

# Body Cooling Technology Study for Shipyard Worker Safety and Performance

Final Project Report 02/25/2025

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# Body Cooling Technology Study - Outline

- Planning and Testing
  - Team, Objectives, Key Tasks and Deliverables
  - Stakeholder Analysis Process, KPIs, 3 Work Scenarios
  - Market Survey, Garment Selection and Purchasing
  - Test Plan Development, Activities and Schedule
- Data Analysis and Interpretation
  - Data Preprocessing and Data Analysis Methods (optional)
  - Test Results and Feedback from the Volunteers
  - Observations and Interpretation of Results
  - Implementation Plan

Multi-SY Team:  
HII Ingalls Shipbuilding  
HII Newport News SB  
Bath Ironworks  
Pearl Harbor Naval SY  
ATI & NSRP reps

# Team, Objectives, Key Tasks and Deliverables

- Prime/Lead

- HII – Ingalls Shipbuilding

- Team Members

- HII – Newport News Shipbuilding
- Bath Iron Works
- Pearl Harbor Naval Shipyard (unfunded participant)

- Objective

- Explore commercially available and high TRL developmental body cooling technologies, for improved safety and performance of shipyard workers

- Duration

- 12 Months (2/2024-2/2025)

- Key Tasks

- Select test garments based on cooling technologies and methods
- Pilot test several options and assess key parameters for heat relief, comfort, ergonomics, and health safety
- Draft potential implementation plans and costs
- Assess financial feasibility to make body cooling widely available to shipbuilders

- Deliverables

- Stakeholder analysis, with KPIs
- Market survey of available products
- Test plan for pilot demonstration
- Test results
- Implementation plan
- Final report

# Stakeholder Analysis Process & KPIs

- Study performed:
  - Interviewed 28 participants from 4 shipyards: Newport News, Ingalls, Bath Ironworks, Pearl Harbor NSY
  - Half were shipyard workers from Operations and Maintenance teams; half were shipyard experts from Environmental Health & Safety, Human Resources, Research & Development, and Labor Relations
- Key Performance Indicators (KPIs):
  - Fire-retardant/flame-resistant – approved for hot work
  - Not bulky, i.e. not prohibiting or restricting movement
  - Not producing water from room-air condensation
  - Worn over clothing vs. worn under jumpsuit; tethered vs. free-moving
  - Cooling method and technology (convection, evaporation, phase change, etc.)
  - Material phase-change temperature (for PCM, water/ice, etc.)
  - Made/manufactured/shipped from a U.S. company
  - Durability, longevity, maintainability, affordability and ownership
- Some common features would be evaluated for each of the body cooling garments tested

## Question Categories

- Part 1: Environmental Health & Safety
- Part 2: Operational Conditions
- Part 3: Prior or Anticipated Use of Cooling Garments

# Three Test Scenarios for this Study

## Scenario 1:

- **Cooling garments are worn under a jumpsuit**
- Needed for stationary work; worker can be tethered to compressed air source
- Example of worker:
  - Paint Blasters
  - Grinders



## Scenario 2:

- **Cooling garments are worn under worker PPE**
- Needed for active, full mobility work
- Example of worker:
  - Firefighters
  - Hazmat Teams
  - Welders



## Scenario 3:

- **Cooling garments need to be lightweight, affordable, and provide SPF coverage**
- Needed for full mobility work in small spaces
- Example of worker:
  - Machinery
  - Electrical
  - Piping



# Garments Selected by Underlying Technology

## Phase Change Materials (PCM)

Materials that store thermal energy. When they absorb heat, they melt (solid to liquid) and must be recharged (frozen) to be used again.

- WATER/ICE changes phase at 32 deg F; easy to access but uncomfortably cold on skin surface
- PCM used in cooling vests melts at 65 deg F; more comfortable and takes longer to melt

**CONDUCTION – PHASE CHANGE**

## Forced Air Cooling

Forced air flow picks up moisture and cools the skin

- TDA cooling shirts have a battery-operated fan attached to the hip which blows air through channels in the shirt and out to environment
- ALLEGRO vests use compressed air (supplied by shop air) plus a vortex tube attachment, which separates warm/cool air then cool air blows through the vest

**CONVECTION – VORTICITY**

## Wet Cooling Materials

AKA “Hydro Active” technology for wet cooling. The garments are wetted prior to wearing, which accelerates natural evaporation (due to exposure to the human body) to cool down the body.

**EVAPORATION – PHASE CHANGE**

## Dry Cooling Materials

AKA “Vapor Active” technology for dry cooling features. The material wicks away sweat off the skin, dispersing out the moisture over a greater surface area so it evaporates faster. User feels cool and dry.

**EVAPORATION – WICKING**

# Test Garments for 3 Scenarios

Technology Legend

PCM
Hydro (wet)
Forced Air
Vapor (wick)

## Testing Scenario 1



8450 Low Profile Vortex Cooling Vest (forced air)



8300 Vortex Cooling Vest (forced air)



Full Mask Vortex Cooling Respirator (forced air)

## Testing Scenario 2



HyperKewl Hydro-Active Orange Vest



TDA Prototype Cooling Shirt (with Fan)



GlacierTek PCM Cool Vest



Baseline against TechNiche Vests

## Testing Scenario 3



Mission Hydro-Active Safety Shirt



Mission Hydro-Active Helmet Liner



Tech Niche Hydro-Active Helmet Liner



Tech Niche Hydro-Active Neck Shade



Mission Hydro-Active Bandana



Ergodyne UV Dry Wicking Long Sleeve



Arctic Cool Wicking White Shirt



Mission Vapor-Active Beanie

Hydro-Active Wet Feel

vs.

Vapor-Active / Wicking Dry Feel

# Test Plan Development

- Garments were purchased in order of speed-to-acquire
  - This became S3 then S2 then S1
- Project team members identified volunteers for testing; provided them with a garment and a questionnaire
- Most tests ran an average of 7 days, with some at 1-day and some 21+ days
  - Two exceptions: 3-months (3.4 Bandana) and 4-months (3.7 Mission safety shirt)
  - Total 1800 man-days tested plus these 2
- Some volunteers tested multiple garments in series (not together)

NSRP

National Shipbuilding Research Program

## Questionnaire for Body Cooling Garment Testing

Please think about these questions while you are testing the products. This questionnaire will be filled out and collected when you are done testing. If you have any questions or need to drop off the questionnaire please contact Paulina Phillips. (228) 935-6876

### Demographics

- 1 What is your Name:
- 2 What is your Department:
- 3 What is the Body Cooling Garment you are testing?
- 4 Date(s):
- 5 Shifts Tested (AM, PM, Both)
- 6 What kind of work do you do?
- 7 What is the shipyard location of where you'll be testing?
- 8 Is that indoors, outdoors, in an open building, in the sun or shade, or onboard a ship?
- 9 Was your work environment cooler, the same, or hotter than ambient outdoor air?
- 10 How long did you wear this garment? (*Total days and hours per day*)

### Assessment

(For scale, 1 is very negative, 2 somewhat negative, 3 neutral, 4 somewhat satisfied, 5 very satisfied)

- 11 Did the garment condensate / collect moisture? *Yes or No*
- 12 Did you feel wet while wearing the garment? *Yes or No*
- 13 Did this product fit well into your work attire requirements? *Yes or No*
- 14 Did the garment keep you cool for a full work shift? *Scale 1-5*
- 15 Did the garment interfere with your ability to perform your work? *Scale 1-5*
- 16 Did this make an improvement in your work day comfort? *Scale 1-5*
- 17 Do you think the garment would fit multiple body types? *Scale 1-5*
- 18 Were you satisfied with the cooling effectiveness if this garment? *Scale 1-5*
- 19 Do you think the garment enhances your personal safety? *Scale 1-5*
- 20 Do you think the garment enhances your job productivity? *Scale 1-5*
- 21 Was the garment fast and easy to put on and remove? *Scale 1-5*
- 22 If this was readily available, would you use this garment? *Scale 1-5*
- 23 Do you have any general feedback or comments? Please describe below. Thank you!



# Test/Activity Timeline 2024-25 (Actual) and Temps

MAR-APR 24    MAY    JUN    JUL    AUG    SEP    OCT    NOV-DEC    JAN-FEB 25

Stakeholder Analysis

Market Survey

Develop Test Plan

Order Garments

Test Scenario 3  
(6/20-8/16)

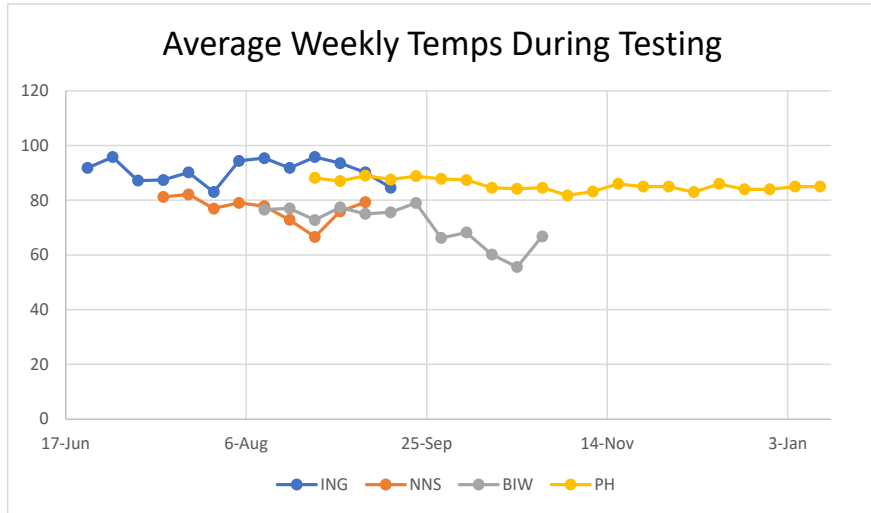
Test Scenario 2  
(7/22 – 9/5)

Test Scenario 1  
(9/4 to 1/10)

Data Analysis

Implementation Plan

Test Report and Final Report



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S	Test Article Number/name	Tests
1	1.1 Allegro 8300 vest	12
	1.2 Allegro 8450 low profile vest	14
	1.3 Allegro 9902 Respirator	0
2	2.1 TDA black shirt	10
	2.2 GlacierTech PCM Vest	20
	2.3 TN/HK Orange Evap Vest	11
	2.4 TN/HK Blue Ice Vest	6
3	3.1 TN/HK Beanie /Helmet Liner	13
	3.2 Mission Beanie/Skullcap (VA)	25
	3.3 Mission Beanie/Helmet Liner (HA)	21
	3.4 Mission Bandana	26
	3.5 TN/HK Neck Shade FR	22
	3.6 Ergodyne LS Sun Shirt	21
	3.7 Mission Safety Shirt (HA) yellow	27
	3.8 Mission Perform Shirt (VA) Red	6
	3.9 Arctic Cool Wicking Shirt White	12
	Sum Total Samples	257

# Data Processing and Data Analysis Methods

- Results from Questionnaires were digitized; score 1 low, 5 high
  - All results concatenated into array; one data sheet per column
- Comments addressed separately, summarized per garment
- Data standardization
  - For example, garments names conform to a consistent name like "2.4 GlacierTech PCM Vest" vs. 'grey vest' or 'cooling vest grey'
- Modified Q15
  - Both question and response for Q15 were flipped, so that a positive response is represented by score of 5; therefore for all Q's, a score of 5 is positive
- Transpose so one data sheet per row; enables sorting
  - Can sort responses by shipyard, garment ID, question, etc.
- Table has average value of each analyzed garment for that question
- Built bar charts to compare and understand results

# Results: Average Score of Each Garment for Each Question

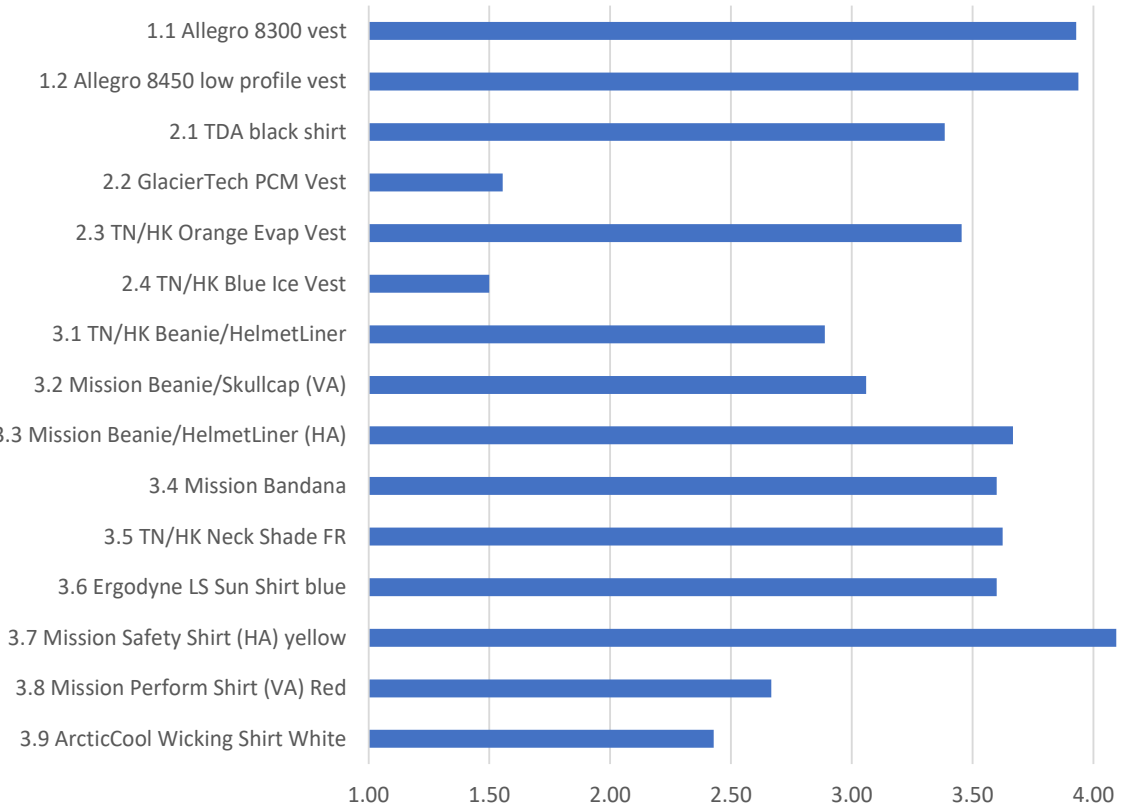
Garments in Column, Questions in top row, Responses rated from low agreement (1) to high agreement (5)	Cool for full work shift?	Not interfere with work	Improve my comfort	Multiple body types?	Effective cooling?	Enhances my Safety?	Enhances my Productivity?	Fast/easy to put on?	If available, would I use?	Sample Size (N)	# Questions averaged 4+
1.1 Allegro 8300 vest	3.93	2.71	2.71	2.64	3.64	2.36	2.71	3.07	2.57	12	0
1.2 Allegro 8450 low profile vest	3.94	2.56	4.06	3.56	4.56	3.22	3.61	4.06	4.19	14	4
2.1 TDA black shirt	3.38	3.15	3.85	2.29	3.32	2.15	3.23	3.31	3.00	10	0
2.2 GlacierTech PCM Vest	1.56	3.68	2.31	2.89	2.37	1.96	2.19	3.38	2.69	20	0
2.3 TN/HK Orange Evap Vest	3.45	4.08	3.70	3.55	3.73	3.60	3.60	4.00	4.00	11	3
2.4 TN/HK Blue Ice Vest	1.50	3.67	2.00	2.83	2.17	1.50	1.83	3.83	1.67	6	0
3.1 TN/HK Beanie/HelmetLiner	2.89	3.92	2.77	4.11	3.38	2.00	2.44	4.33	3.15	12	2
3.2 Mission Beanie/Skullcap (VA)	3.06	3.12	3.20	4.24	3.64	2.53	2.71	4.65	3.56	17	2
3.3 Mission Beanie/HelmetLiner (HA)	3.67	2.52	3.48	4.20	3.57	3.07	3.13	4.87	4.10	15	3
3.4 Mission Bandana	3.60	2.69	3.92	4.35	4.19	3.55	3.40	4.75	4.54	20	4
3.5 TN/HK Neck Shade FR	3.63	2.59	3.55	4.13	3.27	3.63	3.13	4.00	4.05	16	3
3.6 Ergodyne LS Sun Shirt blue	3.60	3.14	3.81	4.47	3.90	2.73	3.53	4.53	3.90	15	2
3.7 Mission Safety Shirt (HA) yellow	4.10	3.00	3.93	4.52	4.07	3.57	3.67	4.90	4.15	21	5
3.8 Mission Perform Shirt (VA) Red	2.67	2.83	2.83	3.33	3.67	3.00	2.17	3.67	3.33	6	0
3.9 ArcticCool Wicking Shirt White	2.43	2.83	2.92	4.00	3.17	2.57	2.43	4.29	3.00	7	2

# Volunteer Testers' Feedback

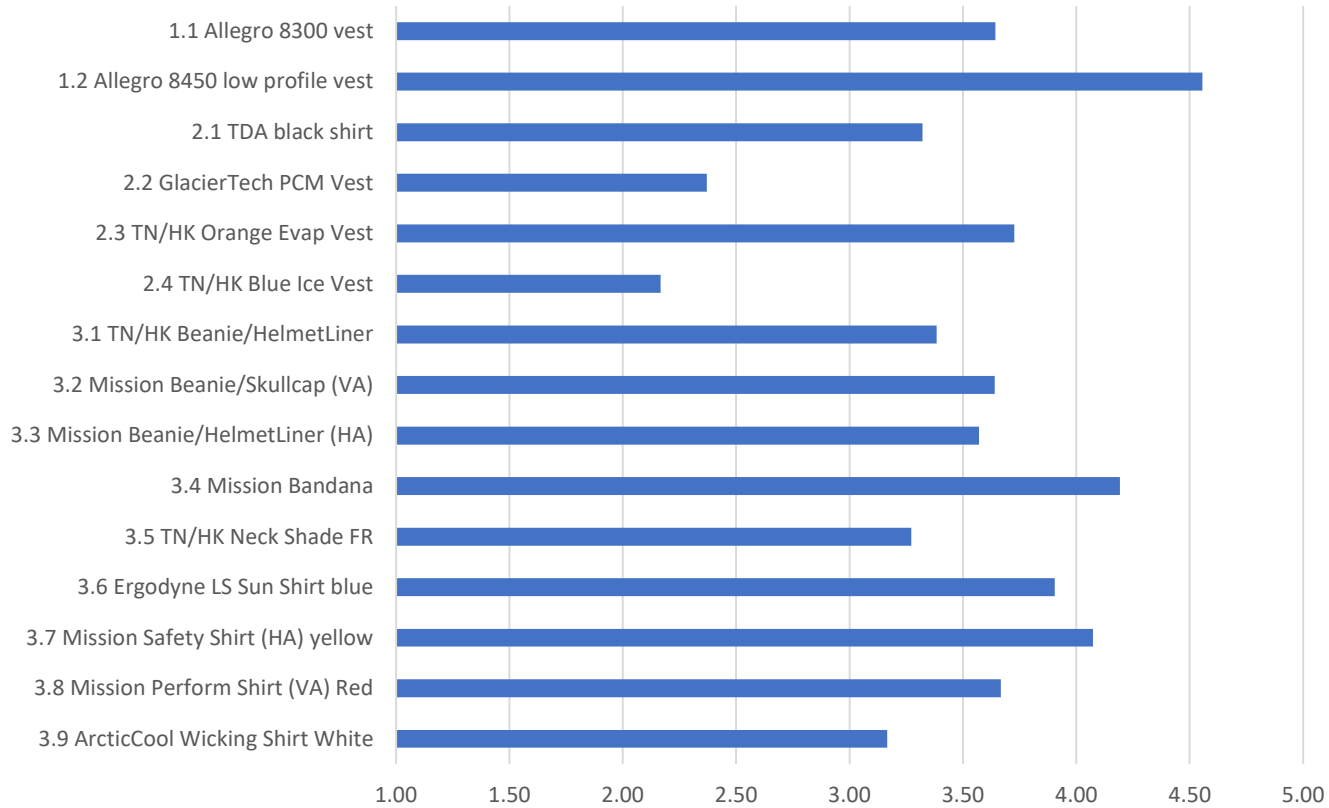
- Item 1.1, Allegro 8300 [Forced air] Vest
  - The vests were big and bulky; vest and air hose didn't fit well under overalls. Testers were excited to test the vests in extreme heat. Vests provided relief that helped them to be more productive and improved work efficiency, for a long time. They were noisy but it was worth the relief. The 8300 vests were boxy on small frame users. Liked the low profile version better.
- Item 1.2, Allegro 8450 Low Profile [Forced air] Vest
  - Similar comments as the 8300 with these exceptions: The vests were ideal for stationary working in the shop. Small frame users noted the vests were more effective at cooling due to slimmer fit. Suggestion to suspend the hose, reducing trip hazard.
- Item 2.1, TDA Black Shirt
  - The leg strap was restrictive due to the detachment feature; it was easy to remove the strap. It could be difficult to maneuver through the hatches with the battery pack on because it was big and bulky. It worked well when doing light work, but did not cool the whole body down and sweat still accumulated.
- Item 2.2, GlacierTech Phase Change Material (PCM) Vest
  - Depending on the type of work the craft worker does, the ice packs could last anywhere from 1-4 hours. Wearers in the inner bottom of the ship noticed that their ice packs lasted about an hour. If they were used during the hotter part of the days, they noticed relief. It did feel cooler when the packs were cold, but they were left damp when the vest [ice packs] thawed out.
  - It would be nice to have multiple packs to exchange and coolers available to freeze the ice packs in the middle of their work shifts. They suggested making the ice packs out of another type of gel/icy material to stay cold longer.
- Item 2.3, Techniche/Hyperkewl (TN/HK) Orange Evaporative Vest
  - Some wearers really liked these and felt the vest was refreshing. Other wearers felt that this garment left them feeling muggy. There was an [odd or unpleasant] smell associated with the vest after it had been worn once and had not properly dried. It was a hassle wetting the vest and rinsing out the excess water. Wearers didn't like feeling wet all day.
- Item 2.4, TN/HK Blue Ice Vest
  - These didn't last longer than 3 hours. They suggested buying multiple packs to trade out so they could get more hours of relief. Note: Ingalls shipyard workers tested these in the prior year and some verbal feedback was that it became wet and attracted dust or was too cold on the skin.
- Item 3.1 TN/HK Beanie (blue)/Helmet liner
  - Some wearers thought the product worked great and was refreshing; some thought it was very thin and didn't tend to work, while one wearer experienced a headache due to it being too tight. Wearers generally said it took some getting used to wearing. One individual felt if it was issued out with PPE, he'd feel encouraged to wear it and thought we may see productivity increase with time.
- Item 3.2 Mission Beanie/Skullcap (Vapor Active)
  - Wearers were not in favor of how tight the skullcaps were. They did say the caps absorbed the sweat very well and fit well under hardhats. Unfortunately, it made their heads slick and their hardhats tended to fall off while they wore the skullcaps.
- Item 3.3 Mission Beanie/Helmet Liner (Hydro Active)
  - Wearers said they would buy these. Said they were comfortable and overall had a nice cooling effect. One wearer said it was tight.
- Item 3.4 Mission Bandana
  - This garment had numerous positive reviews. Wearers seemed to love its versatility. They liked that when they wetted the bandana and wore it, the bandana had a nice cooling effect. They said it's big enough to cover their whole head and they felt cooler and less sweaty while wearing it. Some said the bandanas tend to dry quickly. Some said they didn't have to wet it very often for it to stay cold throughout the day. Many said they'd buy this and that it's a "must have for summers." One wearer said it would be nice for welding attire if it was fire-retardant.
- Item 3.5 TN/HK Neck Shade (Fire Resistant)
  - Many wearers loved the sun coverage on their necks. They would wet it, but felt it provided good cooling affects even without being wet. The open concept allowed a breeze to cool them off while they wore the neck shades. One wearer said he noticed a difference in his level of stamina while wearing it throughout the week.
- Item 3.6 Ergodyne Long Sleeve Sun Shirt
  - They liked that these were lightweight and tended to dry quickly. The shirt soaked up sweat and provided cooling relief. Some suggested turning it into a hoodie to include neck coverage. The only complaint was that it didn't seem to do much when it was placed under long-sleeves when used for welding purposes. Some requested it be fire-retardant. One wearer said he would purchase several of these for personal use.
- Item 3.7 Mission Safety Shirt (Hydro Active) in yellow
  - Most wearers said it was a great shirt. It was comfortable to wear, it collected moisture, provided a good cooling effect and was very versatile. They wish it would have been fire-resistant and they didn't like the color. One wearer noted it helped with productivity and he was able to focus longer and better.
- Item 3.8 Mission Performance Shirt (Vapor Active) in red
  - This seemed to prevent sweat along the torso but not the arms. Wearers said they would have preferred if this were long-sleeve.
- Item 3.9 ArcticCool Wicking Shirt in white
  - Many wearers did not care for the color. They said the white got dirty too quickly. They didn't feel it was appropriate for heavy construction. It was too thin and delicate. It seemed well made, but didn't seem to provide much of a cooling effect.

# Test Results (Garment Avg. Scores for Q14, Q18)

Q14: Did the garment keep you cool for a full work shift?

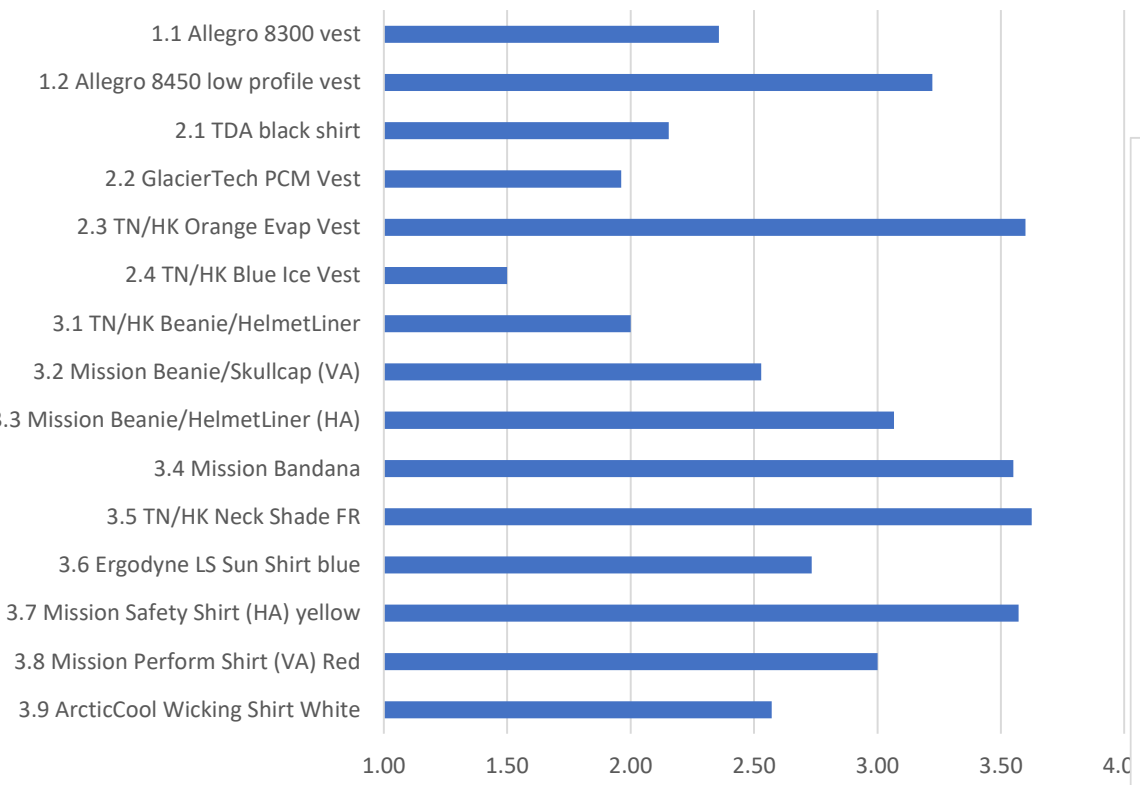


Q18: Were you satisfied with the cooling effectiveness if this garment?

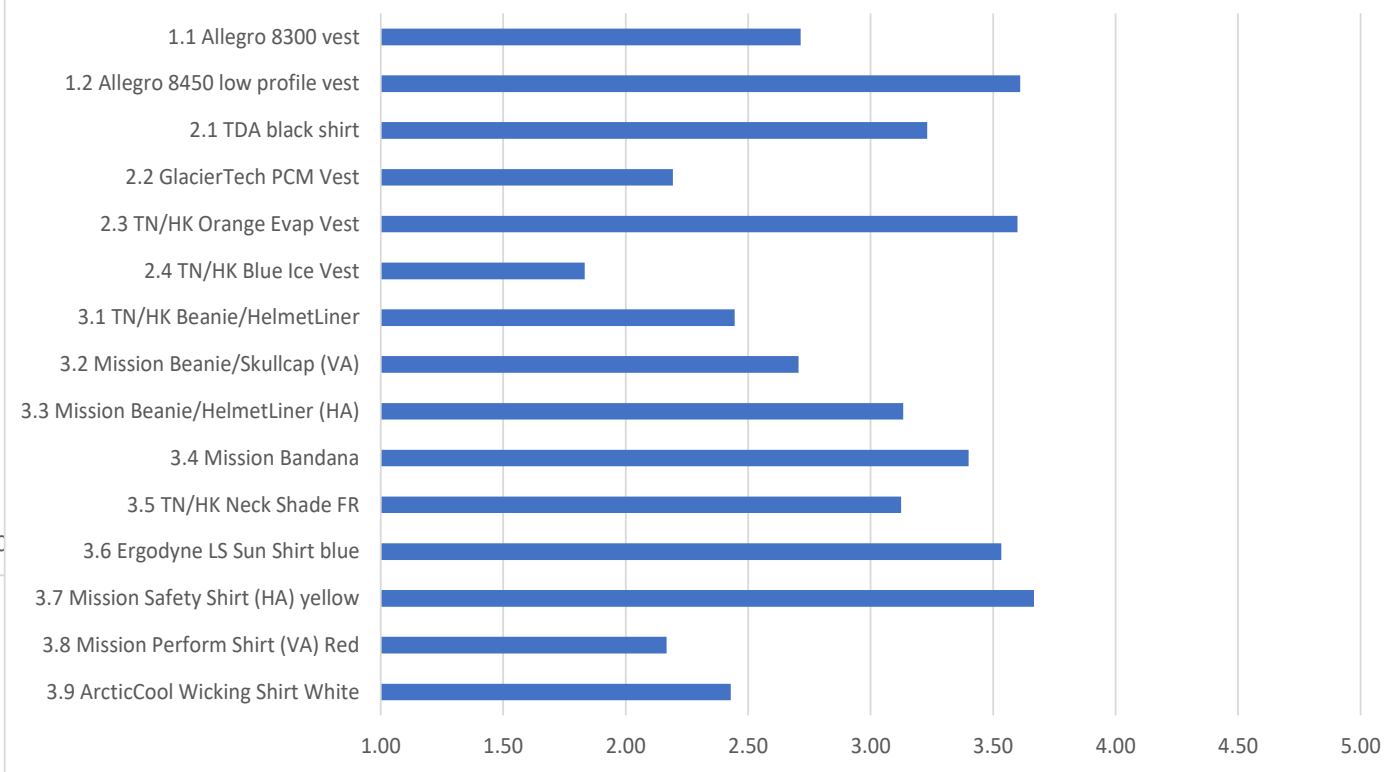


# Test Results (Garment Avg. Scores for Q19, Q20)

Q19: Do you think the garment enhances your personal safety?

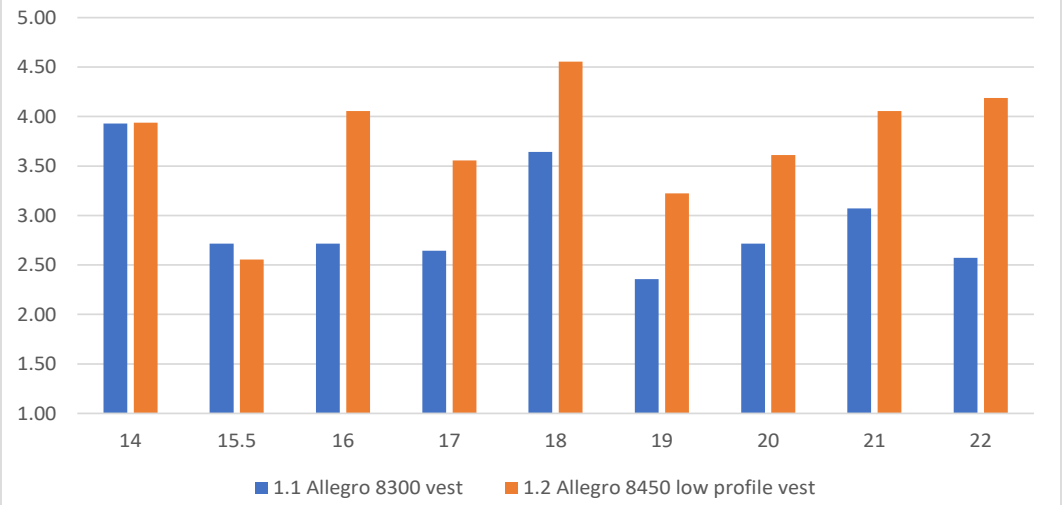


Q20: Do you think the garment enhances your job productivity?

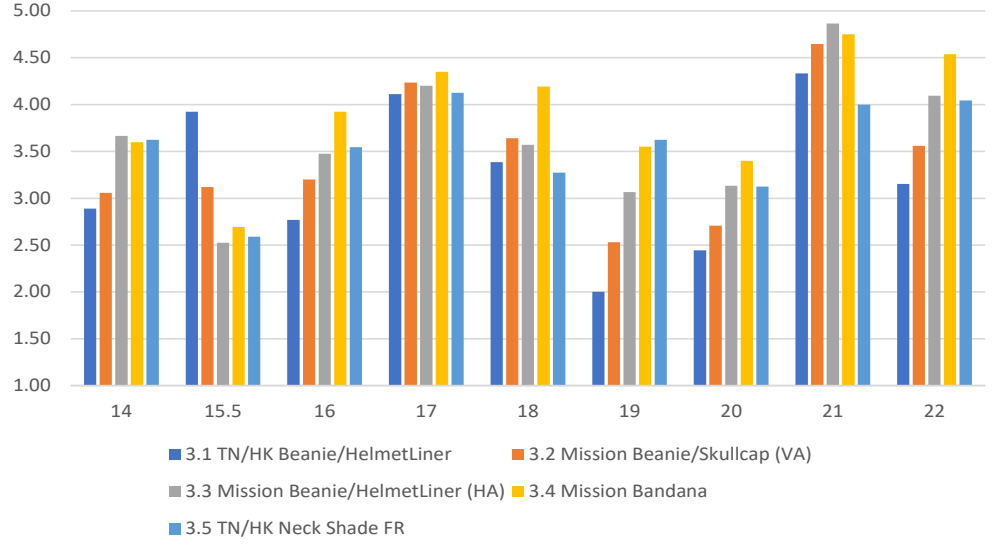


# Test Results (Average Scores vs. Question Number)

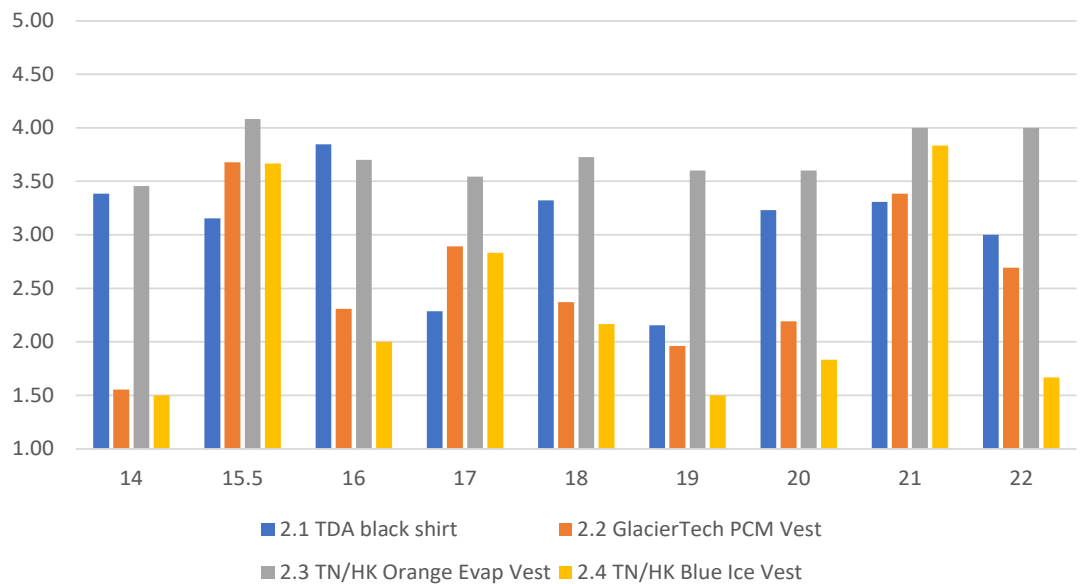
Compare Results for Scenario 1 Garments



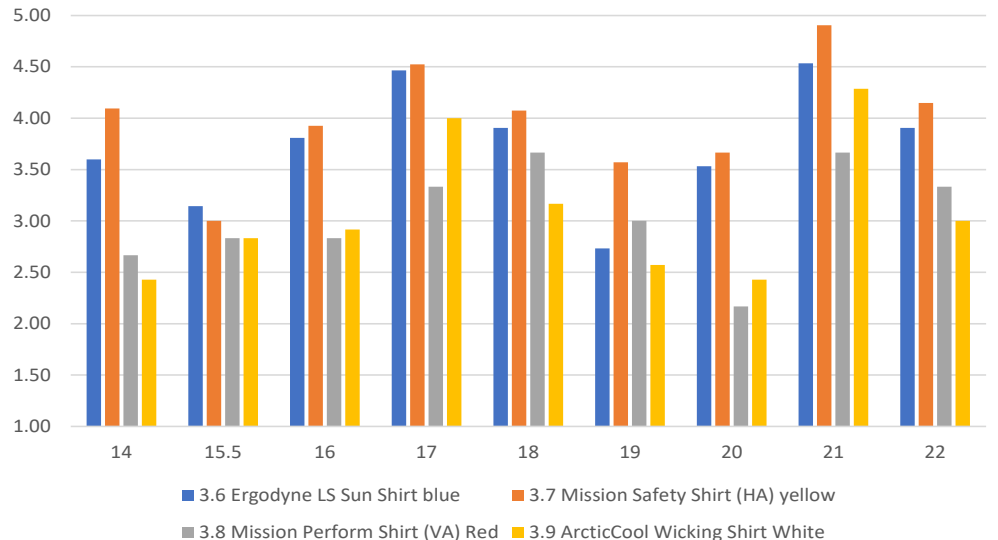
Compare Head/Neck Cover Garments of Scenario 3



Compare Results for Scenario 2 Garments

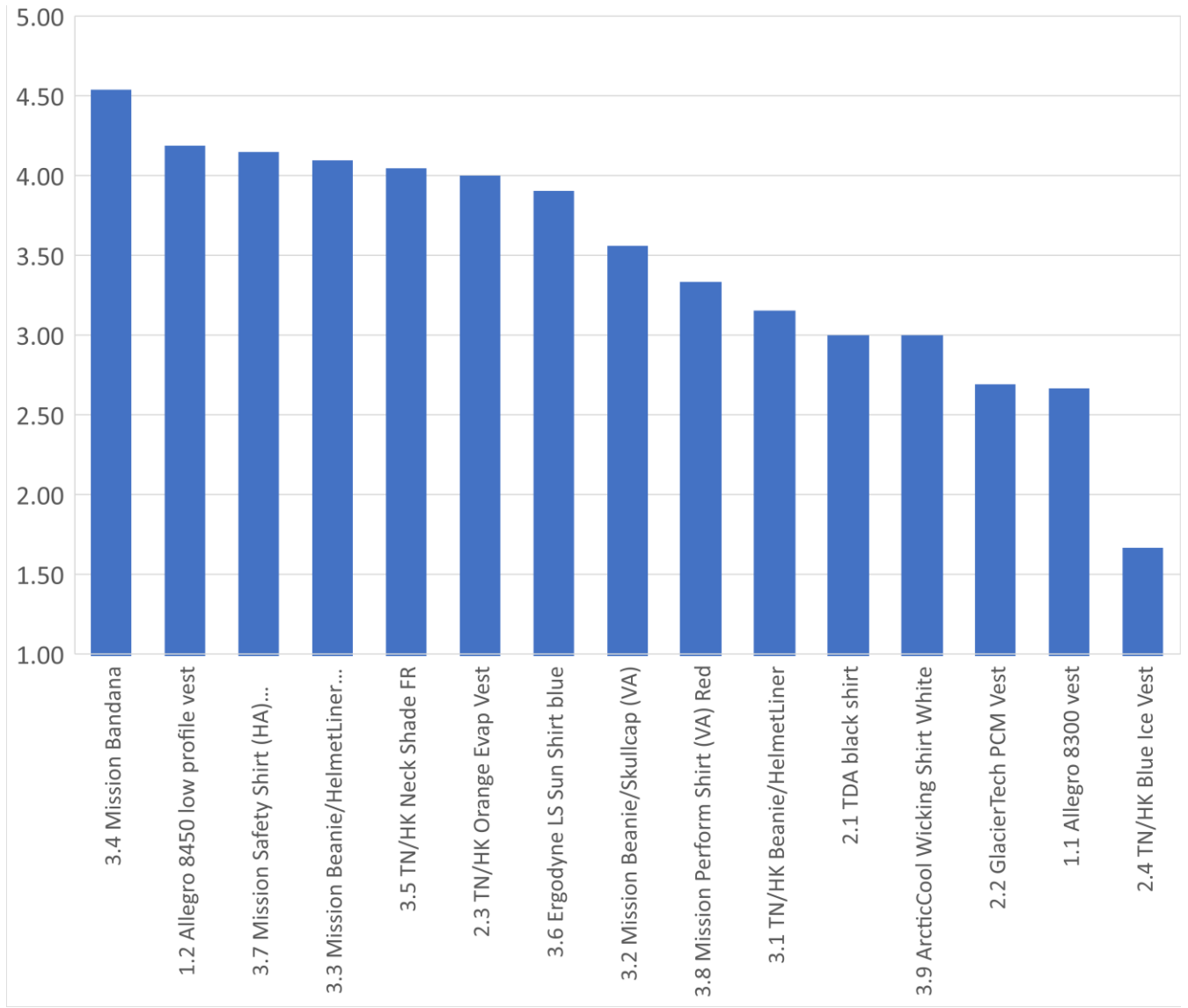


Compare Shirts Garments of Scenario 3





# Test Results: Most Likely to be Adopted



Pareto of Question 22, “If available, would you use this garment?” vs. average score (1 low to 5 high) of each garment

Top scores were

- Item 3.4 Mission Bandana
- Item 1.2 Allegro 8450 low profile vest
- Item 3.7 Mission Safety Shirt (HA)

And several other garments scored well

# Summary of Results

- The top three scoring garments overall were:
  - 3.4 Mission Bandana was most likely to be used and scored high in most categories
  - 1.2 Allegro 8450 low profile vest scored best for comfort and cooling effectiveness
  - 3.7 Mission Safety Shirt (HA) yellow scored best for all-day endurance

Work Scenario	Body Cooling Garment Tested	Q22 Avg. Score	Price per Garment
1) Forced Air Vest	1.2 Allegro 8450 low profile vest	4.19	\$\$\$
2) Mobile Vest	2.3 TN/HK Orange Evap Vest	4.00	\$\$
3/ Head Cover (three options)	3.4 Mission Bandana	4.54	\$
	3.3 Mission Beanie/Helmet Liner (HA)	4.10	\$
	3.5 TN/HK Neck Shade FR	4.05	\$
3/ Shirt (2 options)	3.7 Mission Safety Shirt (HA) yellow	4.15	\$\$
	3.6 Ergodyne LS Sun Shirt blue	3.90	\$\$

\$ = under \$20 Highly Affordable  
 \$\$ = \$20-60 Affordable for Many  
 \$\$\$ = \$60-\$250 Less Affordable for Most  
 \$\$\$\$ = over \$250 Least Affordable

- Effective cooling garments can be found in all price ranges
- Affordable shirts and head coverings can benefit a broad group of users
- Vests for scenario 1-2 may be outside of what individuals can pay out-of-pocket
- These are the recommended items for initial pilot implementation in shipyards

# Implementation Plan Concepts

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  - Question 11: Distribution of More Expensive Garments..... 8
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  - Question 13: Risk and Mitigation ..... 9
  - Question 14: Open Suggestions..... 9

- The team addressed a number of questions and recommendations

# Thank you to NSRP and All the Participants!

ROLE	ORGANIZATION	PERSON	TIME ZONE
Project Lead/Prime	Ingalls Shipbuilding	Karen Cassidy	Central
Industry Team Members	Ingalls Shipbuilding	Paulina Phillips	Central
	Newport News Shipbuilding (NNS)	Ean Greene	Eastern
	Bath Ironworks (BIW)	Scott Christman	Eastern
Participating Navy Stakeholder	Pearl Harbor Naval Shipyard (PHNSY)	Shayla Deitch	Hawaii (East-6H)
NSRP Project Technical Rep (PTR)	NSRP Sustainment Panel	Kaipo Crowell	Hawaii (East-6H)
NSRP Program Manager	Advanced Technologies International (ATI)	Steve Gaschler	Eastern
Advisor	TDA Research Inc.	David Eisenberg	Mountain

