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# Effect of Depth on Diver Thermal Protection in Cold and Warm Water


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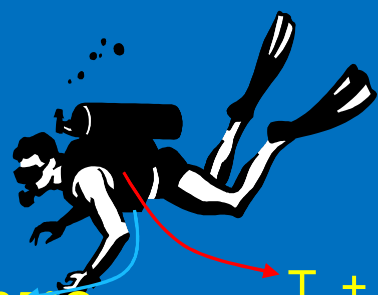
**UHMS Annual Meeting**

**Project Goals: To minimize the impact of thermal issues in dive planning and provide diver thermal protection and comfort**

**Purpose: To engineer, build and test a Diver Thermal Protection System (DTPS) to meet the goals**

5°C $T_w$ 40°C

Depth



>25°C $T_s$ <35°C

$T_c \pm 1$°C

350'

**Rest – Exercise**
**6 hour mission**
**Come – home capability**

**Automatic and programmable control**
**High reliability (simple systems, few moving parts and redundancy)**
**Ease of maintenance (no consumables, constant or rechargeable power supply)**

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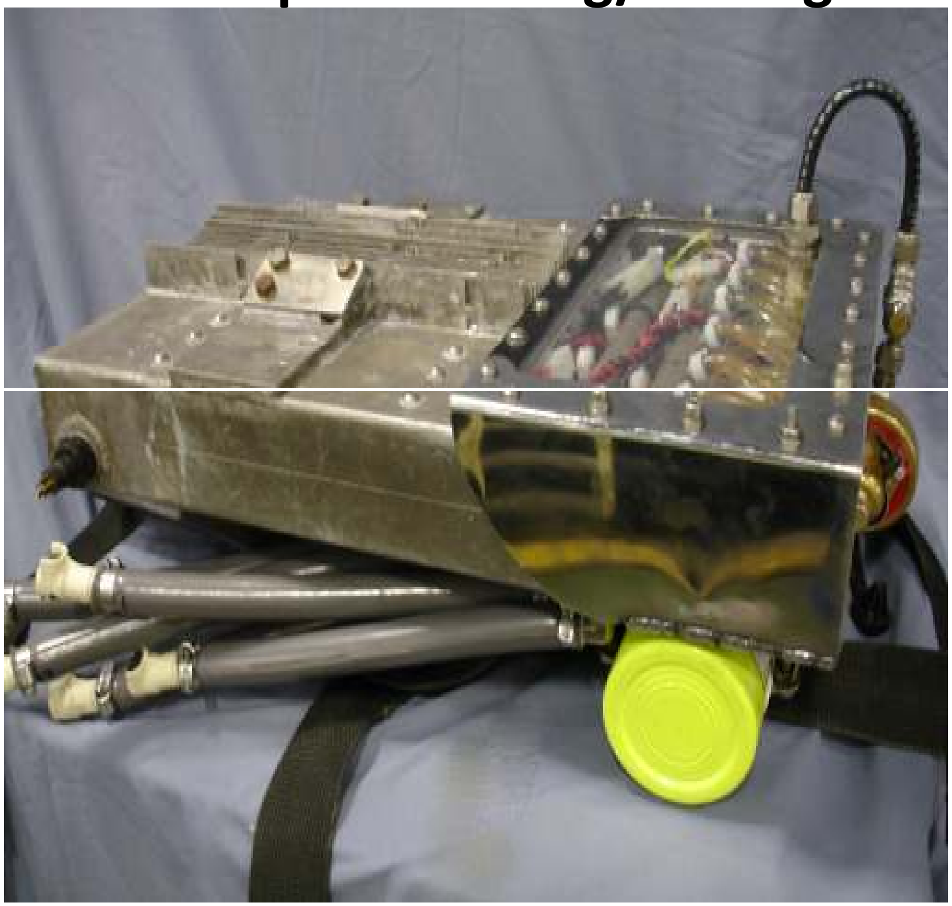
# Diver Thermal Protection System DTPS

- One system heats and cools (tested from 5ºC to 40ºC) in a wet suit
- Provides thermal protection and comfort (fingers/toes ≥ 25ºC; core = 37ºC)
- Works at rest or exercise
- Provides heat to six independent zones of the body
- Can provide over 800W power
- Can be powered by any DC electric source including portable batteries
- Can be used with any insulation (wet or dry suits)
- Automatically controlled
- Programmable (dive profiles and thermal profile)
- Has no consumables and can run endlessly
- Pumps are the only movable part
- Does not need regular maintenance (5 years, 3/week without failure)
- Can be free swum or carried by a vehicle
- Can serve single or multiple divers, divers can disconnect and reconnect

# DTPS Main Components

**Backpack heating/cooling unit**

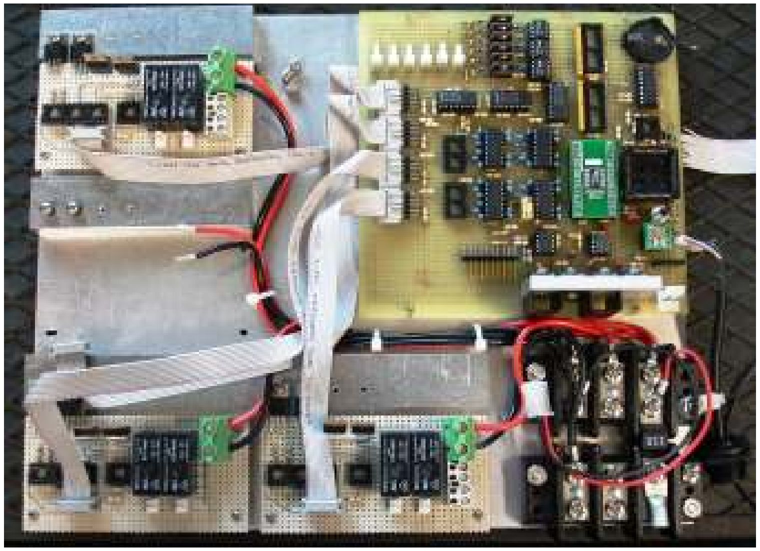


**Six zone tube suit**

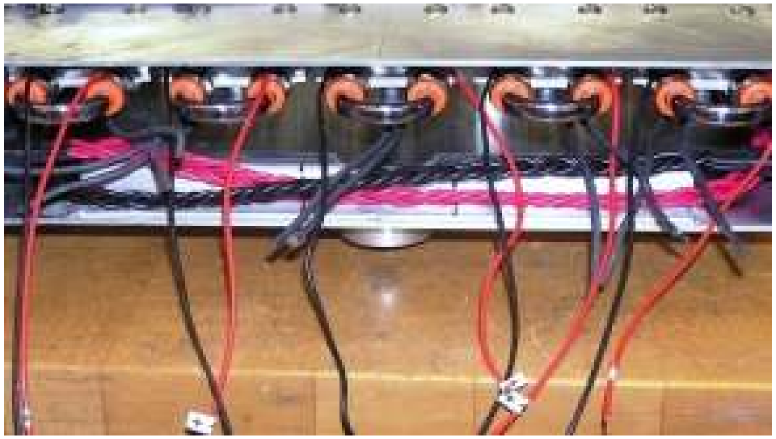
# Backpack components

Gear Pump (B&D Pumps, Inc., UGP-2000P (24VDC)) Outlet and Inlet manifolds


Thermoelectric Assembly (TEC) (Supercool US, Inc., DL-290-24)

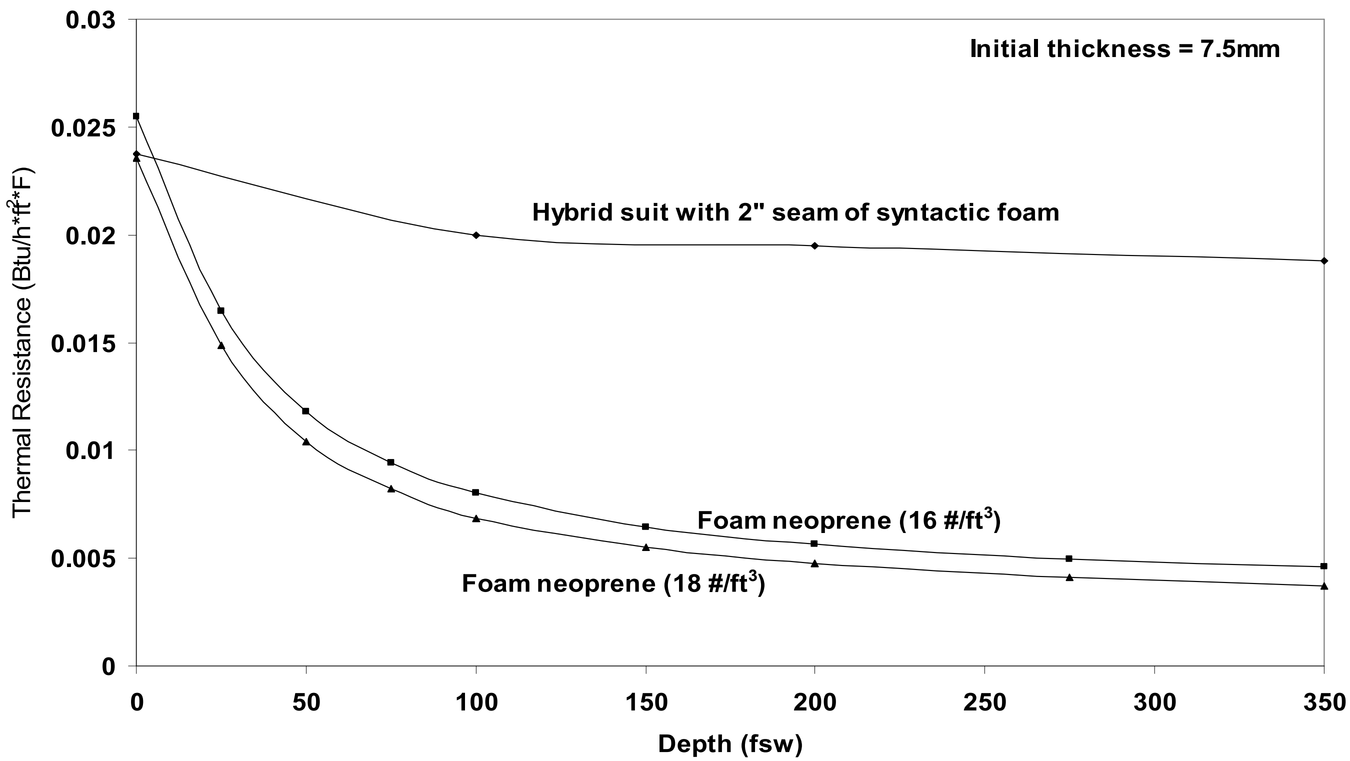


Programmable Controller and data logger



6 TEC units mounted in backpack

# Effect of Depth on Thermal Resistance




- **Thermal resistance decrease exponentially with depth, as air cells are compressed**
- **Thermal resistance is inversely proportional to thickness of wet suit material**
- **Insulation compression increases active heating/cooling**

# Effects of Depth on Core Temperature

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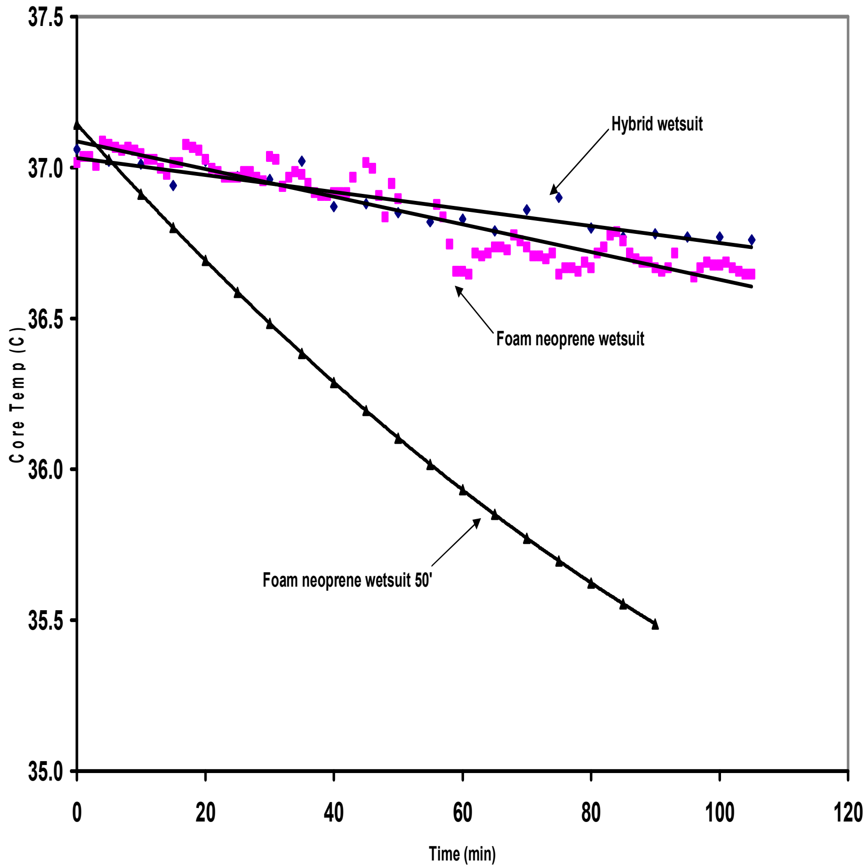
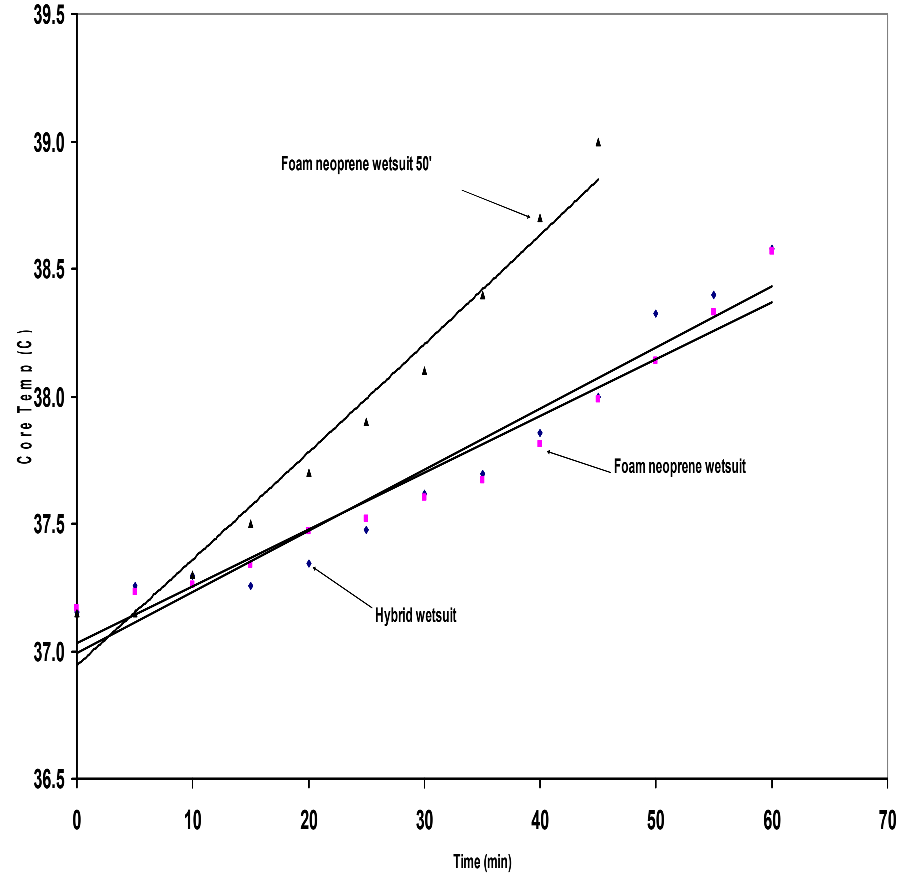
10$^{o}$C Ambient water



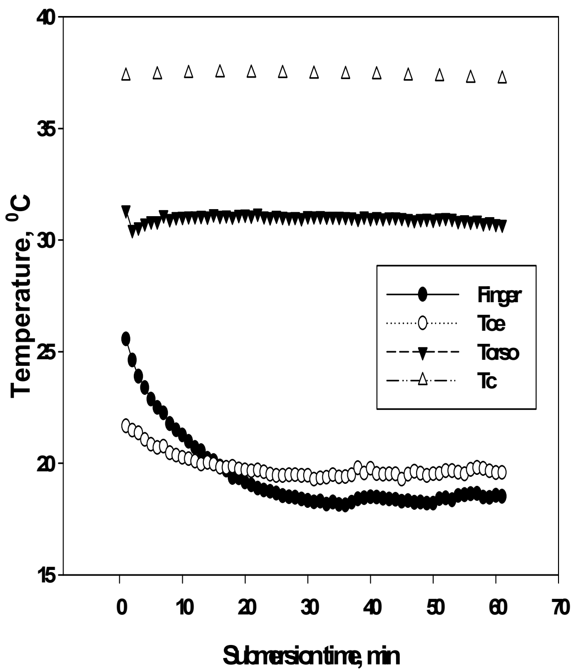

40$^{o}$C Ambient water



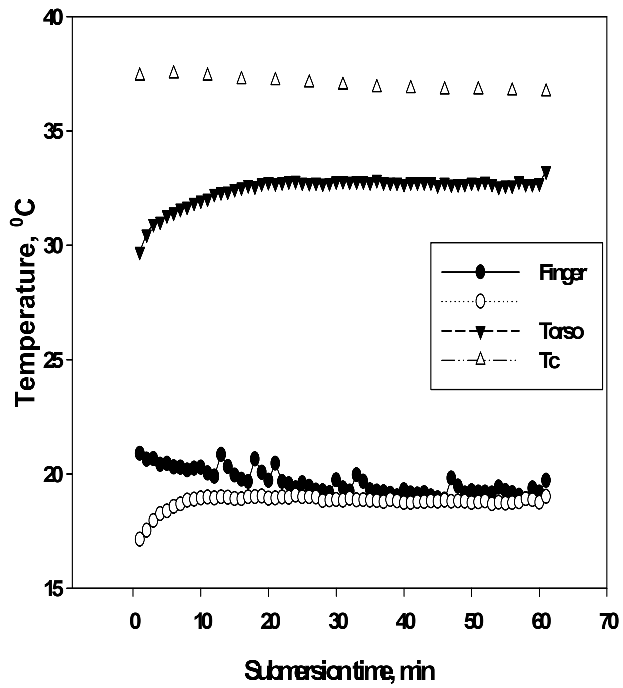

**Divers' unprotected core temperatures dropped or increased at depth due to loss of Insulation of the wet suit as a result of its compression**

# Tcore and Tskin at Depth 10$^{o}$C

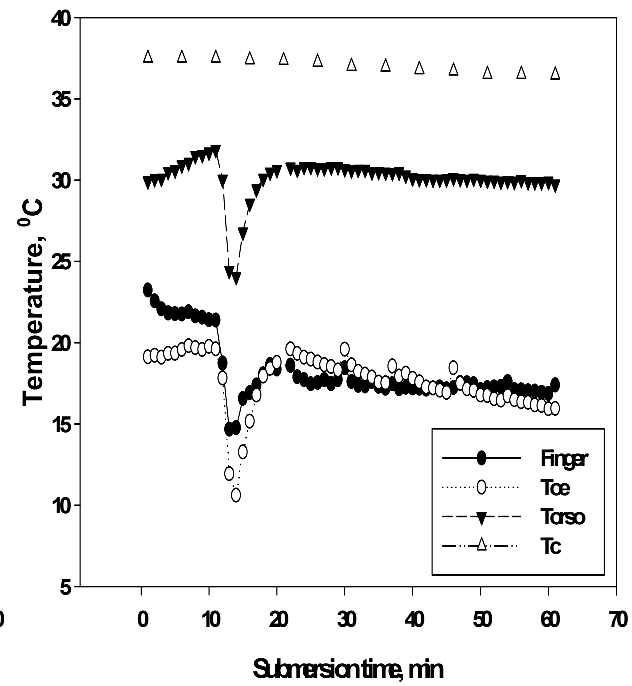
10$^{0}$C at 4 fsw




10$^{0}$C at 55 fsw



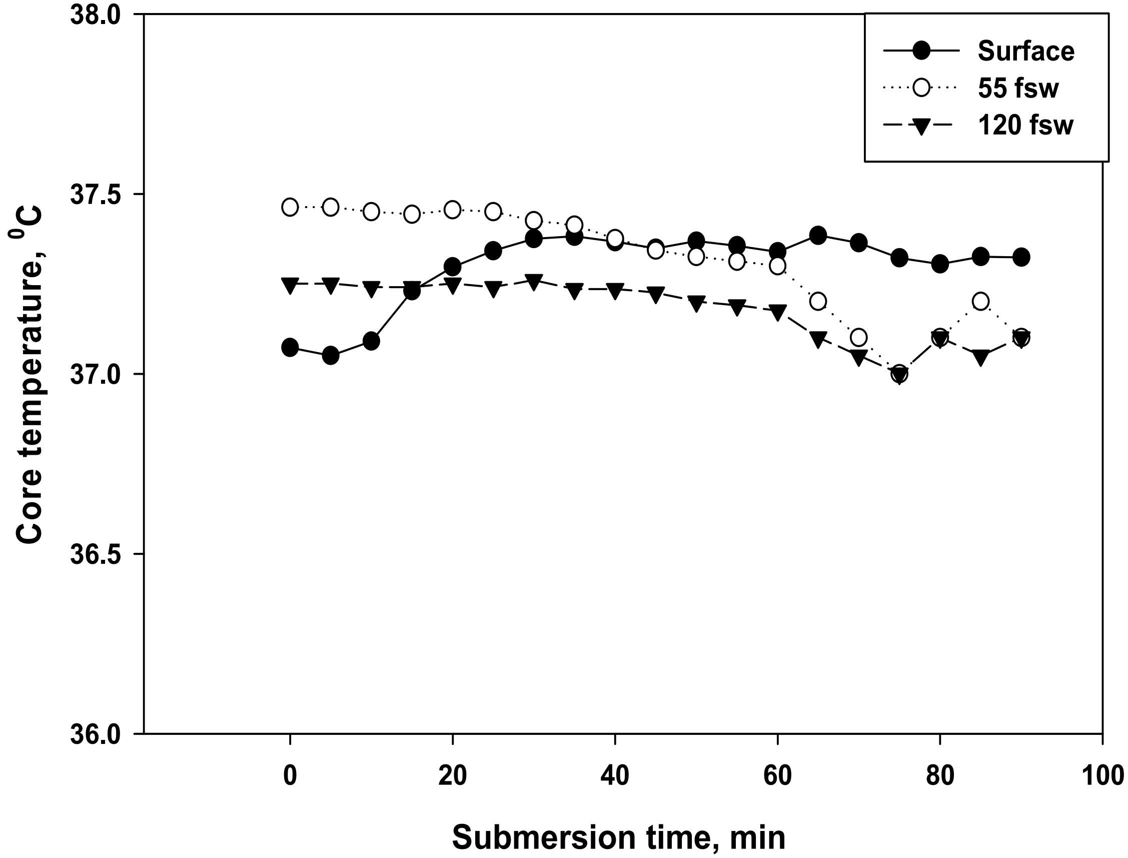

10$^{0}$C at 120 fsw




→ In cold water, core and digit temperatues are critical. Diver core and skin temperatures were maintained by the DTPS within Navy recommended levels at all depths.

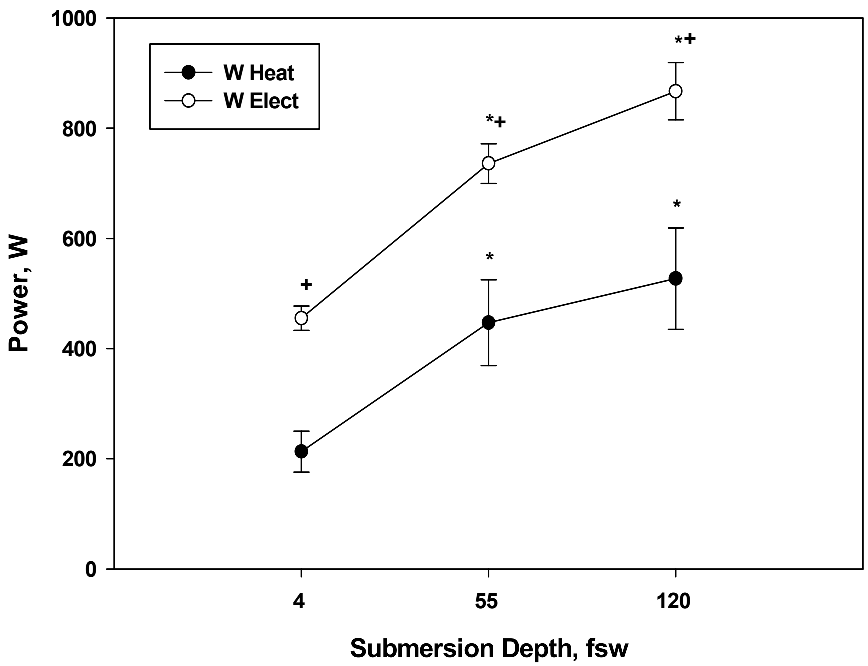
→ In addition, the divers did not report thermal Discomfort, and completed the exercise.

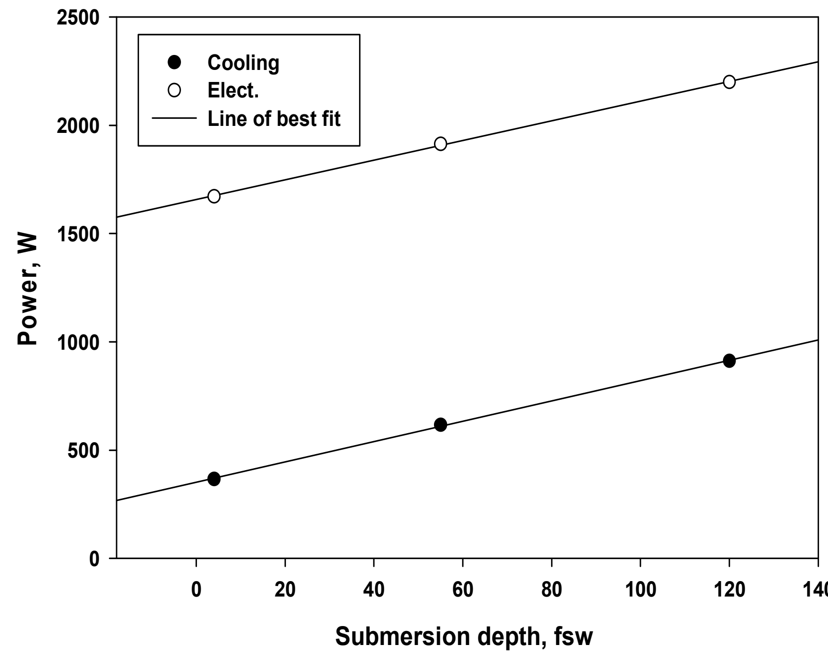
# Tcore at Depth 39$^{o}$C




- → **In warm water, core temperature is the critical body temperature.**
- → **The DTPS maintained core temperature within the Navy recommended level.**
- → **The divers' did not report thermal discomfort and completed the exercise**

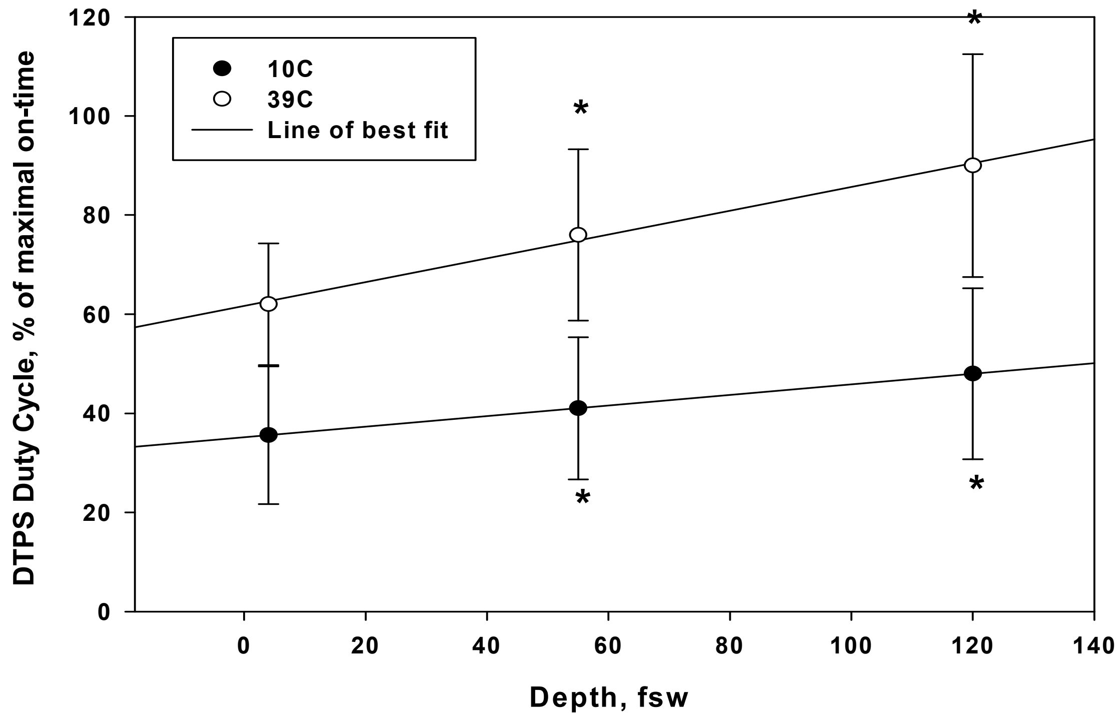
# Effect of Depth on heating-cooling and electrical requirements




- Divers' core and skin temperatures were maintained within limits
- Heating requirement in 10$^{o}$C water increased as a function of depth 3 fold at 120 fsw
- Cooling requirement in 39 $^{o}$C water increased 2-3 fold at 120 fsw
- Electrical power increased proportionally with heating requirement

# Effect of Depth on Duty Cycle




- **Divers' core and skin temperatures were maintained within limits**
- **Duty cycle remained less than 100% under all conditions, with a 20% reserve**

# Conclusion

- **The DTPS maintained wet suited divers' core and skin temperatures within established limits down to a depth of 120 fsw in 10$^{o}$C and 39 $^{o}$C ambient water.**

- **The duty cycle of the DTPS did not exceed 50% in 10$^{o}$C ambient water.**

- **The duty cycle of the DTPS approached 100% in 39$^{o}$C ambient water.**

- **The power requirement increased with depth approaching 600W in 10$^{o}$C at 120 fsw.**

- **The power requirement increased with depth approaching 1000W in 39$^{o}$C at 120 fsw.**