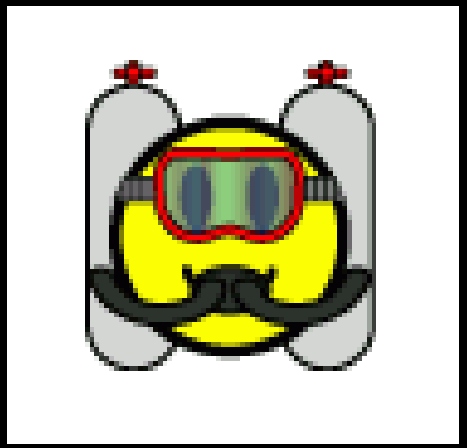
Not Being Cold



Cold

Cold:

Major physiological stressor

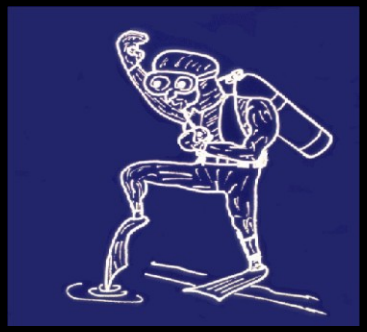
Major obstacle to diving participation

Major obstacle to limited bottom time

This is a course in NOT being cold

LPT

Three Great Truths:



Diving Is Fun

Being Cold Is NOT Fun

Wet & cold divers subsidize those diving warm & dry

Wet-suited divers:
Cold, On deck

Dry-suited divers:
Enjoying third dive

EFFICIENCY AND RELIABILITY

	Wet Suit			Dry Suit		
Temp	Dive Number			Dive Number		
	1st	2nd	3rd	1st	2nd	3rd
70°F	100%	100%	100%	100%	100%	100%
60°F	100%	90%	80%	100%	100%	100%
50°F	80%	70%	50%	100%	100%	100%
40°F	50%	25%	*	100%	85%	75%
32°F	*	*	*	100%	75%	55%

*Not Recommended
Table Based On 30 Minute Dives At Depth Of 50 Feet

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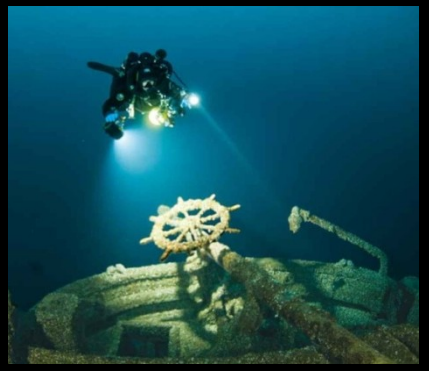
Must Understand Heat Loss to Protect From the Cold



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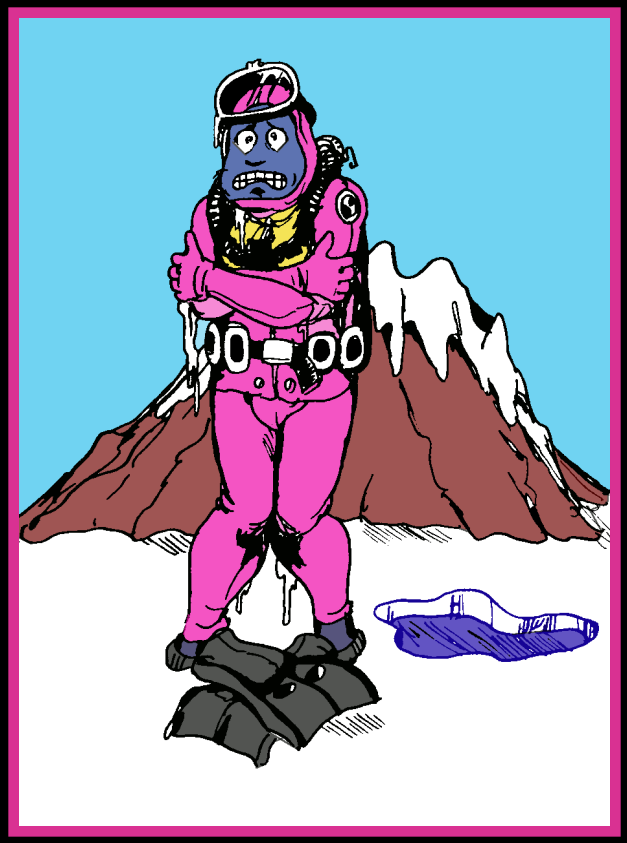
Ignoring (or Not Understanding) Heat Loss



It is always the "not known" that poses the greatest risk

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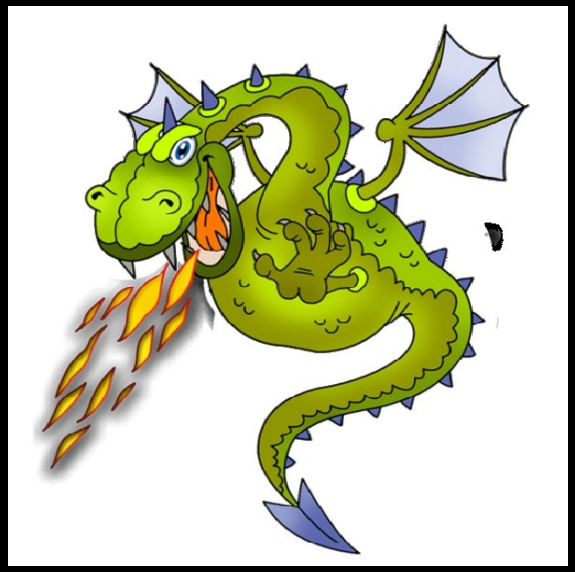
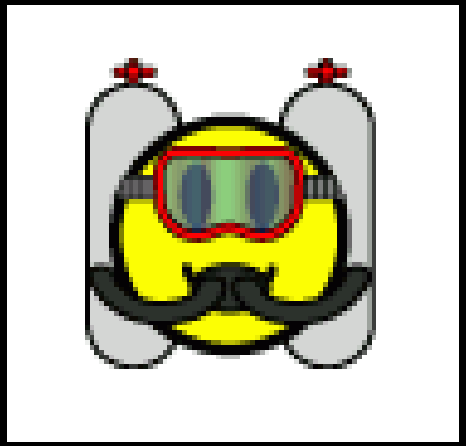


Heat



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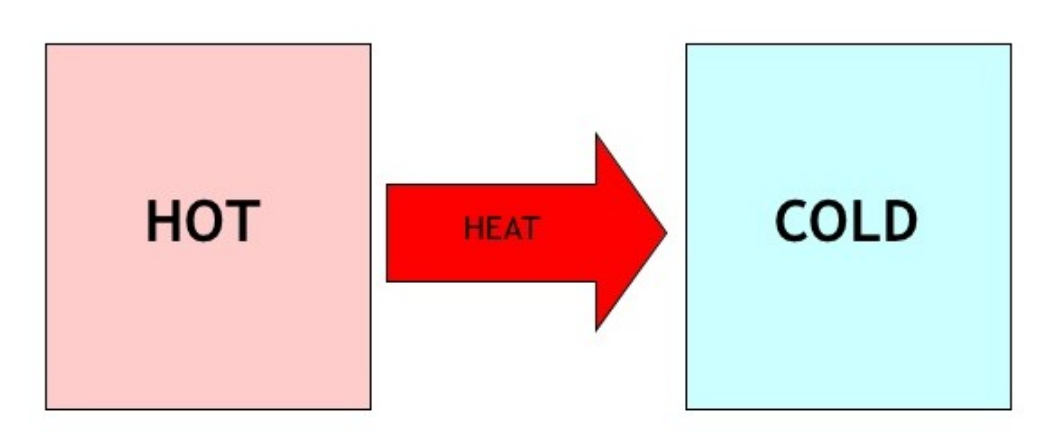
Heat is a Fluid



Flows from hotter to colder
until
temperatures are equal

Cannot stop movement
Protection comes from slowing process

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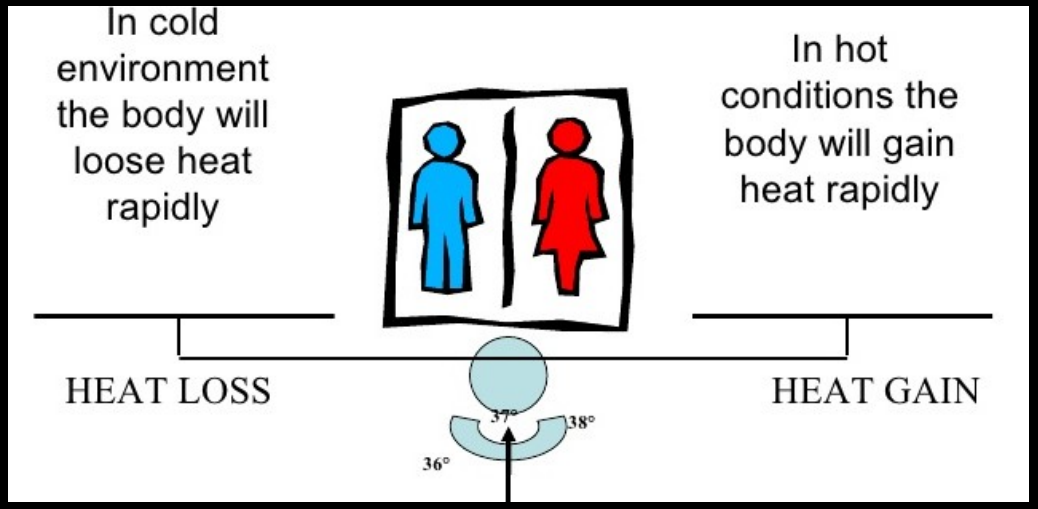
Thermal Balance

Heat Out:

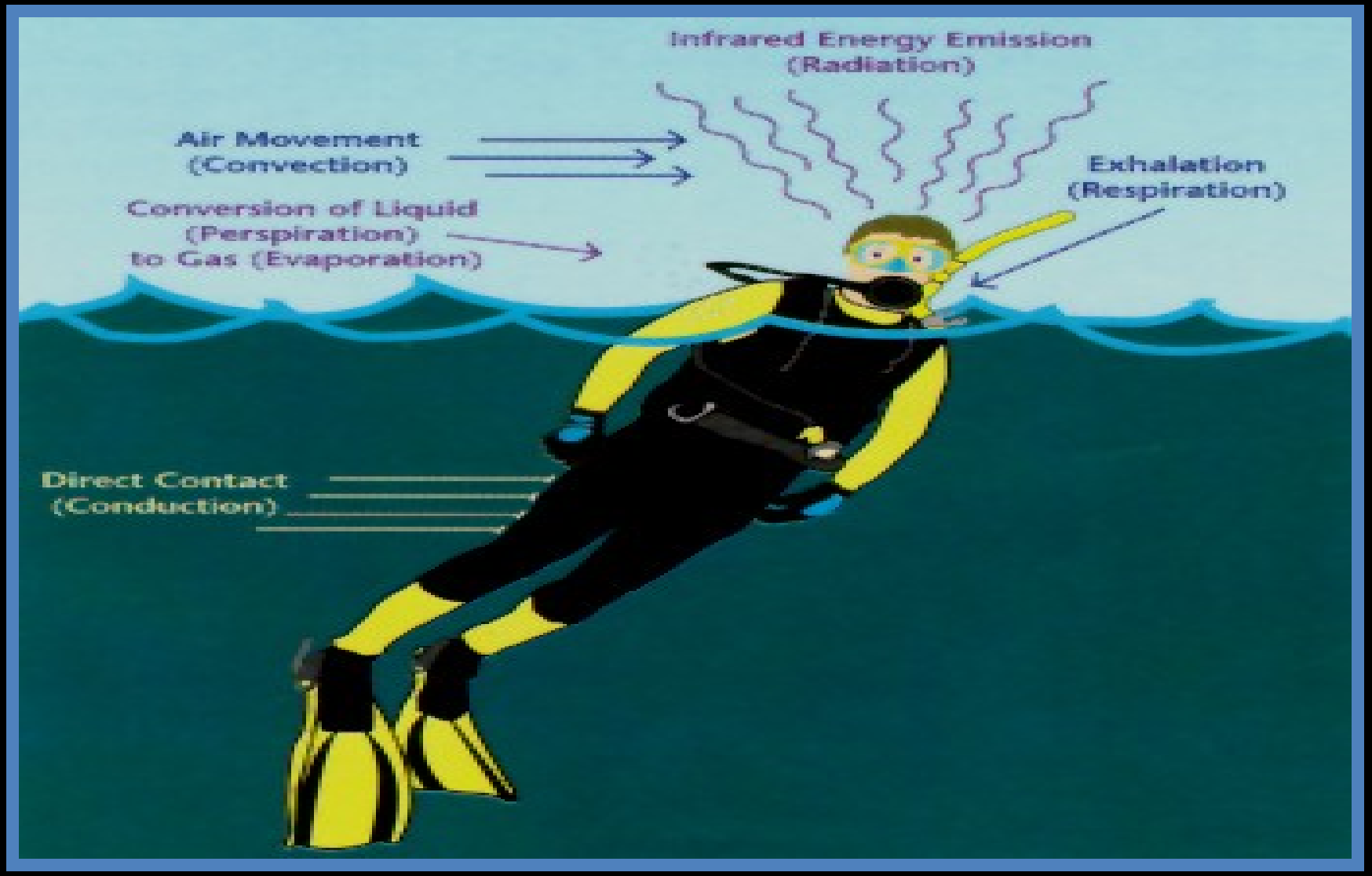
- **Environment**
  - Conduction
  - Convection
  - Radiation
- **Cooling**
  - Respiration
  - Perspiration
  - Excretion
- **Disease**



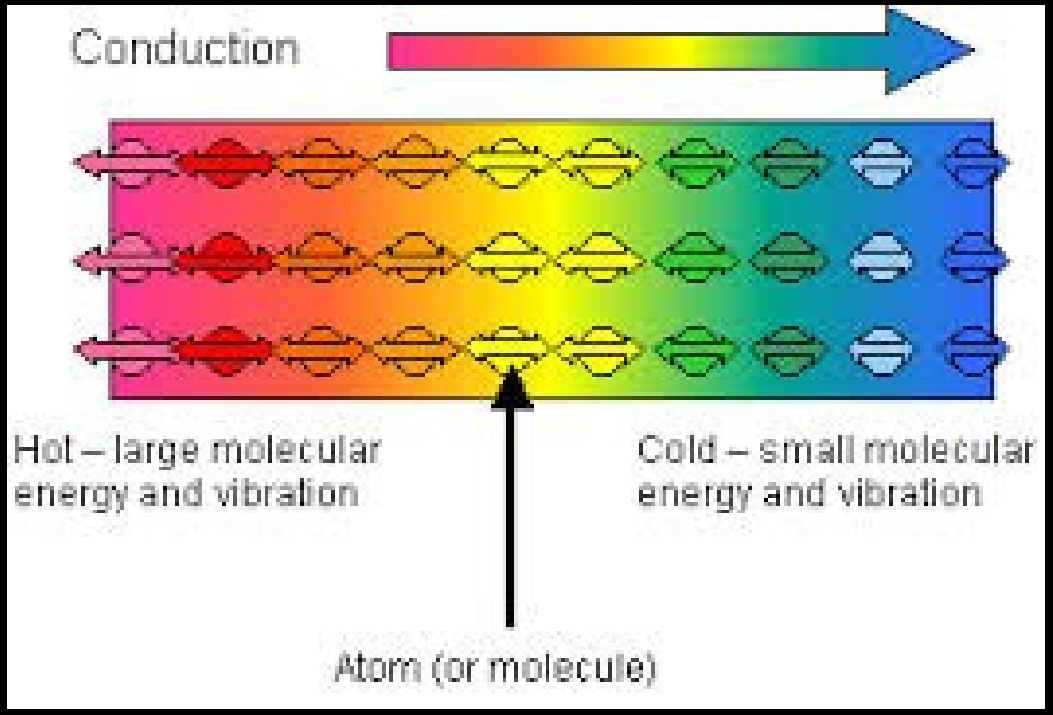
Heat In:

- **Metabolism**
- **Muscle Movement**
- **Environment**
  - Conduction
  - Radiation

In-Water Heat Loss



Thermal Loss: Conduction



Water removes heat ~ 25 x faster than dry, still air at same temperature

Direct transfer of energy at the molecular level

Major source of in-water heat loss

Heat loss to water

Heat loss warming breathing gas

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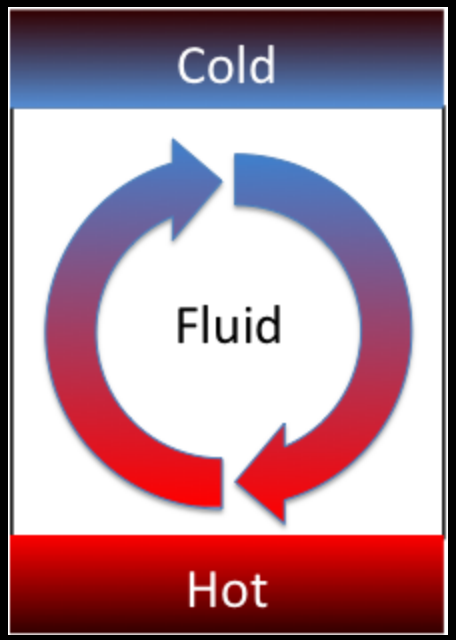
Thermal Loss: Convection



Moving liquid removes heat

Continual process

Wet suits restrict convective flow

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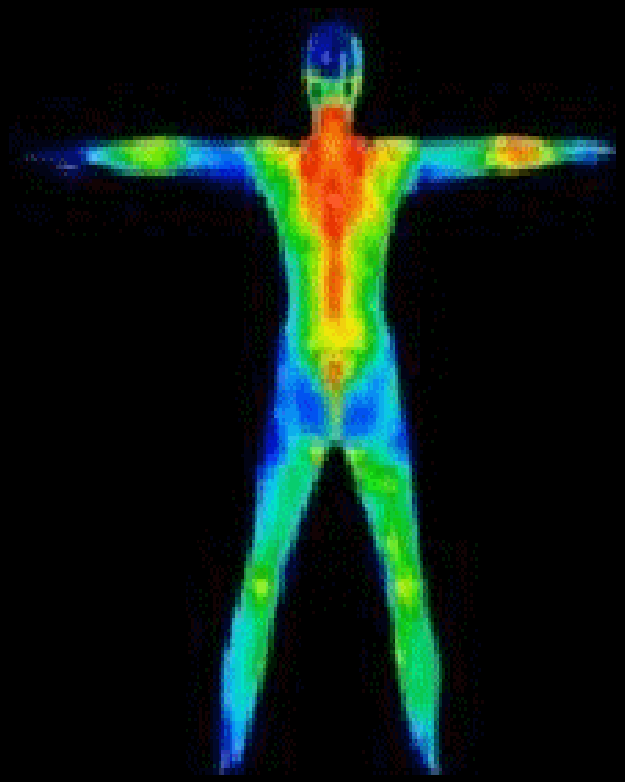
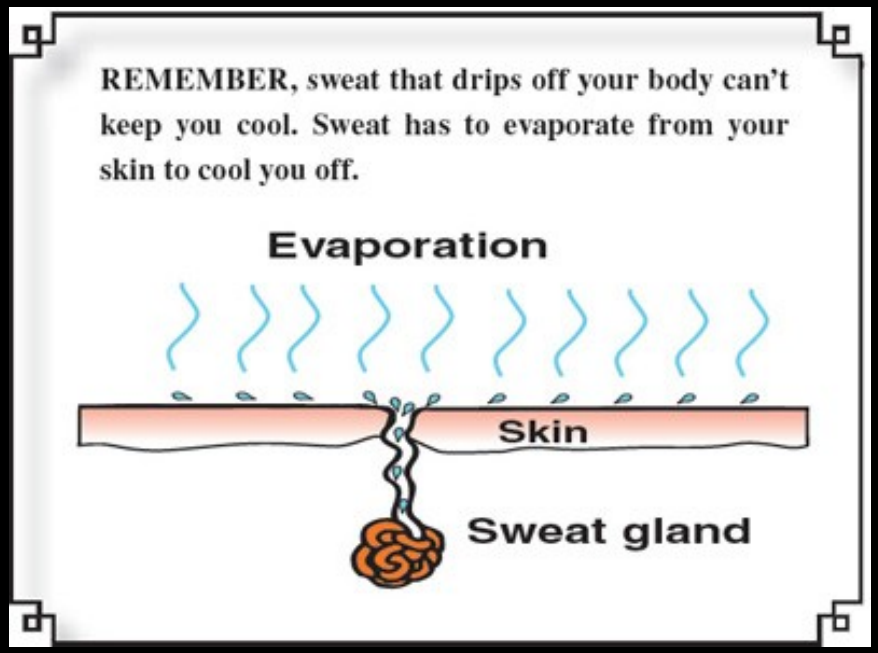
Thermal Loss: Radiation



Emission of infra red radiation

Minor problem in the water

Thermal Loss: Evaporation / Respiration

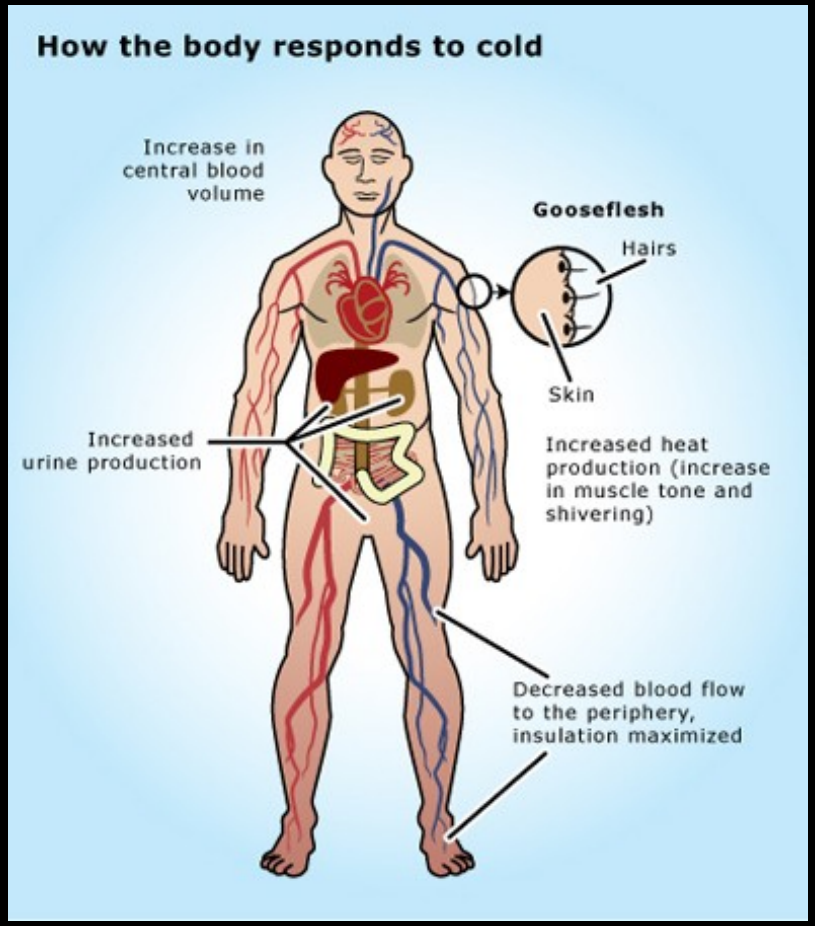


Change of state:
Liquid → gas
Requires energy

9.72 kcal / mole

Pre-dive sweating
Insensible perspiration
Humidifying dry breathing gas

Humans are Tropical Critters
Better coping with heat than cold



Hot	Cold
Vasodilation Arterioles dilate (enlarge) so more blood enters skin capillaries and heat is lost.	**Vasoconstriction** Arterioles get smaller to reduce blood going to skin: keeping core warm.
Sweating Sudorific glands secrete sweat which removes heat when water changes state.	**Shivering** Rapid contraction and relaxing of skeletal muscles. Heat produced by respiration.
Pilorelaxation This means the hairs flatten.	**Piloerection** Hairs on skin stand up.
Stretching Out By opening up, the body was a larger surface area.	**Curling Up** Making yourself smaller so smaller surface area.

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Simplistic View of a Biochemist:

Heat = Life

Cold Robs Heat

No Heat = No Life

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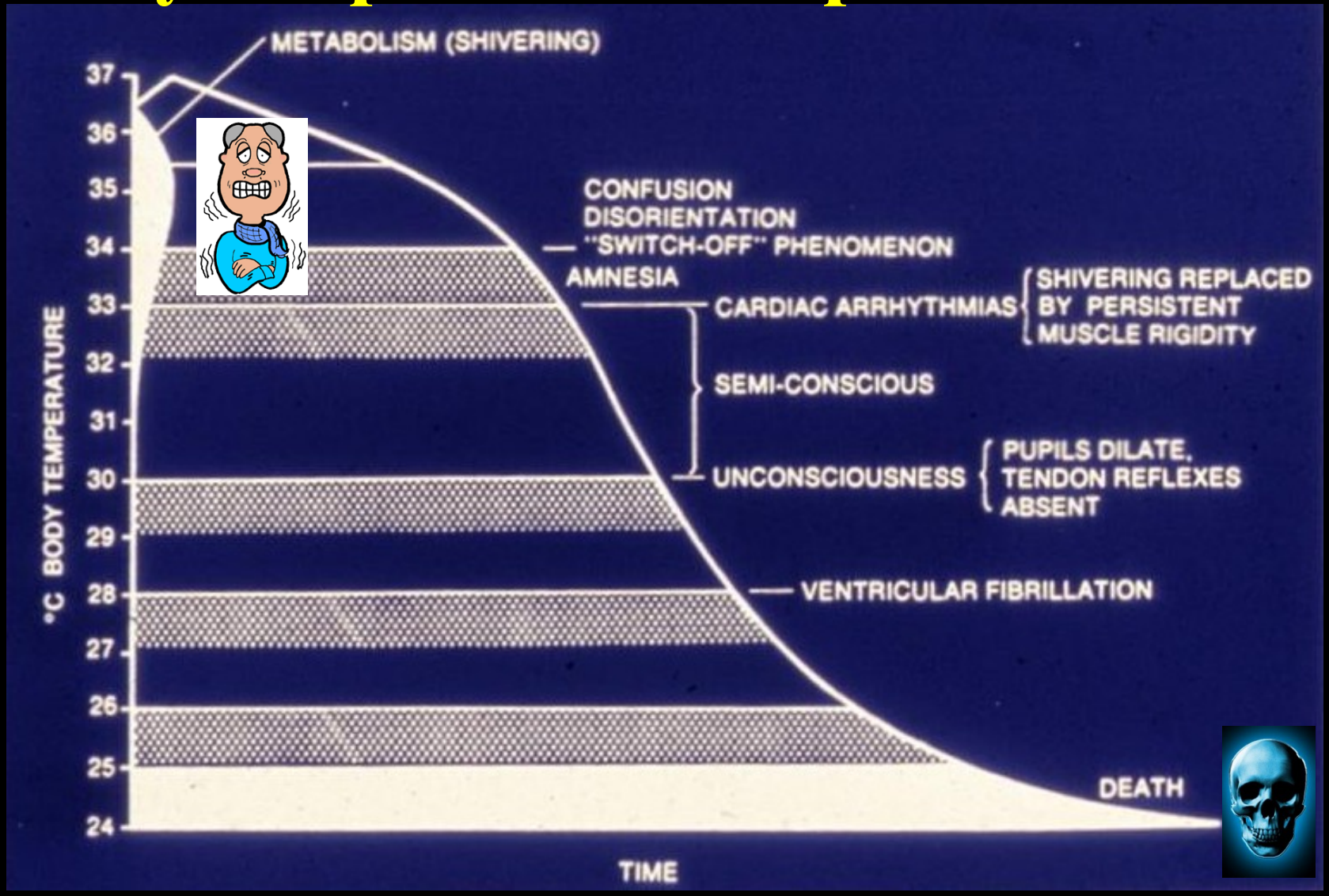
Body Response to Temperature Loss



First Shiver: Abort the dive!

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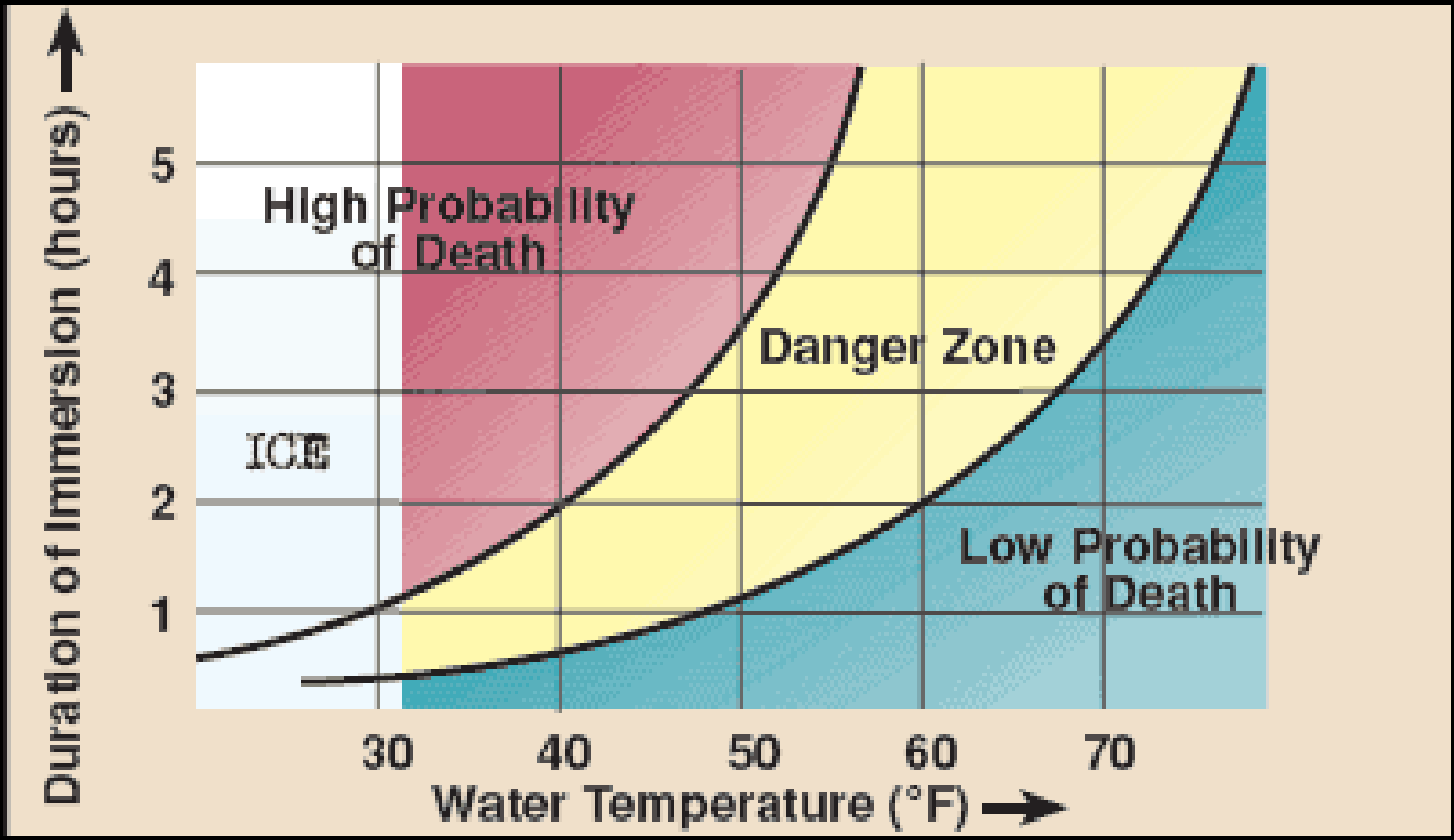
Estimated Unprotected In-Water Survival Time



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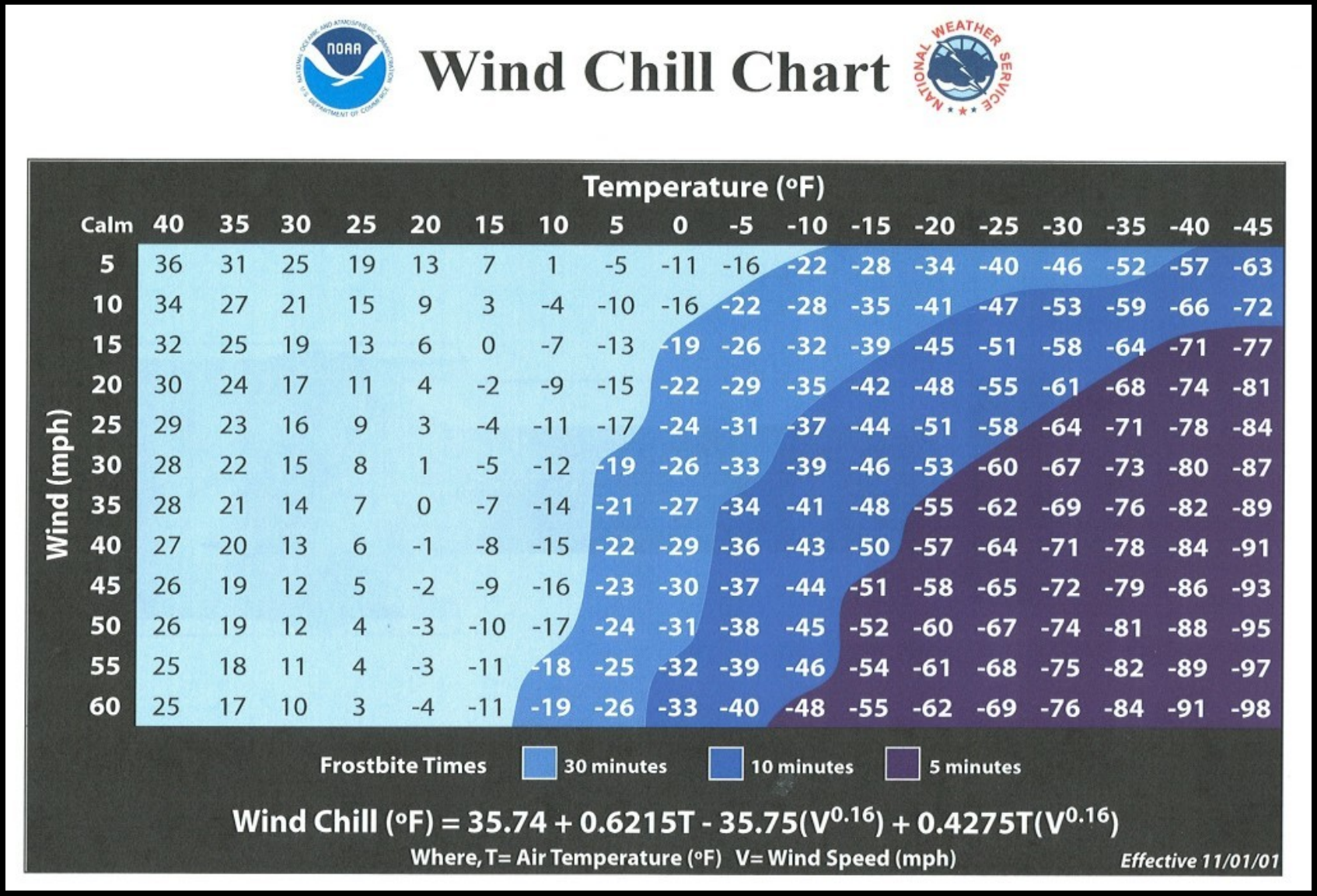
Wind Chill Can Lead to Substantial Heat Loss



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Commercial Divers Often Use Hot Water Suits

Surface supplied:

- Tether
- Breathing mix
- Communications
- Hot water

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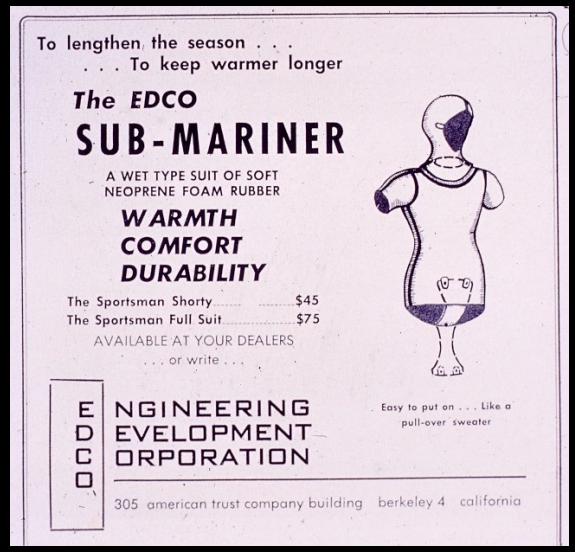
Historic Thermal Protection Schemes



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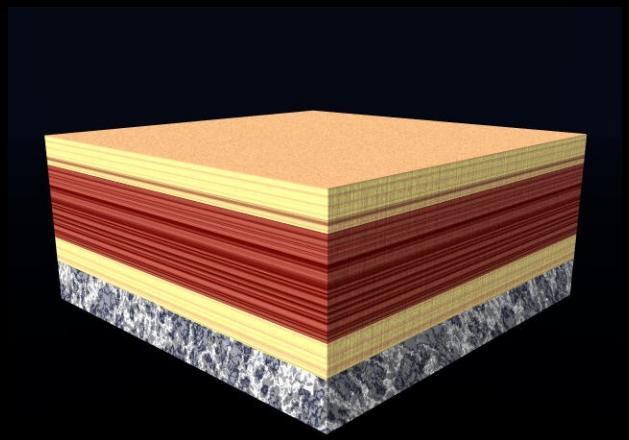
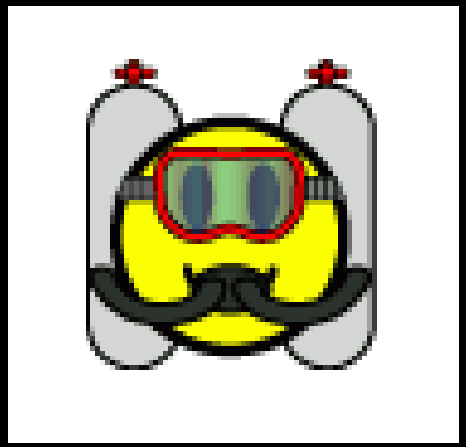


The Layer Concept



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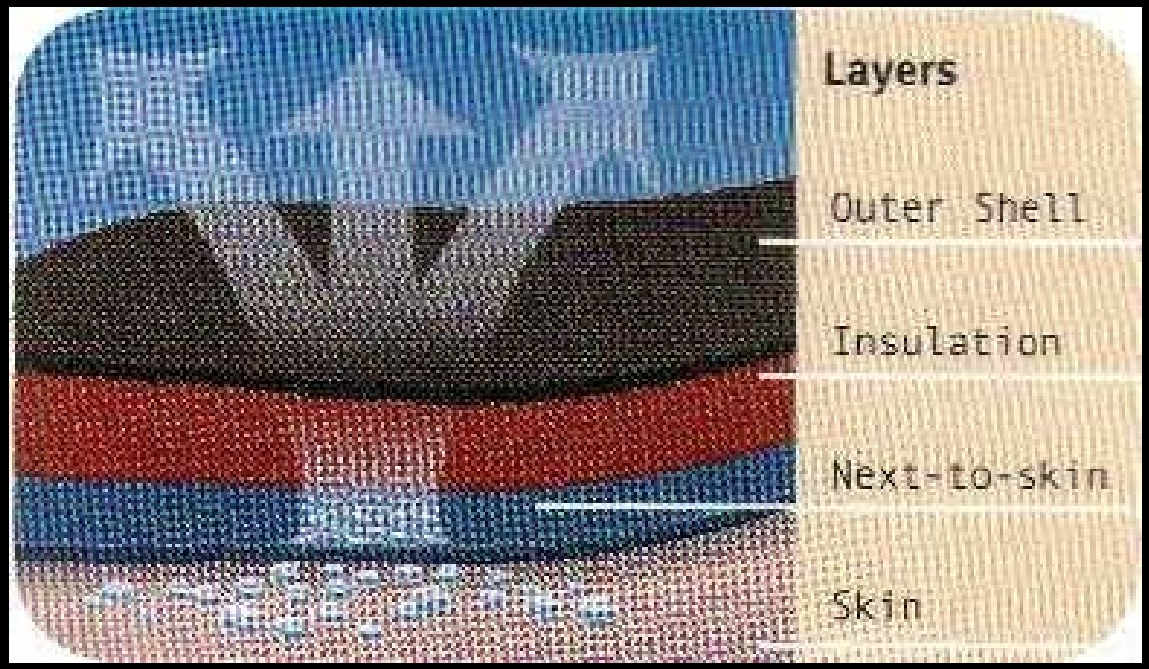
Three Layers of Thermal Protection



Layers varied depending on

Environmental conditions

Workload

Personal Comfort

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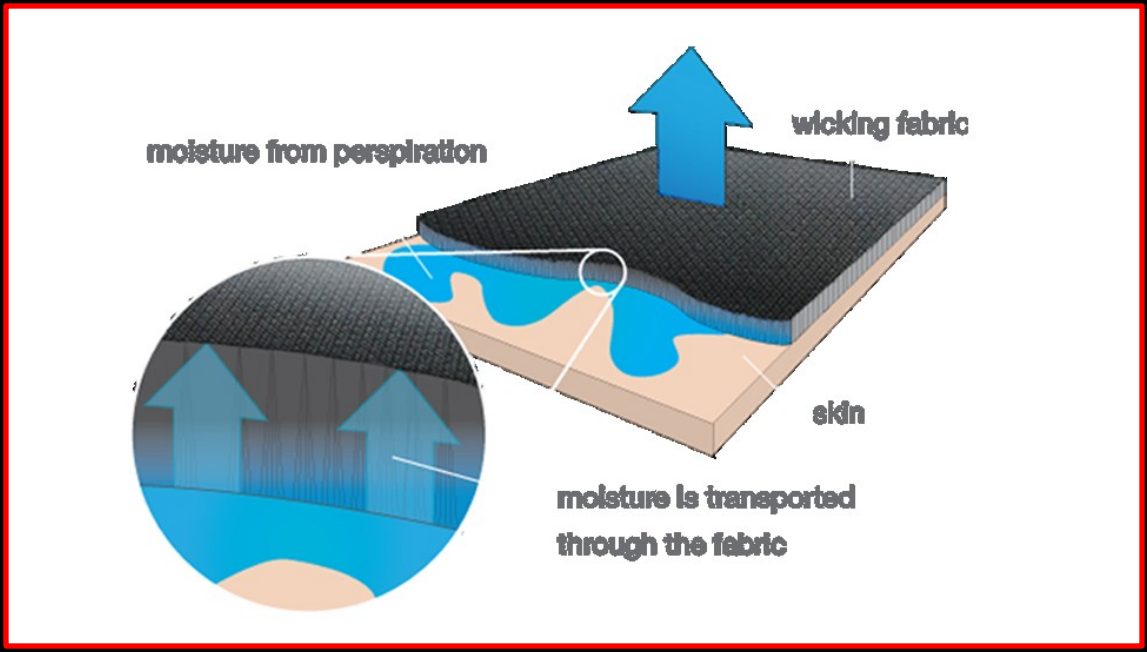
First Layer: Next to Skin

Purpose: Keep Skin Dry



Hydrophobic microfiber wicks water away from skin

Dry skin loses heat much slower than moist skin

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First Layer: Next to Skin

Polypropylene
Capilene
Dry Base
Xerotherm
Dry Max (Socks)

Must be synthetic material (all natural fibers absorb water)
Different weights available (dependent on temperatures/workload)

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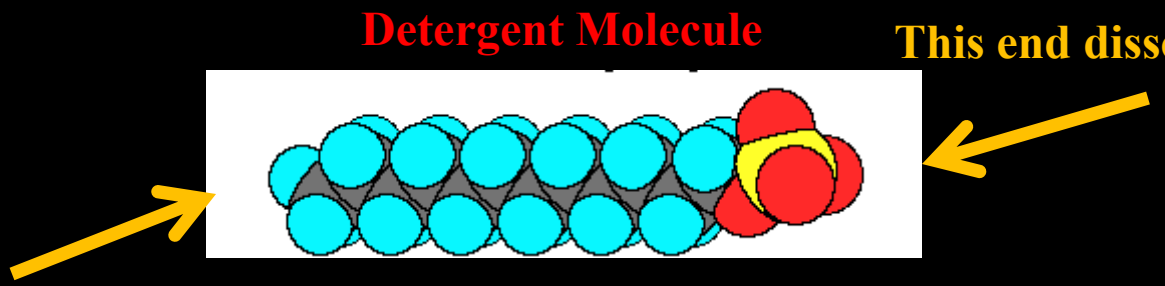
Hydrophobic Materials Soon Acquire a Foul Body Smell (Body oils stick to hydrophobic material and turn rancid)

Wash with breathable fabric detergent, (tiny amount of detergent) in cold water then smell the garment



If detergent odor present:
(This "stuck" detergent can absorb water / lessen insulation)
Wash with only cold water until detergent smell is gone

On trips, best to have multiple sets of first layer garment

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Second Layer: Insulation

Primary resistance to heat loss

Fabric is matrix to hold trapped gas (the insulator)

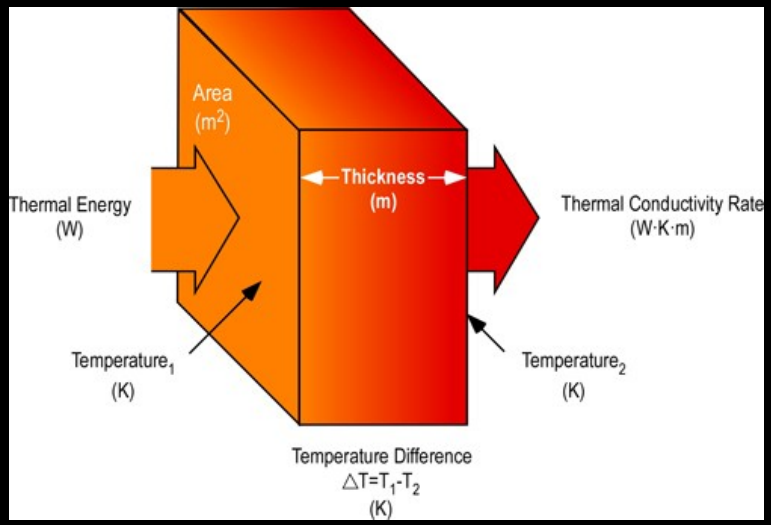
$$\text{Insulation value} = \frac{\Delta T \; A \; t}{C}$$

ΔT : temperature difference

A : cross-sectional area

t: time

C: Thermal Conductivity



Heat loss depends on:

- Temperature difference across barrier
- Thickness & area of insulation
- Thermal resistance / conductivity of insulator
- Time

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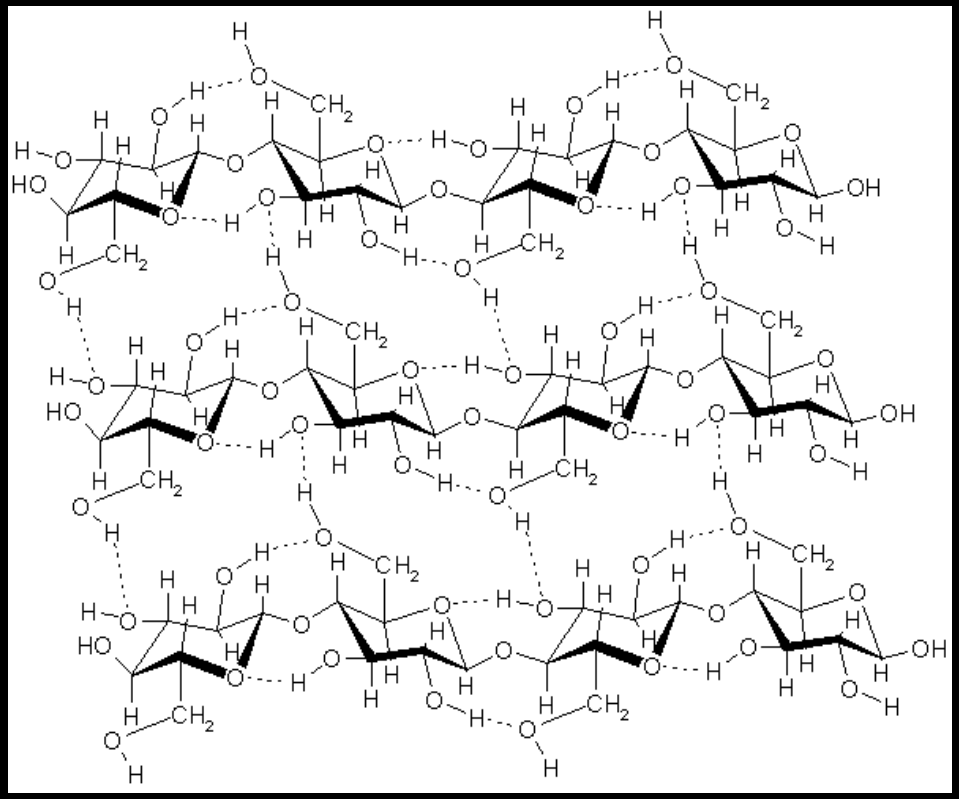
Second Layer: Insulation

Cotton (cellulose) is a No! No!



Cotton is a poly-sugar

Every –OH can grab water

All natural fibers absorb water

Water decreases insulation

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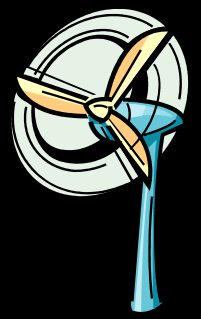
Cellulose (Cotton)

Ability to hold water makes cotton a "great' summer fabric

- perspiration "grabbed" by cotton fibers
- water evaporates
- evaporation takes heat
- result is a cooling effect



Ability to hold water makes cotton an undesirable in-water fabric

- evaporative cooling promotes heat loss & hypothermia
- water removes heat ~25 x faster than dry still air of same temperature
- Fogery : > 50% wilderness deaths a result of wearing cotton jeans
- Yosemite Rangers: wearing cotton in winter → "death-seeking behavior"

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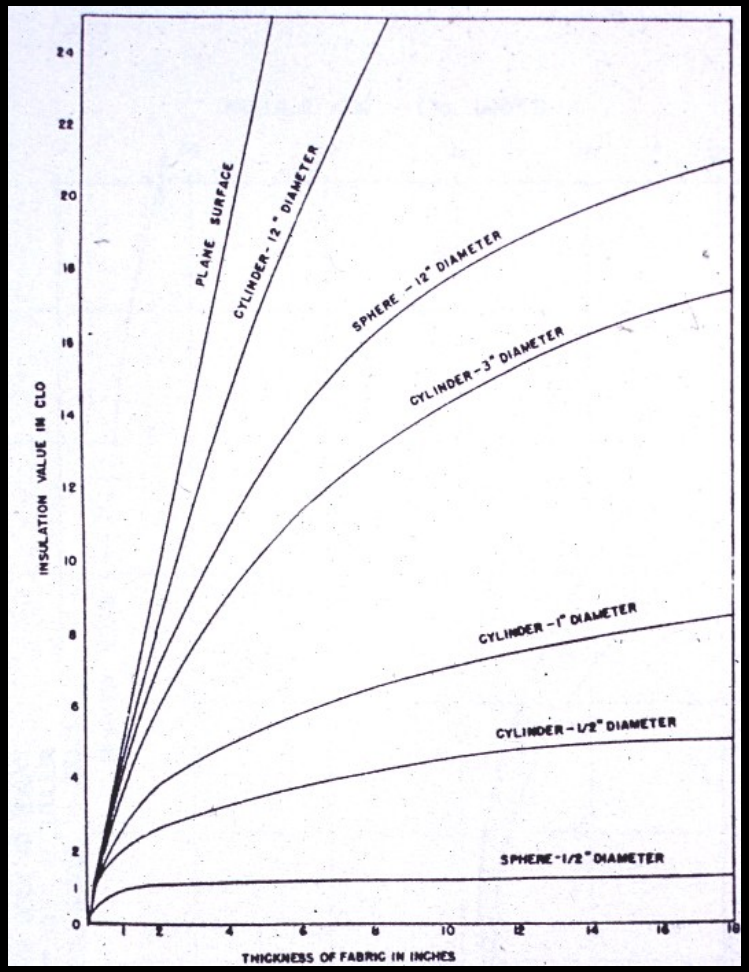
Second Layer: Insulation

Shape of insulator affects heat loss



Best Resistance : planar surface (at right angles to heat flow)

In general:

Planar > cylindrical > spherical

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Second Layer: “Wooly Bears”

Wool or synthetic “pile”

Very comfortable next to skin

Warm, as long as dry

Loses insulation rapidly when wet

Loses insulation when compressed

Decent insulation at reasonable price

Least expensive protection

Pile may clog valves

Value based on # fibers / area; not weight

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Second Layer: Open Cell Foam

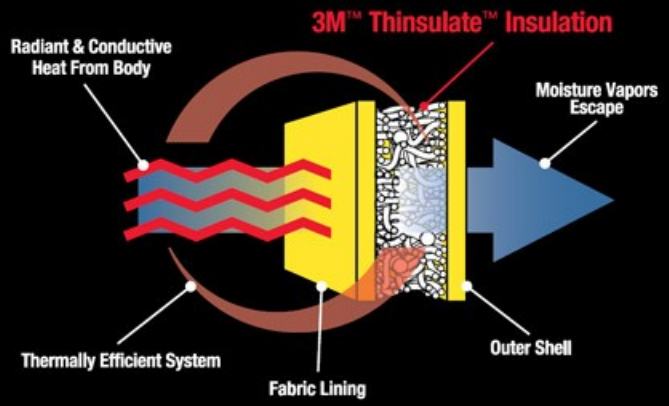
Synthetic foam open cell structure
First compression resistant underwear
Warm when dry
Holds insulation at depth
Rapidly loses insulation when wet

Foam structure a bit non-flexible

Second Layer: Type b Marine Thinsulate

Synthetic microfilament polypropylene
Compression resistant
Warm when dry
Holds insulation at depth
Holds insulation (~85 %) when wet

Expensive
Best insulation for wet environments



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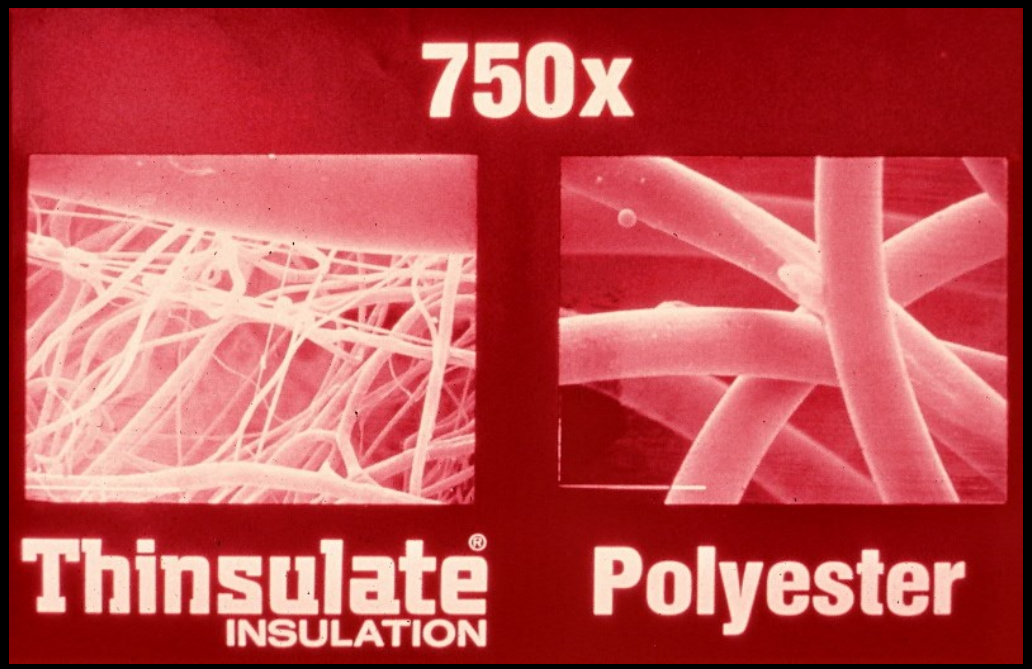
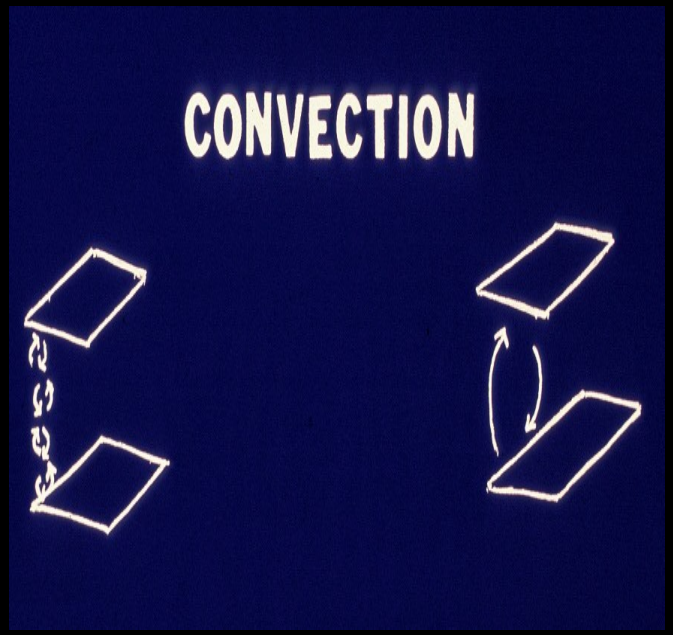
Second Layer: Type b Marine Thinsulate





Smaller cell size traps more air (insulator)

Requires more convective / conduction steps to transverse garment

Second Layer: Polartec

Polatec: series of > 300 synthetic hydrophobic fabrics

Polyester: polyethylene terephthalate (PET)

Napped (fuzzy) insulator

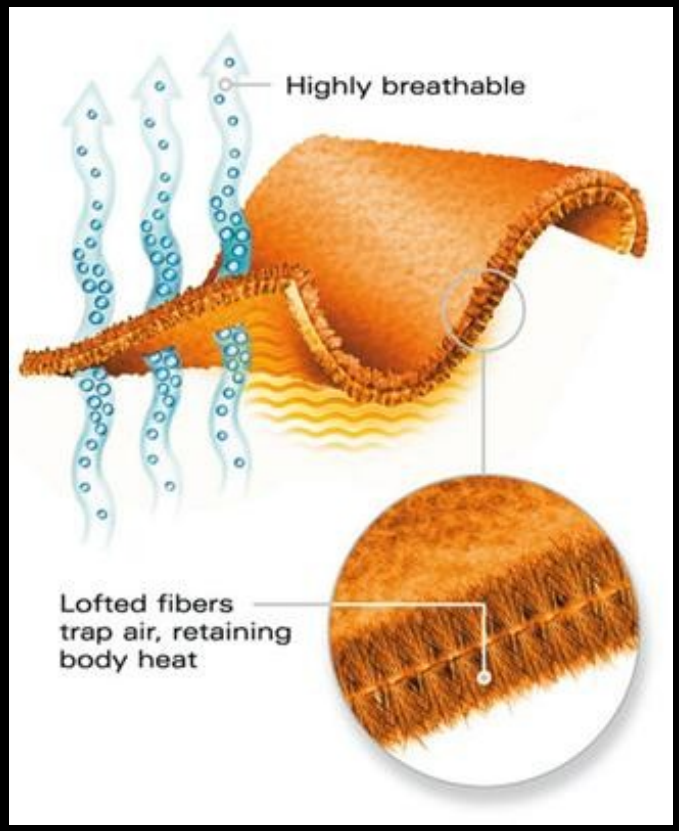
Can serve as

Layer 1

Layer 1 & 2 combined

Layer 1, 2 , & 3 (with waterproof shell)

Depends on weight and design of fabric



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Second Layer: Radiant Barrier

Metallic heat reflective coat underneath cloth layer

Radiant barriers work extremely well in a vacuum
Reasonable in sealed, dry, surface garments
Not effective underwater

Experimental in the 1980's
Sold under brand name Underwave
Did not stay long on the market
Occasionally surfaces on e-bay

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Second Layer: Blue Heat

Active electrical heating system
Boots, gloves, and full torso sold separately

Lasts about 2 hours on 100% power
Designed to supplement, not replace, thermal undergarments
Very expensive

Concern that heating may increase DCI risk
- Use on lowest power
- Best used on final ascent

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Second Layer: Insulating Gas

Primary insulation:
Thermal resistance of gas in the suit

Thermal conductivity: ***the quantity of heat transmitted through a unit thickness of a material - in a direction normal to a surface of unit area - due to a unit temperature gradient under steady state conditions*** **(measured in watts per meter Kelvin, W/(m · K).**
Examples:

Air, atmosphere	**(gas)**	**0.024**
Argon	**(gas)**	**0.016**
Carbon dioxide	**(gas)**	**0.0146**
Helium	**(gas)**	**0.142**
Nitrogen	**(gas)**	**0.024**
Water	**(liquid)**	**0.58**

The lower the value,
The better the insulation

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Second Layer: Insulating Gas

Carbon Dioxide (CO_2)

Tried because of thermal conductivity

Readily available and inexpensive

$CO_2 + H_2O \rightarrow H_2CO_3$ (carbonic acid)

Carbonic acid creates itching and rashes

Argon (Ar)

Studies show little value (as practiced) when used with air diving

(Effective with 6 fill/empty cycles to provide all Argon insulation)

Valuable when diving tri-mix (N_2, He, O_2; heli-air) or heliox

(Can't use breathing gas 'cause of heat loss with helium)

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Second Layer: Argon Inflation System

Valve on Bottom
Easier to control

Connects to Suit Inflator

May need 2 cylinders:
One to fill/flush 6 times
One for dive

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Second Layer: Aerogel ?

Low density, open-cell nanopore structure
~ 20 nm cells approximate air molecule movement in vacuum
Structure is ~ 95% air

Extremely low thermal conductivity

Expensive: US Navy experimental dive suit: $ 5,200,000
Underwear: $ 1,200,000

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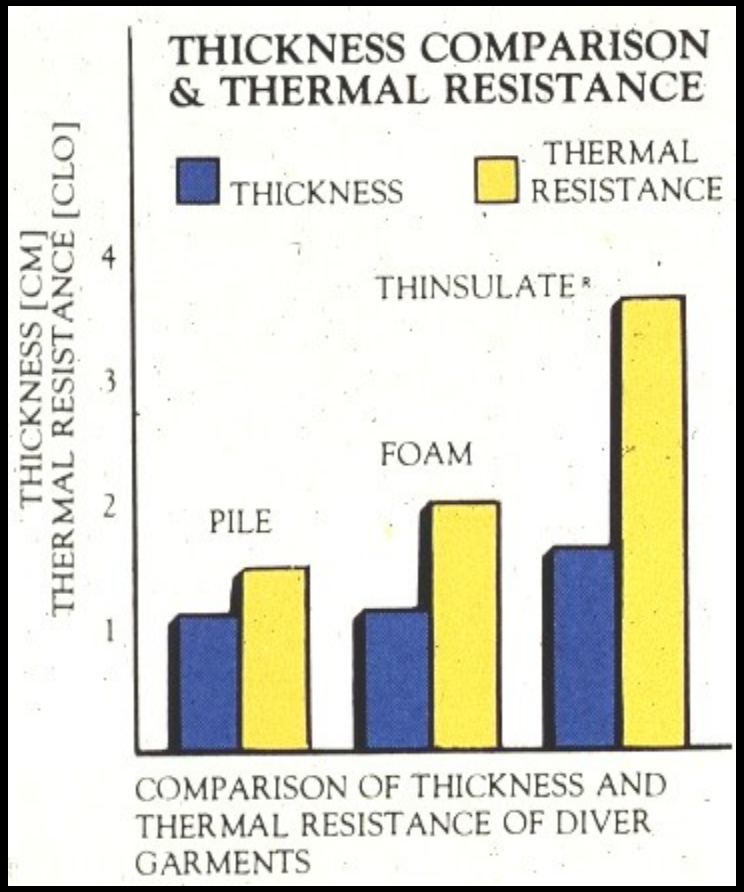
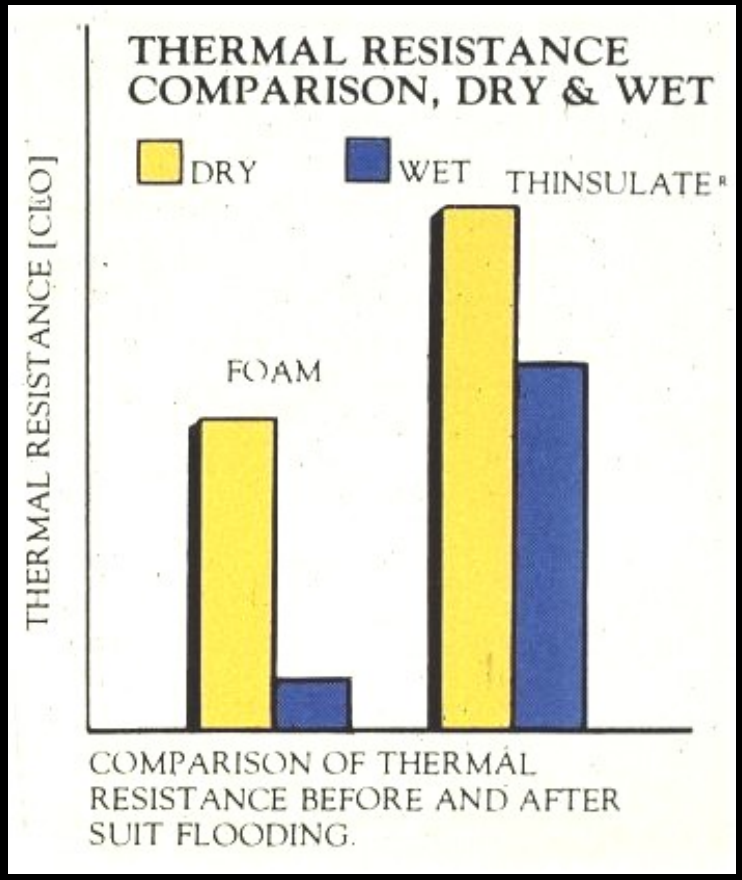
Insulation Value Comparisons





Thinsulate holds thermal protection even when submerged

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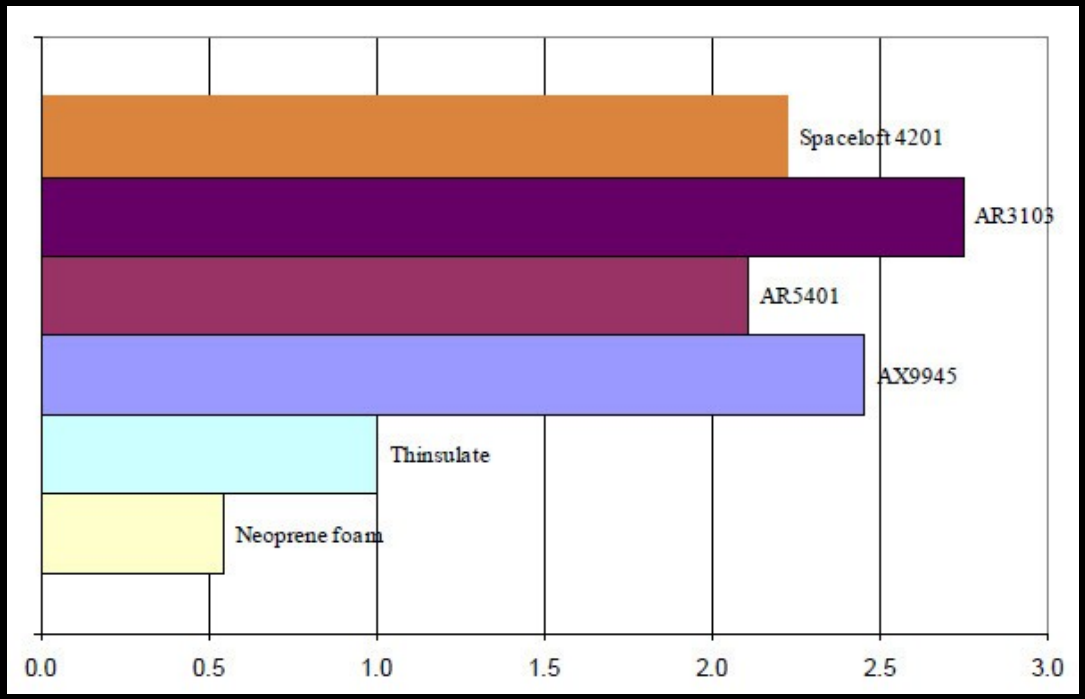
Insulation Dry Value Comparisons



Top four are aerogels

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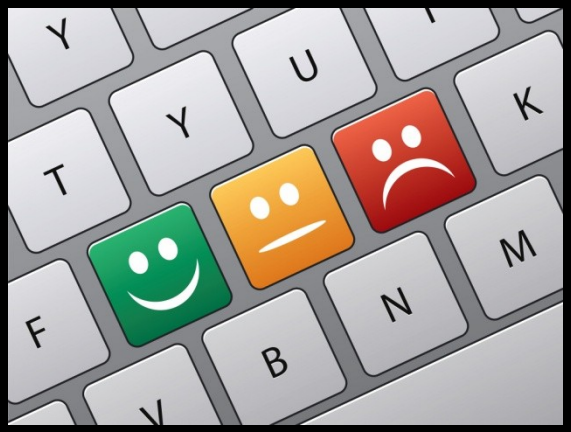
Diver Ratings Of Underwear

Insulation Value	Comfort	Insulation When Wet
Thinsulate	Pile	Thinsulate
Foam	Thinsulate	Pile
Pile	Foam	Foam

Overall: Thinsulate Preferred



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From 1982: Personal Test of Diving Underwear

THERMAL EVALUATIONS: TESTS

3/16" DUI "CAT" SUIT
1/4" COLD WATER HOOD
3-FINGERED MITTENS

FIRST LAYER: POLYPROPYLENE

50 F FRESH WATER
LITTLE MOVEMENT

UNDERWEAR	TIME TO FIRST SHIVER
BUNTING/ RADIANT BARRIER	28 MINUTES
ACRYLIC PILE	68 MINUTES
OPEN-CELLED FOAM	88 MINUTES
THINSULATE (C2)	128 MINUTES

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From 1982: Personal Test of Diving Underwear

THERMAL EVALUATIONS : CONTROL

1/8" HOODED "CHICKEN VEST"
1/4" FARMER JOHN WET SUIT
1/4" COLD WATER HOOD
1/4" 3-FINGERED MITTENS

50 F FRESH WATER
LITTLE MOVEMENT

TIME TO FIRST SHIVER = 55 MINUTES

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Underwear Selection Bottom Line:

No single underwear package will
Work in all combinations of water temperature and workload

Divers need multiple packages
Experience needed to match package with diving conditions

Multiple divers on the same site may have different packages
But, each will have individually correct system for their needs

LPT

DUI'S

Thermal Guidelines

THERMAL STRESS IS

The Greatest Limiting Factor
In Diving Today

THERMAL STRESS IS

Tolerated In Most Diving Operations
Which Is A Mistake

THERMAL STRESS IS

A Factor In Most Diving Accidents

LPT

THERMAL STRESS IS

Predictable And Preventable

People Produce **HEAT** At Different Rates

People Lose **BODY TEMPERATURE** At Different Rates

OUR GOAL:

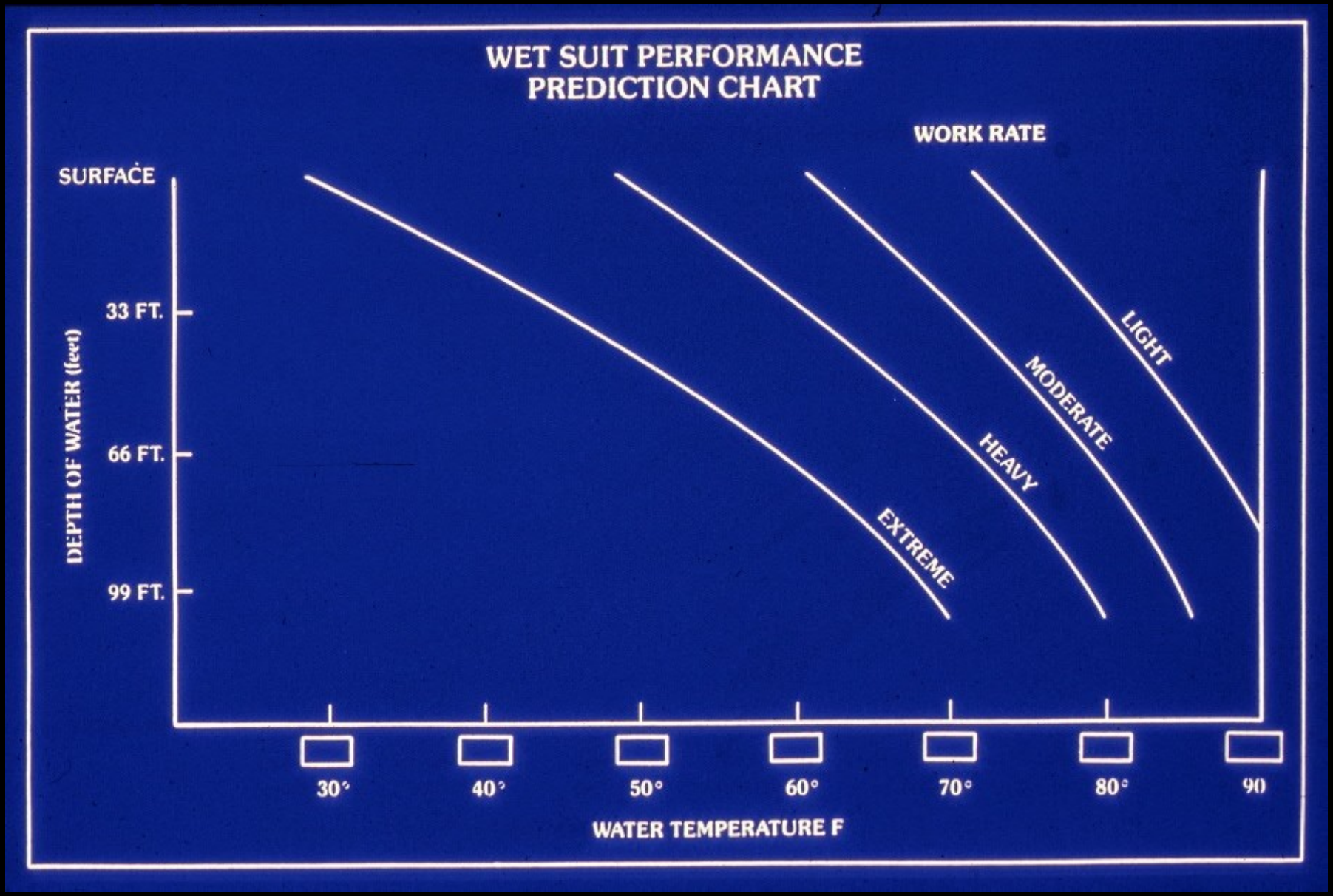
Each Diver Performing At 100% Efficiency And Reliability

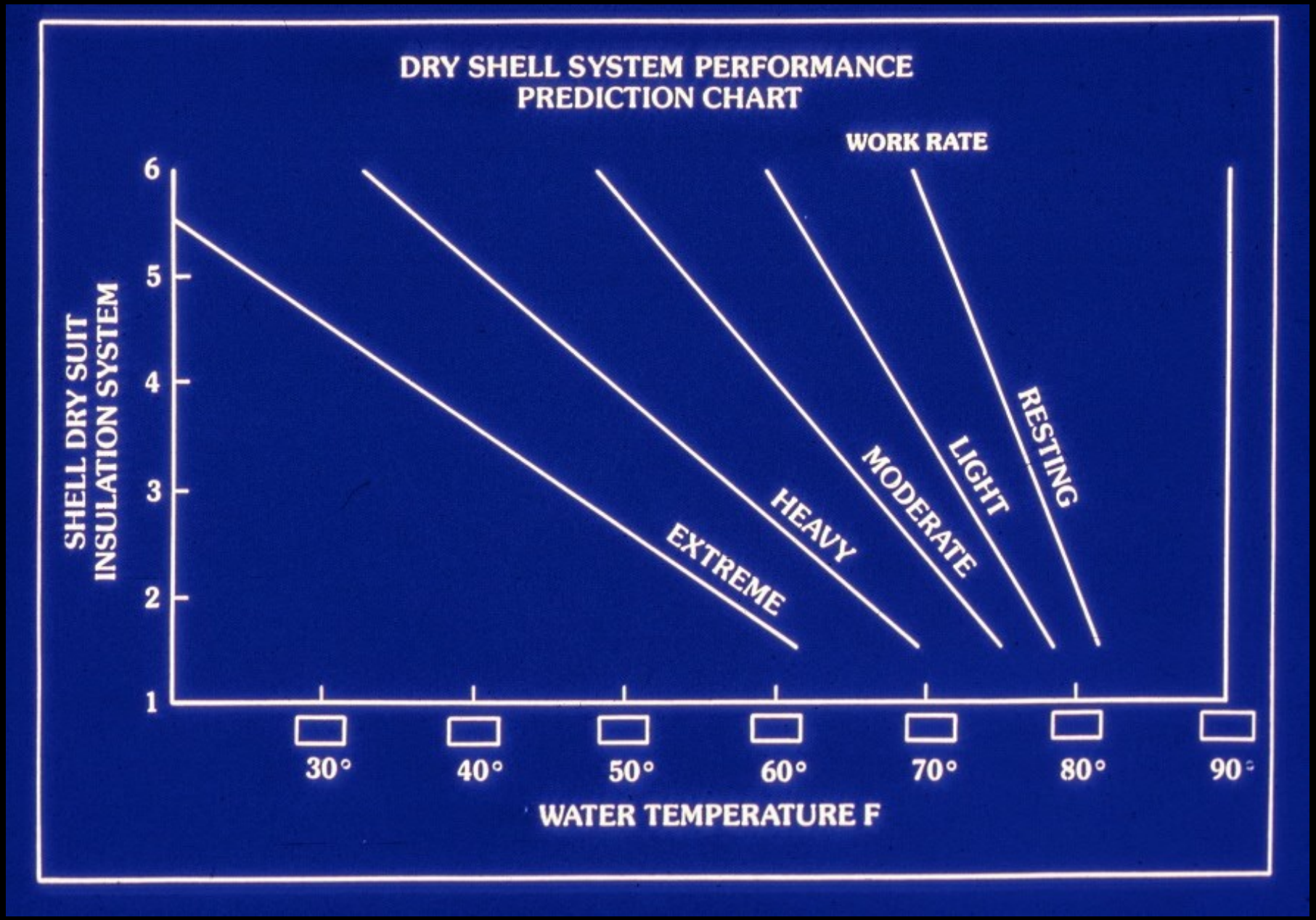
EXERCISE RATE

Light - Taking Photographs Or Observing

Moderate - Normal Swimming

Heavy - Strong Swimming Or Dragging An Object Across The Bottom


WET SUIT PERFORMANCE
PREDICTION CHART
WORK RATE
SURFACE
33 FT.
66 FT.
99 FT.
DEPTH OF WATER (feet)
LIGHT
MODERATE
HEAVY
EXTREME
30°
40°
50°
60°
70°
80°
90
WATER TEMPERATURE F


DRY SHELL SYSTEM PERFORMANCE
PREDICTION CHART
WORK RATE
SHELL DRY SUIT
INSULATION SYSTEM
6
5
4
3
2
1
EXTREME
HEAVY
MODERATE
LIGHT
RESTING
30°
40°
50°
60°
70°
80°
90°
WATER TEMPERATURE F

PLUS RATING TABLE

Your Body Weight

		90	105	120	135	150	165	180	195	210	225	245
-4	-2	0	+2	+4	+6	+8	+10	+12	+14	+16	+18	+20

Degrees

Find Your Plus Rating As Listed Below Your Body Weight

IF COMFORTABLE

- No Modifications

Example: 165 Lb. Person Is a +10

IF TOO WARM

- Open Collar Shirt
- Loose Clothing
- Move Up 2°

Example: +10° To +12°

IF YOU PERSPIRE

- Move Up 4°

Example: +10° To 14°

IF TOO COLD

- Button Up
- Wear Long Sleeves
- Move Down 2°

Example: +10° To +8°

NEED A SWEATER

- Move Down 4°

Example: +10° To +6°

IF YOU USE

A DUI CF 200 Dry Suit

- Move Up 4°

Example: +10° To +14°

DIVER _____

DRY SUIT + 10 DIVER

ACTIVITY Heavy	Moderate	Light		Insulation Level	Weight Added Salt	Fresh
Water Temp °F						
74	78	82	A	Expeditionary weight polypropylene underwear		____
64	72	76	B	Single layer bunting or lightweight pile*		
54	63	70	C	50°-65° DUI Thinsulate divewear*		
47	58	66	D	Double weight bunting* DUI pile plush, heavy-weight high quality pile* or V. foam	____	____
34	48	60	E	35°-50° DUI Thinsulate divewear*	____	____

Note: Includes appropriately matched boots and gloves.
*Also includes medium weight polypropylene underwear.

WET SUIT + 10 DIVER

WATER Depth Feet	ACTIVITY Heavy	Moderate	Light
	Water Temp °F		
0'	48	62	72
33'	60	70	80
66'	72	78	88
99'	78	84	

Temperature in order to be at thermal equilibrium

AUXILIARY INSULATION

Degrees F	Insulation	Weight Added Salt	Fresh
+5° to +10°	Back-packing bunting or pile suit top and bottom	_____	_____
+10°	Heavy polyester or poly nylon sweat pants and shirt	_____	_____
+5° to +7°	Heavy jogging suit	_____	_____
+5°	Mountaineering expedition weight or wool polypropylene top and bottom	_____	_____
+5° to +7°	Heavy wool/acrylic sweater	_____	_____
+5°	DUI plus 5 vest	_____	_____

EFFICIENCY AND RELIABILITY

TEMP	WET SUIT DIVE NUMBER 1st	2nd	3rd	DRY SUIT DIVE NUMBER 1st	2nd	3rd
70°F	100%	100%	100%	100%	100%	100%
60°F	100%	90%	80%	100%	100%	100%
50°F	80%	70%	50%	100%	100%	100%
40°F	50%	25%	*	100%	85%	75%
32°F	*	*		100%	75%	55%

*Not recommended unless involved in a life saving rescue.

Table based on 30 minute dives at depth of 50 feet.

MISERY INDEX

TEMPERATURE DIFFERENCE FROM THERMAL COMFORT °F	FOR DIVES LONGER THAN 20 MINUTES BUT LESS THAN 60 MINUTES RESULT
-5°	Diver will rewarm between dives.
-10°	Outer body shell will accumulate thermal debt, but can be tolerated.
15°	Degrade diver in water performance and accumulate body shell thermal debt.
20°	Significant performance degradation, poor efficiency.
-25°	Reduce diver to shivering and misery.
-30°	Should not be attempted.
+5°	Can be tolerated, take off glove or ventilate water through hood.
+10°	Must be careful, watch for signs of heat prostration. If occurring, terminate dive.
+15°	Substantial heat build-up, can lead to disastrous results.

DUI INC.

Diving Unlimited International • 1-800 327-8439
1148 Delvan Drive, San Diego, CA 92102-2499

A DUI dry suit is thermal insurance where the dividend is always more than the premium.

WET SUIT + 10 DIVER

WATER Depth Feet	ACTIVITY Heavy	Moderate	Light
	Water Temp °F		
0	48	62	72
33	60	70	80
66	72	78	88
99	78	84	

Temperature In Order To Be At Thermal Equilibrium

MISERY INDEX

Dives Longer Than 20 Mins. But Less Than 60 Mins.

TEMPERATURE DIFFERENCE

-5° Diver Will Rewarm Between Dives

-10° Outer Body Shell Will Accumulate Thermal Debt, But Can Be Tolerated

-15° Degrade Diver In Water Performance And Accumulate Body Shell Thermal Debt

TEMPERATURE DIFFERENCE

-20° Significant Performance Degradation, Poor Efficiency

-25° Reduce Diver To Shivering And Misery

-30° Should Not Be Attempted

TEMPERATURE DIFFERENCE

+5° Can Be Tolerated, Take Off Glove Or Ventilate Water Through Hood

+10° Must Be Careful, Watch For Signs Of Heat Prostration. If Occurring, Terminate Dive

+15° Substantial Heat Build-Up, Can Lead To Disastrous Results

COLD HURTS

HEAT KILLS

DRY SUIT + 10 DIVER

Activity: Heavy	Activity: Moderate	Activity: Light	Insulation Level	Weight Added: Salt	Weight Added: Fresh
	Water Temp °F				
34	48	60	E 35°-50° DUI Thinsulate Divewear*	—	—

Note: Includes Appropriately Matched Boots And Gloves. *Also Includes Medium Weight Polypropylene Underwear

DIVER _____

DRY SUIT + 10 DIVER

Activity: Heavy	Activity: Moderate	Activity: Light		Insulation Level	Weight Added: Salt	Weight Added: Fresh
	Water Temp °F					
74	78	82	A	Expeditionary weight polypropylene underwear	____	____
64	72	76	B	Single layer bunting or lightweight pile*	____	____
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47	58	66	D	Double weight bunting* DUI pile plush, heavy-weight high quality pile* or V. foam	____	____
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Note: Includes appropriately matched boots and gloves.
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DIVER _____

DRY SUIT + 10 DIVER

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DRY SUIT + 10 DIVER

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Heavy	Moderate	Light		Salt	Fresh
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Degrees F	Insulation	Weight Added Salt	Weight Added Fresh
+5° To +10°	Back-Packing Bunting Or Pile Suit Top And Bottom	—	—
+10°	Heavy Polyester Or Poly Nylon Sweat Pants And Shirt	—	—
+5° To +7°	Heavy Jogging Suit	—	—
+5°	Mountaineering Expedition Weight Or Wool Polypropylene Top And Bottom	—	—
+5° To +7°	Heavy Wool/Acrylic Sweater	—	—
+5°	DUI Plus 5 Vest	—	—

EFFICIENCY AND RELIABILITY

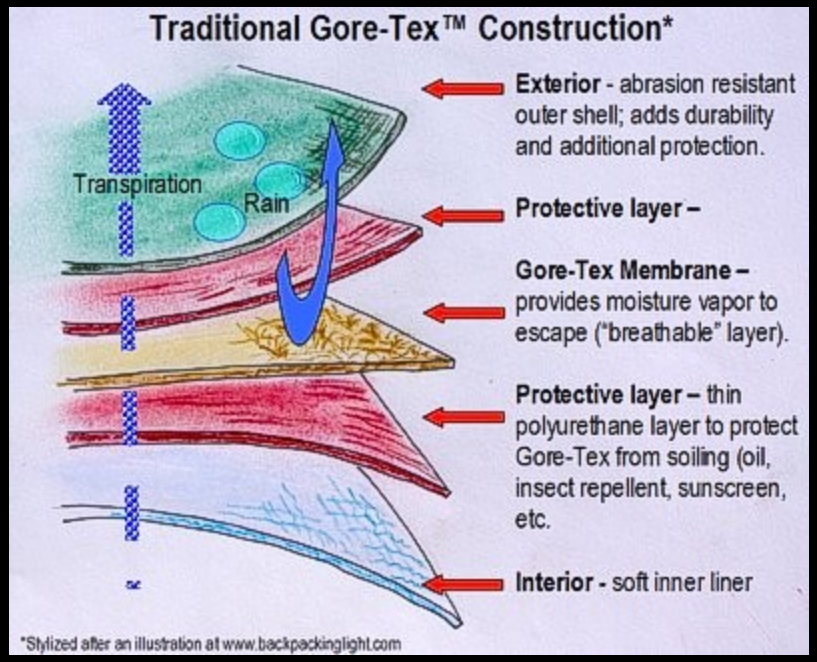
Temp	Wet Suit Dive Number			Dry Suit Dive Number		
	1st	2nd	3rd	1st	2nd	3rd
70°F	100%	100%	100%	100%	100%	100%
60°F	100%	90%	80%	100%	100%	100%
50°F	80%	70%	50%	100%	100%	100%
40°F	50%	25%	*	100%	85%	75%
32°F	*	*	*	100%	75%	55%

*Not Recommended
Table Based On 30 Minute Dives At Depth Of 50 Feet

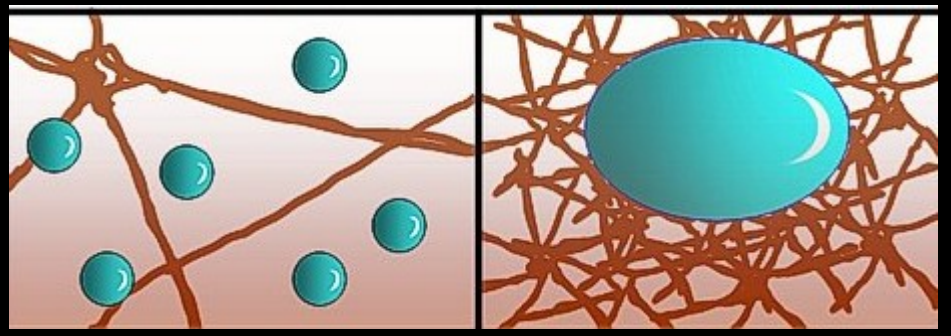
Third Layer: Gore Tex

Short for Gore's textile fabric

Used for outdoor wear; not intended for in-water use



Gore Tex membrane:
Excludes water droplets
Passes water vapor



9 billion pores per square inch
Each pore 20,000 x smaller than water droplet

Wash with warm water & breathable fabric detergent; no fabric softener or bleach

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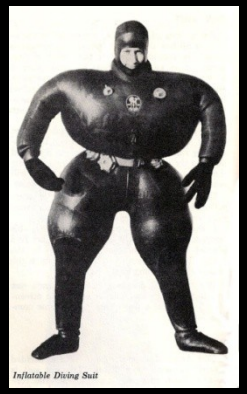
Third Layer: Dry Suit

Keeps the insulation dry
Protects insulation from abrasion
Allows efficient, reliable cold water diving



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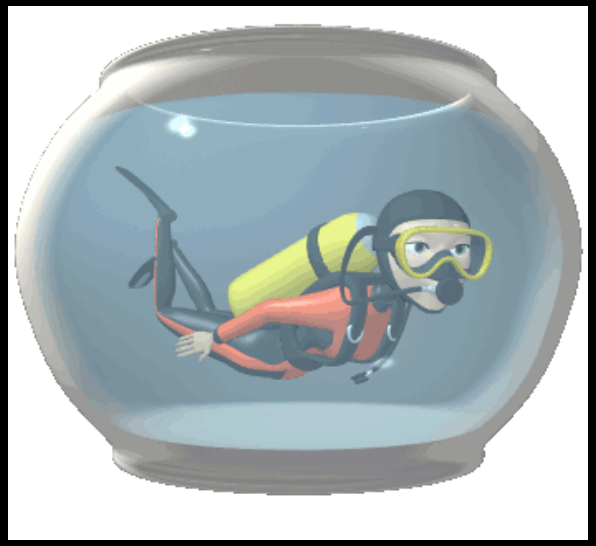
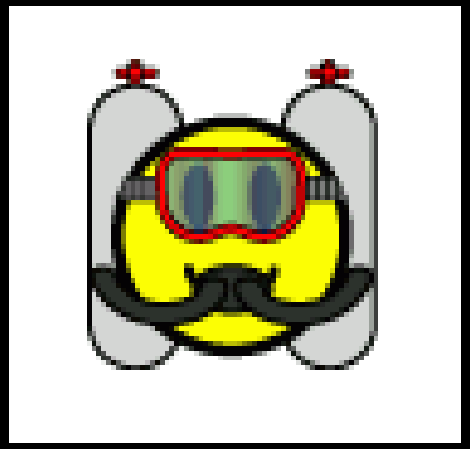


Wet vs. Dry Suits



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Summary of Wet Suit Properties

Insulation: gas trapped in neoprene material
tight fit restricts water flow (conductive / convective heat loss)

Advantages: inexpensive
reasonable protection in temperate water environments
rapid deployment

Disadvantages: insulation (gas bubbles) decreases with depth
insulation decreases with age (gas bubble cells rupture)
buoyancy decreases with depth
ineffective in water below 60 ^{o}F
wind-chill on the surface
needs close fit
rush of cold water on entry
repair only when dry
chill increases air consumption

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Summary of Dry Suit Properties

Insulation: separate from outer shell
variable to match diver to water temp, work load and comfort

Advantages: constant insulation thermal protection
constant insulation buoyancy
don't need perfect fit
easy field repairs
no cold water rush on entry
consistent air consumption
longer "dive season"
Reasonable post-dive thermal protection

Disadvantages: expensive
requires multiple undergarment packages
specialized training to use efficiently
longer deployment time
can overheat on surface
require more weight than wet suit

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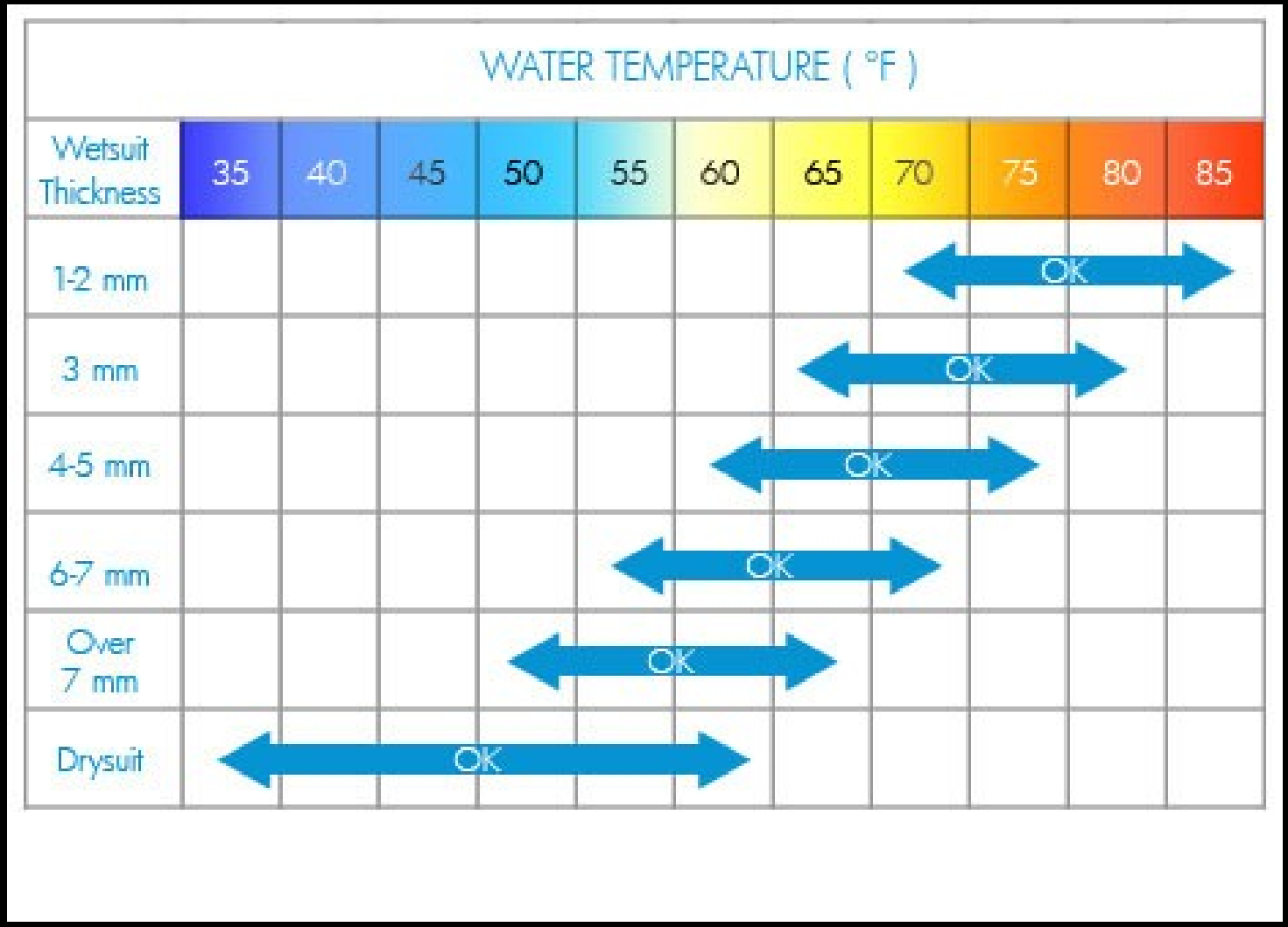
General Guidelines for Personal Thermal Protection



Cold Water is defined as < 70 º F

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Suit Thickness

mm	inches
2	0.089
3	0.118
4	0.157
5	0.197
6	0.236
7	0.276
8	0.315
10	0.394
12	0.472
14	0.551

Can be listed in either Metric or English Units

Fraction	Decimal
1/8	0.125
1/4	0.250
1/2	0.500

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Wet vs Dry Suits

WETSUITS

-Warmth from water trapped close to skin

-Wet = Warm

-Neoprene insulation

-Inexpensive option

-Multiple styles

-Multiple thicknesses

DRYSUITS

-Warmth from full body protection

-Wrist and neck seals

-Integrated booties

-Fully waterproof

-Loose fitting

-Expensive

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