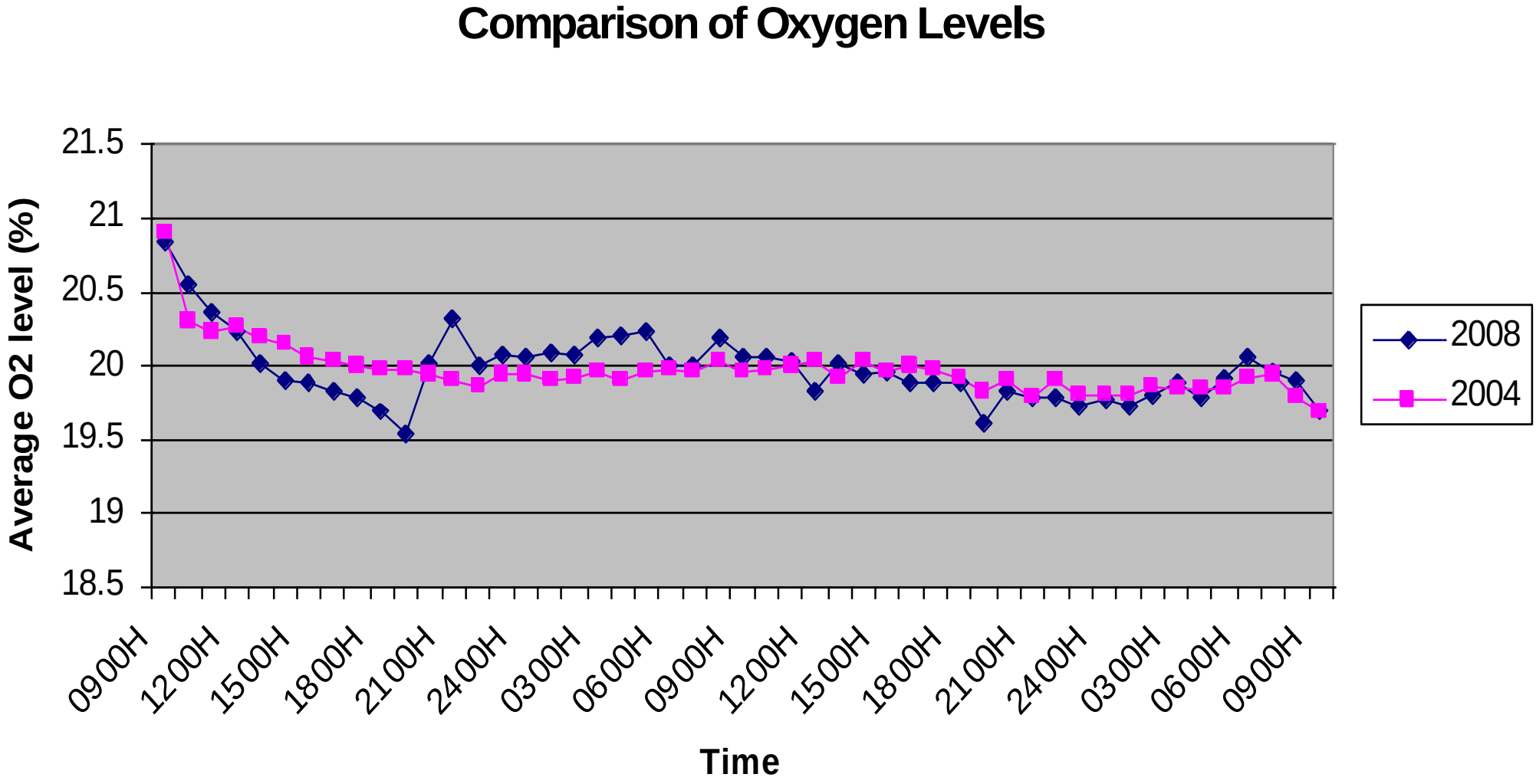


2008 DISSUB Trial Results

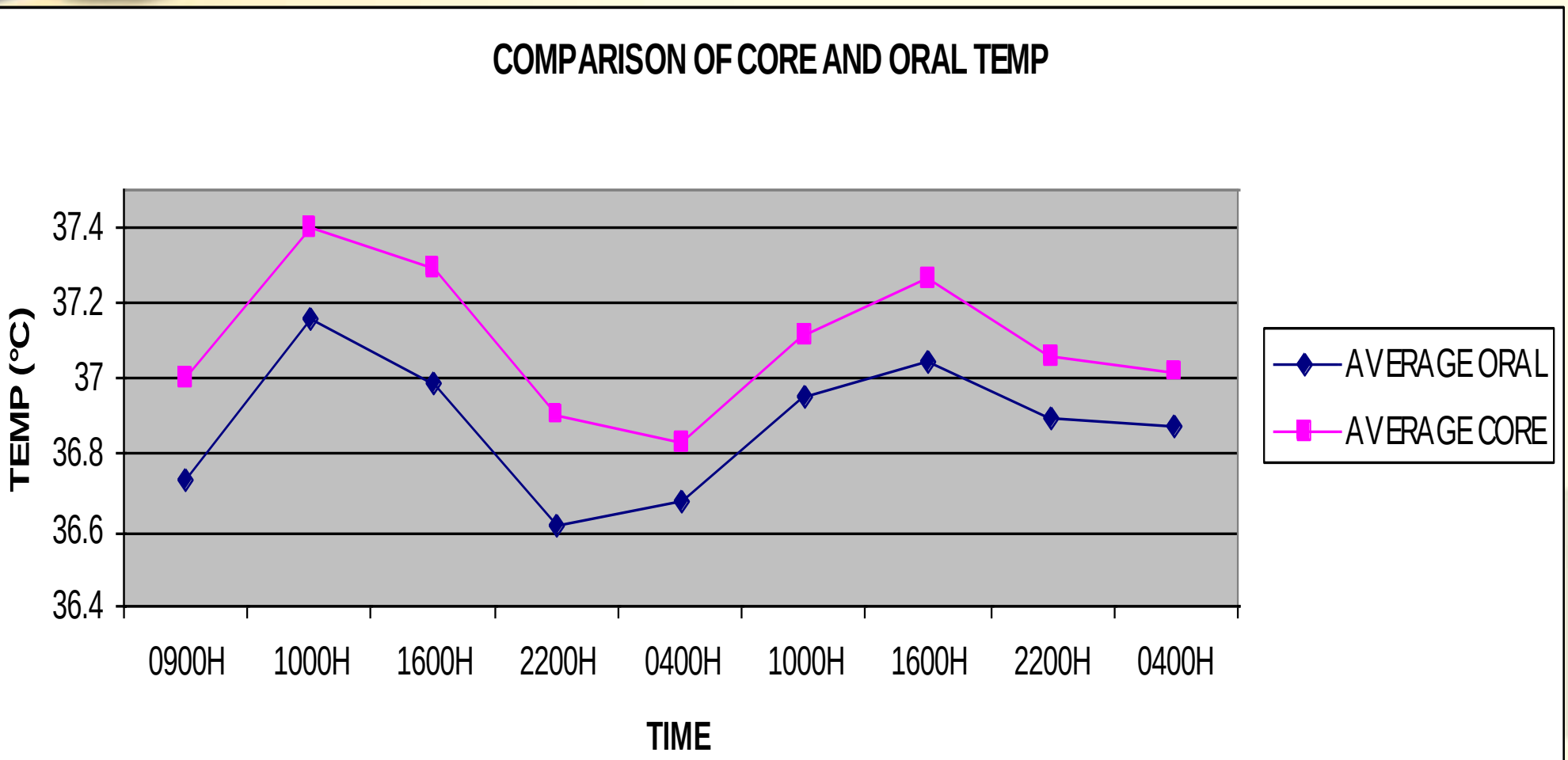


•Oxygen maintained at ~ 20% with O2 released periodically from storage tanks to maintain ambient levels

2008 DISSUB Trial Results

- CO_2 level kept well below safety level of 2%; max level at end of 48hrs was 1.28%
- CO_2 was maintained at 0.1 to 0.2 % for 24 hours before steadily rising to 1.28%
- No significant difference in CO_2 measurements at the 5 separate sampling points
- 1.5kg of Lithium Hydroxide (in the form of ExtendAir curtains) per man per day adequate to maintain CO2 levels < 1.5%

2008 DISSUB Trial Results – Physiological parameters

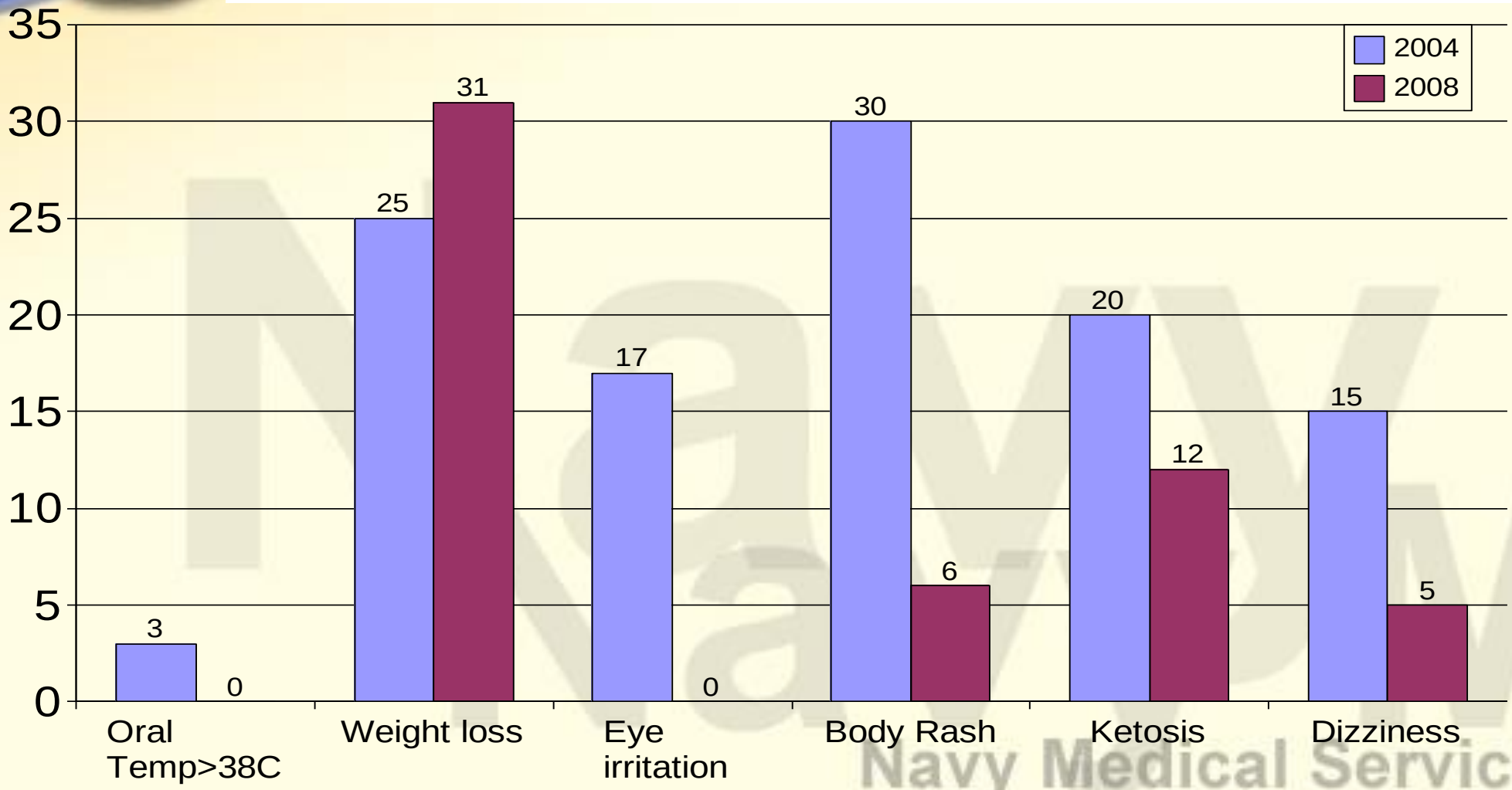


Comparison of physiological data

	2004	2008
Maximum Oral Temp (DegC)	38.5	37.8
Pulse Rate(% increase)	25.7	18
Average Weight loss (Kg)	2.0	2.2
Average Urine Output for 48H (L)	2.9	4.2
Water intake for 48H (L)	7.4	7.14

Comparison of physiological data

Symptoms experienced by DISSUB crew



2008 DISSUB Trial
Significant Observations

- Only 20% of crew developed generalised rashes (compared to 90% when using Sodalime)
- None had eye irritation (compared to 50% when using Sodalime in 2004)
- No complaints of persistent headaches
- Approximately half the crew were ketotic (sign of starvation) – similar to 2004 trial
- Similar lack of appetite and desire to drink despite mild dehydration

2008 DISSUB Trial
Significant Observations

- Crew who drank water equivalent to approximately 5% of their body weight maintained adequate urine output of 0.5ml/kg/hr - ~3.5L per day for 70kg man
  - However, blood investigations done at end of trial showed that all crew members were able to maintain water and electrolyte balance

CONCLUSION

- Heat stress and dehydration shown to be a significant problem for DISSUBs in tropical/ warm water environments
  - Compounded by high humidity (up to 100%)
  - Sufficient water needs to be ingested to prevent dehydration (equivalent to 5% of body weight)
- Heat, high humidity, and exposure to Sodalime granules (even when used with Battelle curtains) associated with a number of health concerns

CONCLUSION

- Use of Lithium Hydroxide curtains in a DISSUB situation associated with the following:
  - Favourable CO_2 absorption profile
  - Avoids exposure to CO_2 absorbent granules – may minimise health effects associated with contact with CO_2 absorbents (dust)
  - Less CO_2 absorbent required to maintain CO_2 levels < 1.5%
  - More exothermic than Sodalime – may potentially raise ambient temperatures more than Sodalime

Comparison data of two CO_2 scrubbing technology

Properties	ExtendAir LiOH curtains	Battelle curtains with sodalime granules
Health effects	Less skin rashes with no eye irritation / airway problems.	Skin rashes and eye irritation observed.
Weight of LiOH / Sodalime required to keep CO2 < 1.5% for 48 hours	98.2 kg	161.7 kg
Stowage space required for storage of CO2 absorbents	0.2418 m3 (new packaging x 31)	0.1935 m3 (20L plastic containers x 8) (Excluding Battelle curtains)
CO2 levels	CO2 kept at 0.1-0.2% for 24 hours	CO2 kept at 0.4% for 24 hours
Rate of CO2 increase	Steep increase	Gradual increase
Heat generation	LiOH raises compartment ambient temperature by 1ºC more than Sodalime.	
Ease of use	Easily hung up. No dusting. Saves time.	Requires 5 minutes to prep each curtain. Creates dusting.

ExtendAir® LiOH Curtains for DISSUB CO_2 Control

Alternate Packaging Solution

OM-0610K, 3.2 kg minimum LiOH

ExtendAir®
CO_2 ABSORBENT
LIFE SUPPORT CARTRIDGES


Thank You