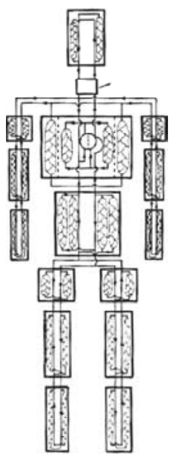
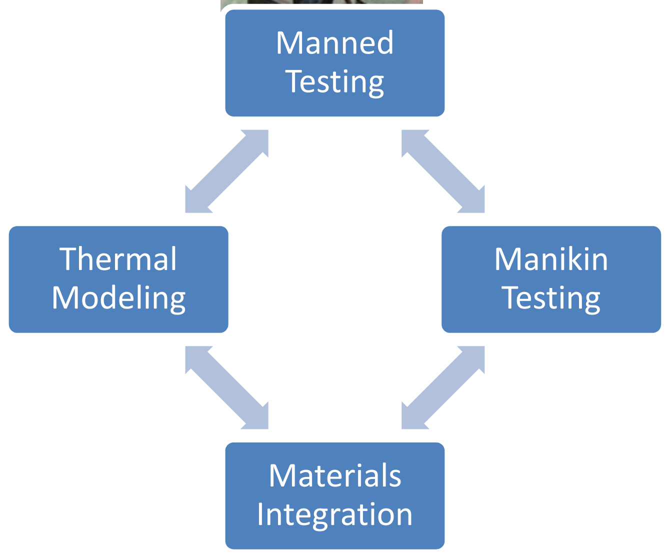
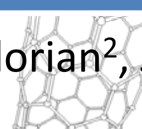
INTEGRATION OF ACTIVE AND PASSIVE THERMAL PROTECTION FOR COLD WATER DIVING







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ONR ONGOING
2011 Undersea Medicine Review

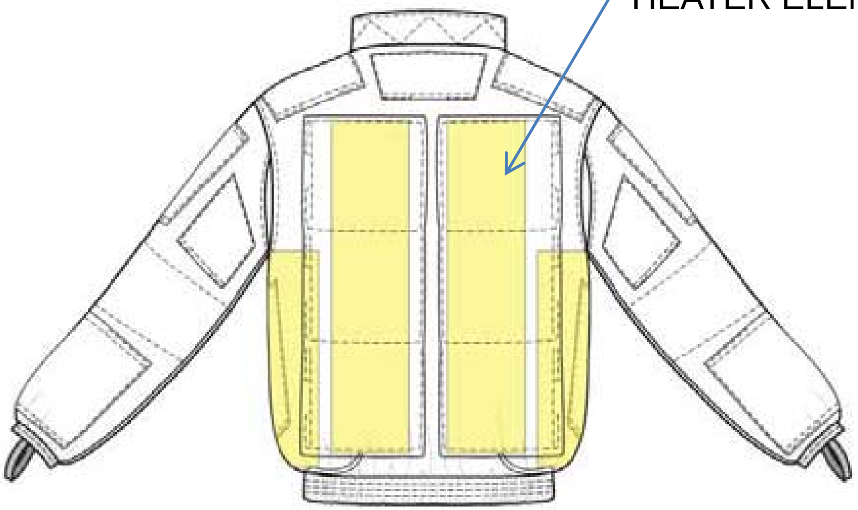
OVER THE BEACH (OTB) OPERATIONS

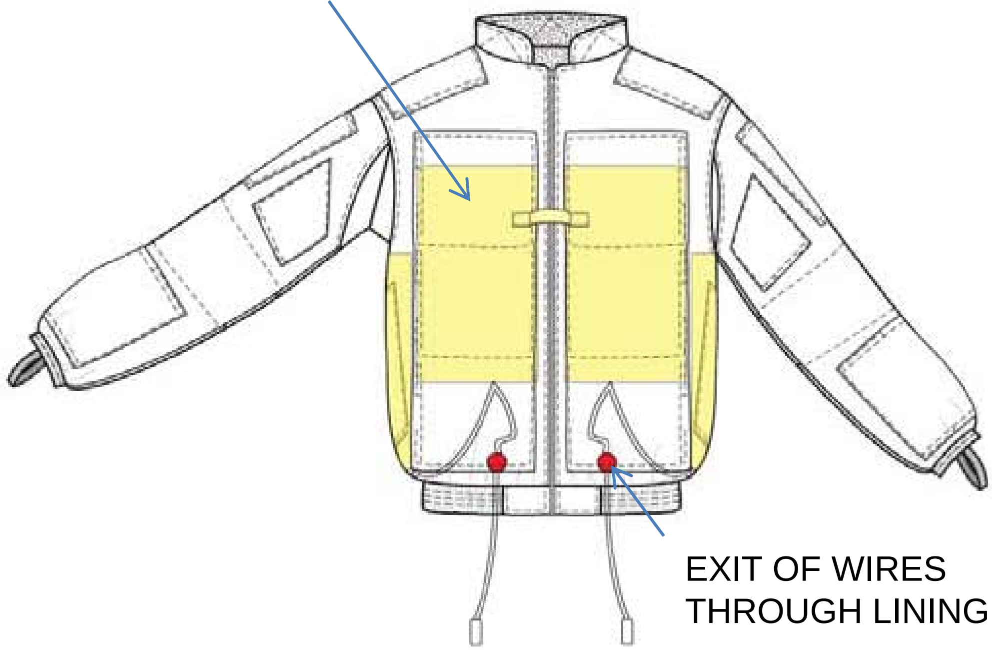
- Navy SEALs are required to stow and pack out all diving gear during OTB operations
- Although current thermal garments have been found to provide sufficient protection for long duration, cold water SDV missions, they are excessively bulky for OTB operations
- An alternative, less bulky approach is to integrate active heating elements within thinner, lower insulating garments.

Constant vs Variable Protection

- Current heating estimates are based on a weighted average CLO values and uniform heating distribution.
- Are uniform regional insulation values necessary?
  - Potential to reduce bulk by reducing unnecessary localized insulation thickness
- What localized heating regions give best physiological bang for the buck?
  - Torso heating: http://soldiersystems.net/2009/05/10/torso-heating-for-dexterity-in-the-cold-system/
  - Extremity heating: Grahn DA, Cao VH, and Heller HC, ***Heat extraction through the palm of one hand improves aerobic exercise endurance in a hot environment***, J Appl Physiol, May 5, 2005.
  - Kidney heating: Personal communication with Simon Morris, BARE Sports, Inc

Ongoing Near Term Solution





HEATED CRYE 4A AEROGEL SUIT PROTOTYPES
80 watts distributed on torso

LONG TERM SOLUTION

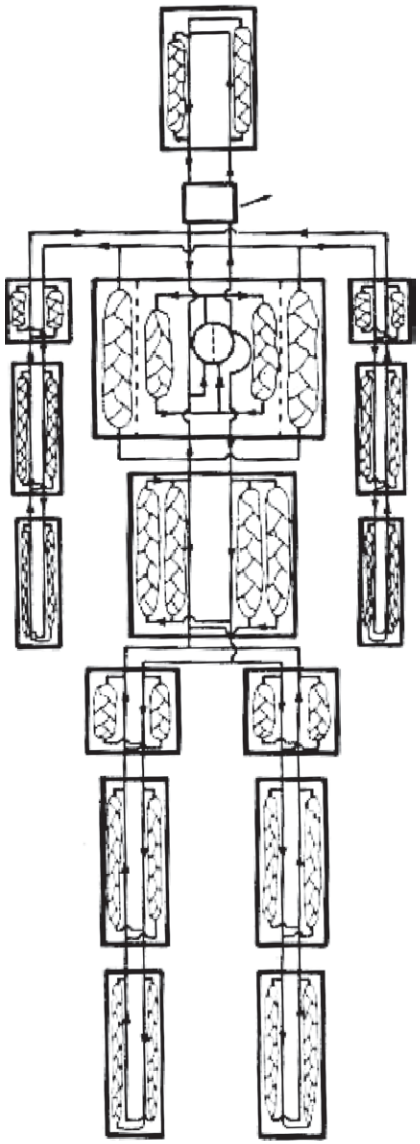
•Optimize localized insulation thicknesses

Locate active heating regions to maximize physiological impact

Constraints on Establishing Actively Heated Garment Design

- Trial and error approach to garment design is inefficient
  - Limited resources to construct optional prototype garments
- Limited manned testing iterations available
- Limited power available
  - Competes with SDV propulsion
  - Electrical shock hazards
- Streamline design process using thermophysiological modeling

NON-STEADY-STATE THERMOPHYSIOLOGICAL MODELING



WISSLER MODEL

- 21-element model
  - head is represented by two elements
  - trunk is represented by three elements
  - each arm and leg is represented by four elements.
- six homogeneous cylindrical elements which are connected by circulating blood
- Six additional external cylindrical elements to simulate clothing
- thermal energy balance for blood make allowances for the effect of countercurrent heat transfer between arterial and venous blood
- skin blood flow, sweating, and shivering regulated by central temperature and mean skin temperature

•Wissler, E.H.,"*A Mathematical Model of the Human Thermal System*", Bulletin of Mathematical Biophysics, 62, p.66-78, 1964

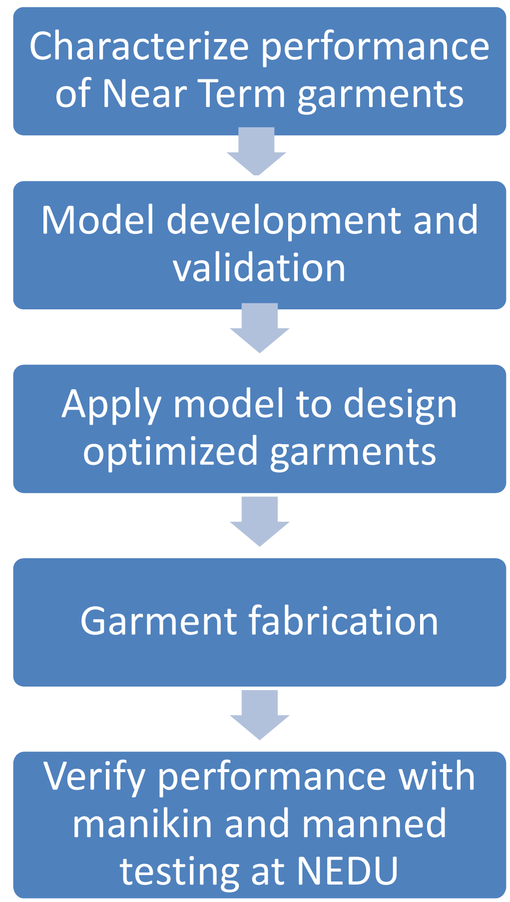
• Wissler, E. H. (1985). Mathematical simulation of human thermal behavior using whole-body models. New York, Plenum Press

LONG RANGE SOLUTION

APPROACH

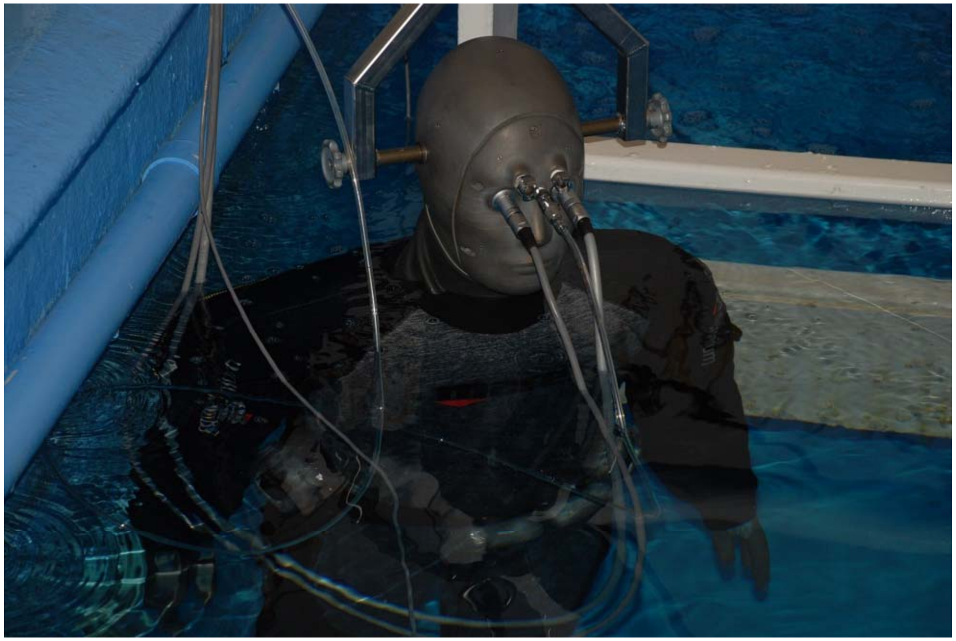
Maximize thermal protection by judiciously locating insulation and heating while minimizing suit bulk

- Characterize thermal performance of Near Term garments using manikin testing, manned testing, and physiological modeling (surface and immersion)
- Develop and validate physiological model using NEDU manned testing data
- Apply model to determine the quantity and optimal distribution of heating and insulation to most effectively protect the diver (“what if” investigations)
- Fabricate thermal protection garments based on applying findings from above
- Conduct manikin and manned testing at NEDU to verify effectiveness of active/passive garments



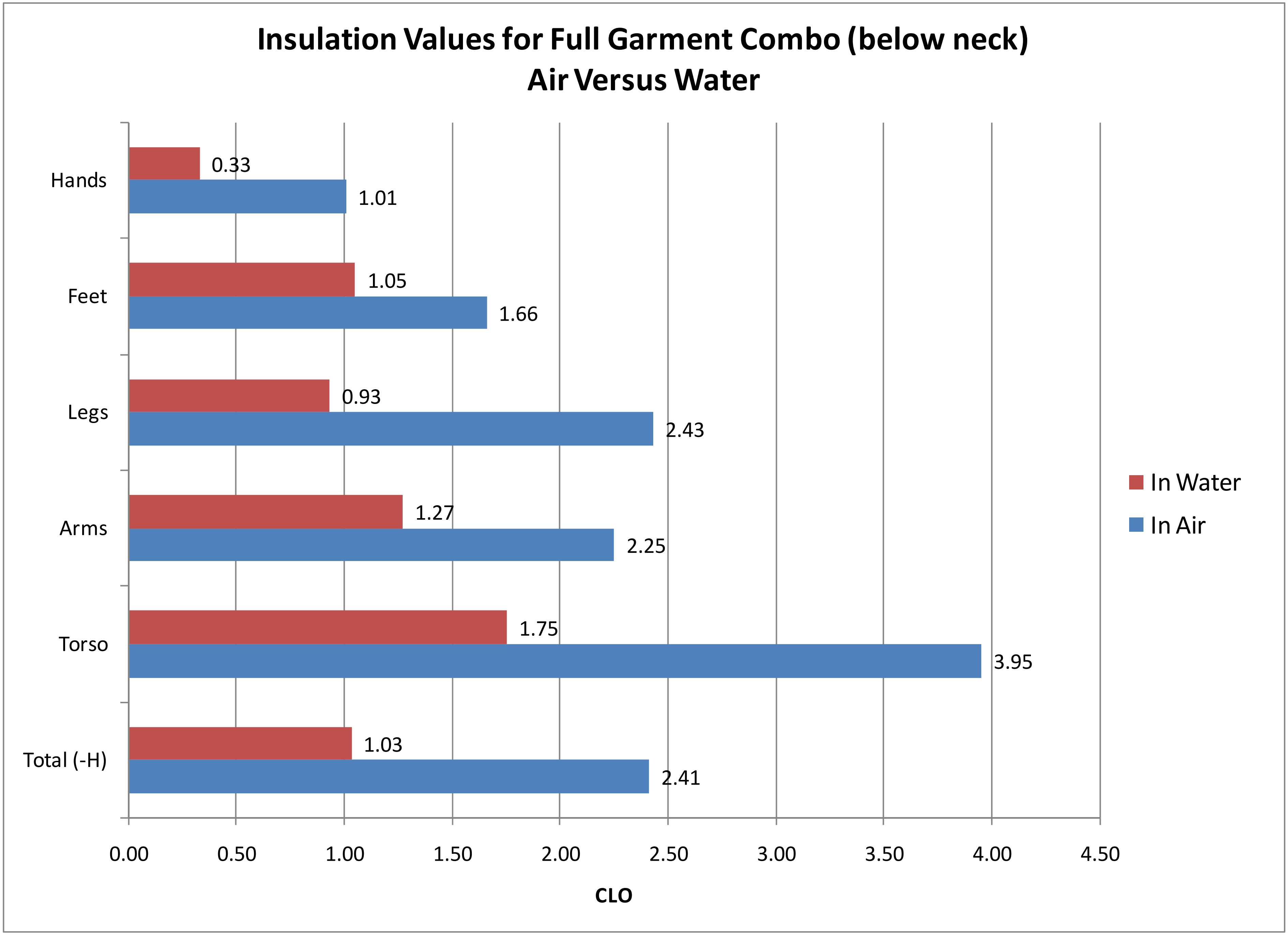
MANIKIN TESTING

Air Testing



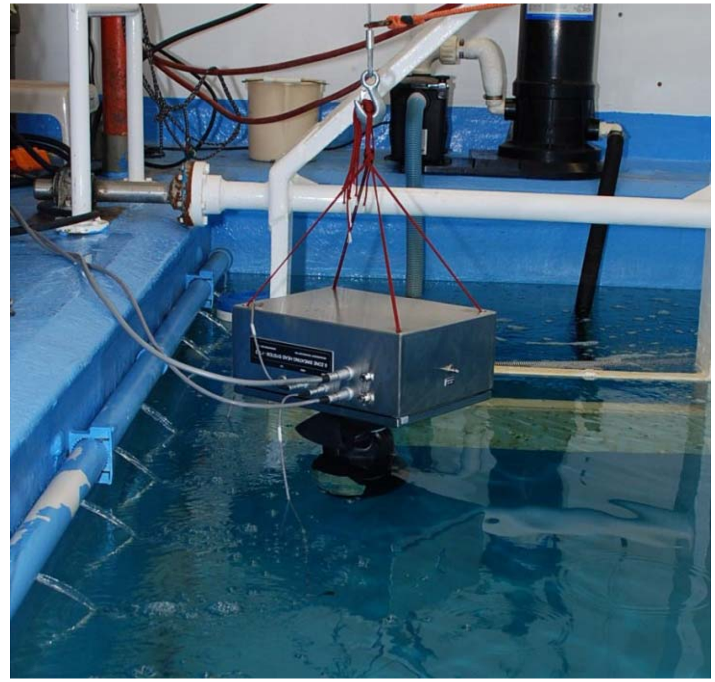
Immersion Testing

Suit Description
- High density tubesuit with gloves and booties
- Wool socks
- 200 weight Thinsulate undergarment with booties
- 2mm compressed foam drysuit
- 2mm dry gloves


Insulation Values for Full Garment Combo (below neck)
Air Versus Water
Hands
0.33
1.01
Feet
1.05
1.66
Legs
0.93
2.43
Arms
1.27
2.25
Torso
1.75
3.95
Total (-H)
1.03
2.41
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
CLO
In Water
In Air

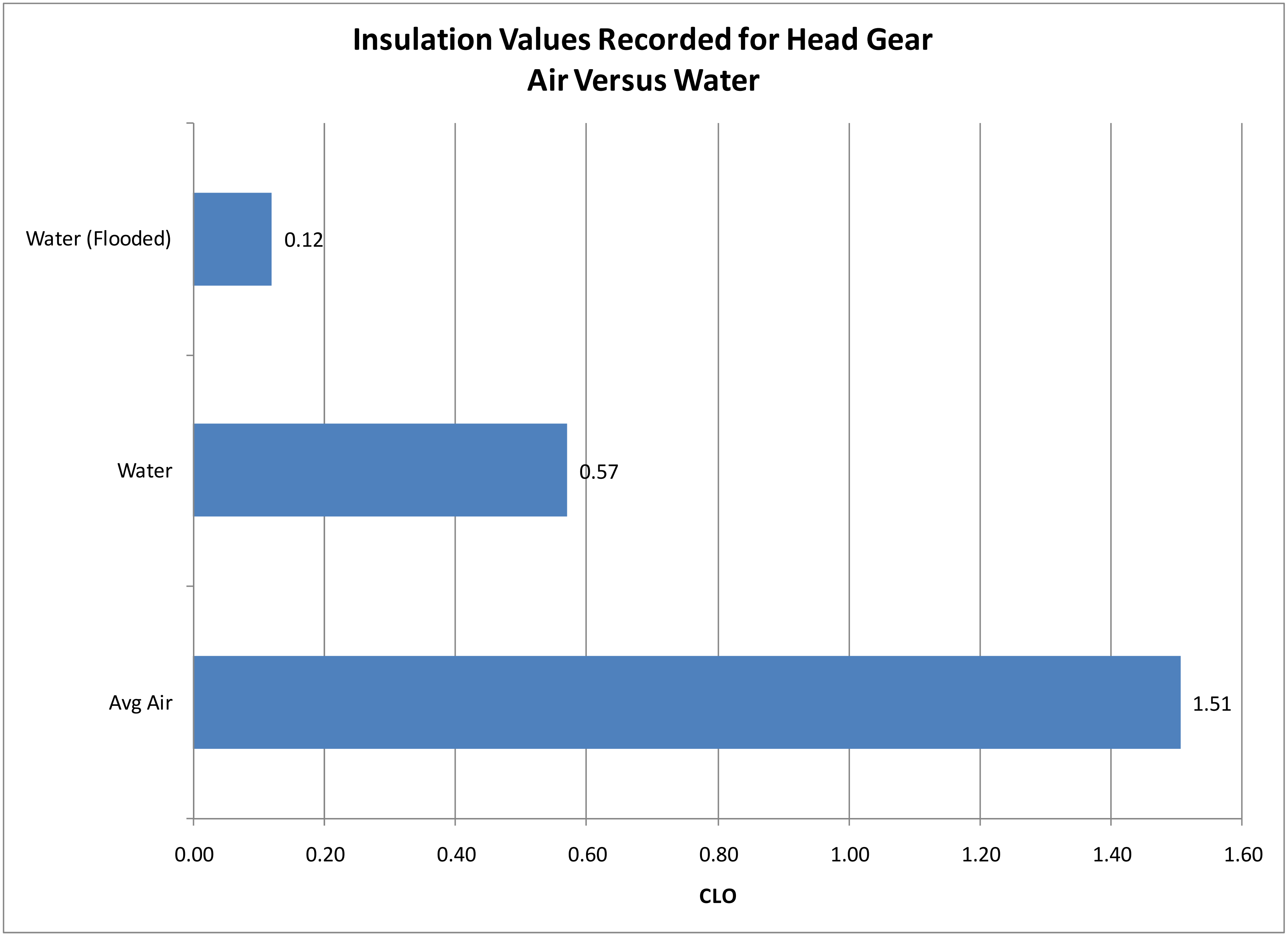
HEAD CALORIMETER TESTING

Air Testing

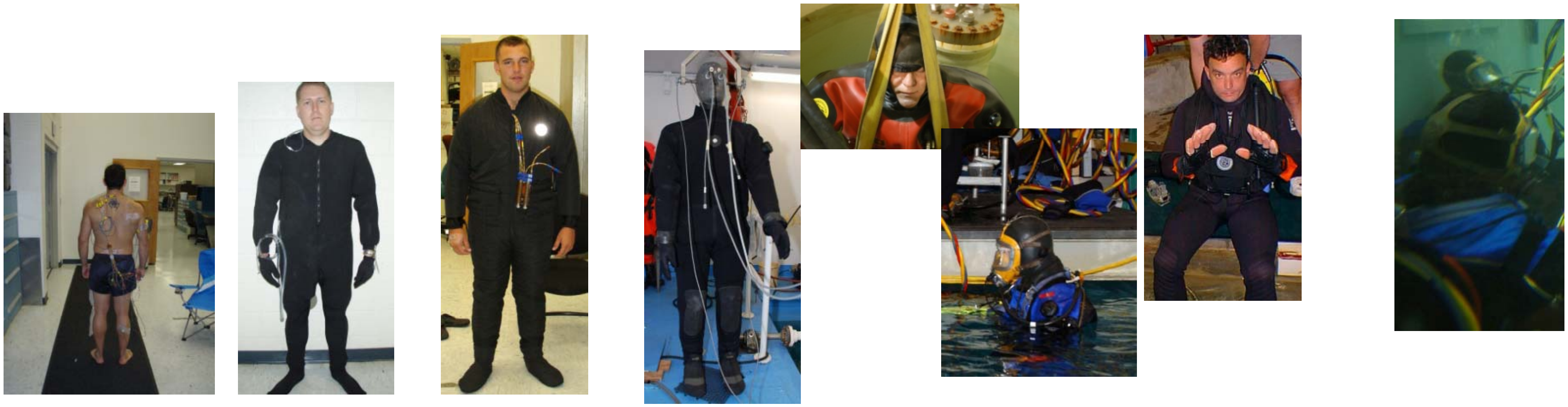


Immersion Testing

Head Gear Description
- High density tubesuit hood
- Thick fleece skull cap
- Thin latex hood


Insulation Values Recorded for Head Gear
Air Versus Water
Water (Flooded)
0.12
Water
0.57
Avg Air
1.51
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
CLO

Dive Scenario Timeline



Event	Baseline/ Instr Attach	Inst Check	Dress Tubesuit	Dress CT200	Baseline 2	Dress Drysuit	Head out Dress Hoods	Dress Full Facemask	Dress Gloves	Final Check	Immerse Test
Duration, min	60	10	10	5	5	10	5	5	5	5	60-180
Start Time	0	60	70	80	85	90	100	105	110	115	120
Met Rate watts		117	150	150	150	150	150	150	150	150	175

What's Next

- Modify and validate thermo-physiological model(s) with NEDU manned testing
  - Wissler
  - ThermoAnalytics
  - ARIEM
- Apply thermo-physiological model to optimize suit configuration
  - Identify localized insulation thickness
  - Identify localized heat levels
- Fabricate low bulk garments using model predictions
- Validate with manikin and pool testing