Physiological Status Monitoring (PSM) for the National Guard Bureau's Weapons of Mass Destruction – Civil Support Teams (WMD-CSTs)

William J. Tharion, MS, MBA
william.j.tharion.civ@mail.mil

Biophysics and Biomedical Modeling Division
U.S. Army Research Institute of Environmental Medicine
Building 42, 10 General Greene Avenue
Natick, MA 01760

BRIEFING OUTLINE

1. **Outcomes, Requirements, and Capability Gaps**

2. **Thermal Physiology – Basic Overview**

3. **Accomplishments – Science and Technology**
   - Understanding User Needs
   - Development Efforts (System and Algorithms) and Testing

4. **Acquisition Strategy**
   - Source Selection; Commercial-of-the-Shelf (COTS) vs. Government Developed
   - Funding
   - Documentation Required for Approval

5. **Future Objectives – Address Other CBRN User Needs**

1. Outcomes, Requirements, and Capability Gaps

Need for Real Time Heat Strain Monitoring (RT-HSM)

- **The US faces unprecedented CBRN threats**
  - Encapsulated CBRN operators risk heat illness or injury but lack individualized heat strain monitoring capabilities
  - Training exercises commonly minimize heat strain by limiting work intensity and duration, and avoiding unfavorable weather conditions
  - ***What happens when actual events demand intense, sustained work under adverse conditions?***
    - Excessive heat strain, compromised operational effectiveness and personnel safety
    - Potential compromised training could lead to comprised responses in addressing real-world problems
- **Capability gap**: RT-HSM capability

Functionally Aligned WMD-CST Personnel Outcomes

- **Human Dimension -** Assessment, Readiness and Resiliency - The Army requires Soldiers/Operators be able to endure a wide range of physical, mental, and environmental stresses of future full spectrum operations

- **Sustainment** - The future medical force requires the capability to capture, process, and disseminate real-time medical information on the Soldier's/Operator's physiological status, injuries, illnesses, and treatment provided from the point of injury through definitive care. This provides the commander and medical personnel a greater awareness of Soldier/Operator status .

2. Thermal Physiology - Basic Overview

WMD-CST personnel engaged in CBRN missions routinely face excessive thermal-work strain and risk of heat illness or injury

Basics of Heat Balance

Metabolic Energy (M)

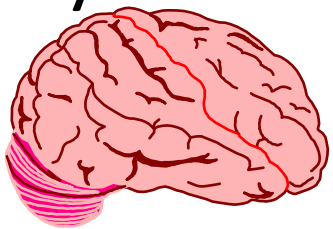
Work (W)

~20%

Heat

~80%

Body Core & Brain



↑ Skin Blood Flow

(R + C)

Radiative & Convective heat loss or gain

↑ Sweating

(E)

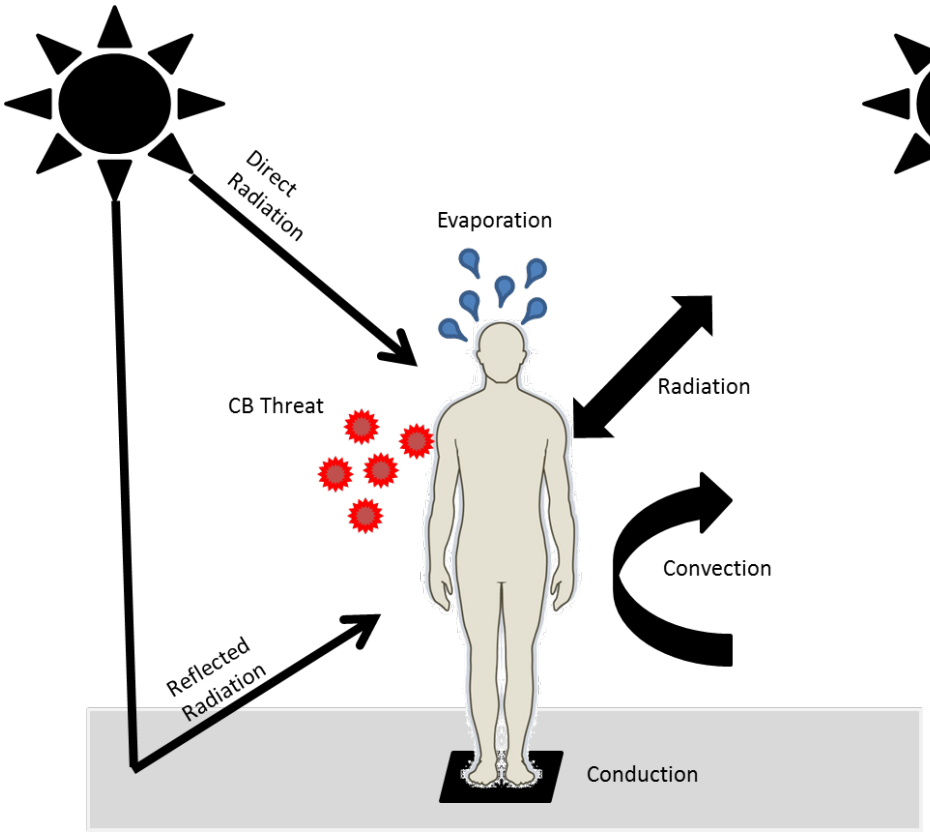
Evaporative heat loss

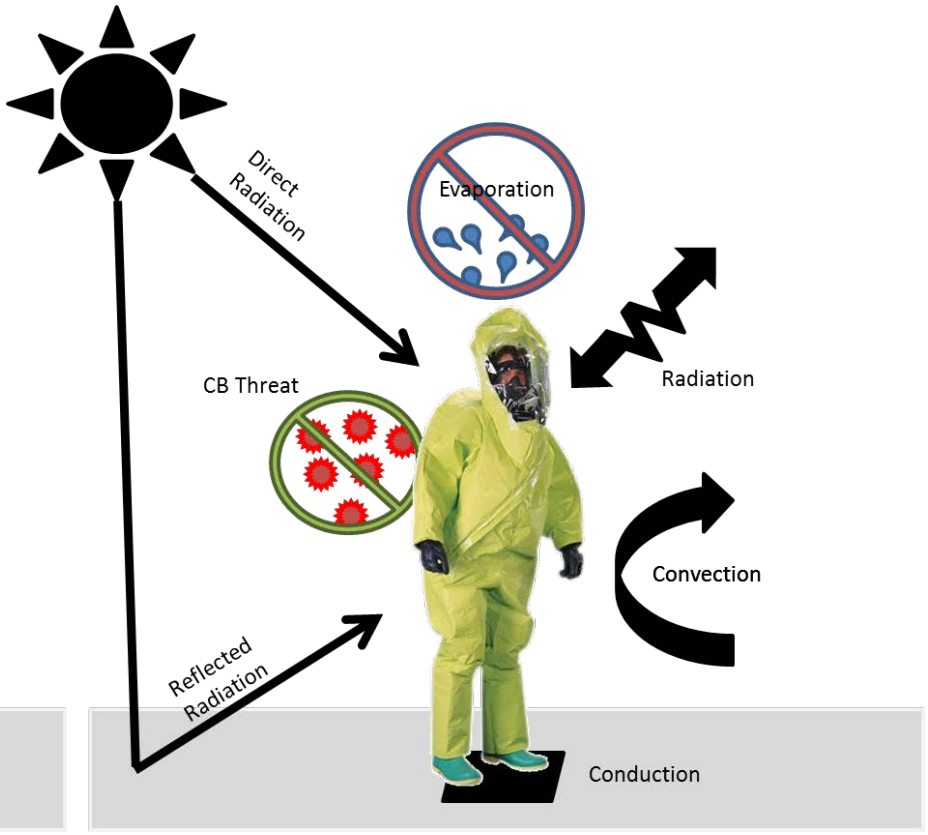
Basics of Heat Balance

$$S = M - W \pm (R+C) - E$$

- M = total metabolic energy production
- W = energy expended in useful work
- R+C = dry heat loss (cool) or heat gain (hot)
- E = evaporative heat loss (sweating)
- S = heat stored

Encapsulation Restricts Heat Loss





Heat Exchange (Radiation/Conduction/ Convection)

Heat Loss (E)

Heat Exchange (Radiation/Conduction/ Convection)

Heat Loss (E)

Thermal Strain Effects

Cardiac output → Brain
Cardiac output → Working muscle
Cardiac output → Skin (thermoregulation)

Increased skin blood flow:

- ↓ Nutritive flow to CNS & working skeletal muscles
- ↑ Work intensity (↑ % VO2max) for a given task
- ↓ Capacity for sustained work, & ↓ cognitive capacity
- ↑ Risk of heat exhaustion and fainting

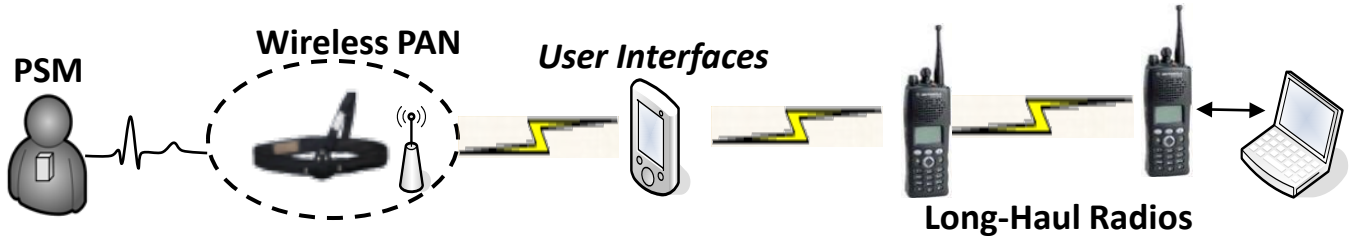
Signs of heat illness

- Dizziness/fainting
- Headache
- Nausea/vomiting
- Weakness
- Muscle cramps
- Unsteady walk
- Rectal temp >38.6°C
- Rapid pulse

3. Accomplishments - Science and Technology

Demonstration of Real-Time Heat Strain Monitoring
22nd Technical Escort, Edgewood, MD

Real-Time Heat Strain Monitoring (RT-HSM) System



Buddy Display

Command Post - Physiological Status & Location

- 14 test volunteers
- Training Exercise: Search and Clear
- PPE: JSLIST with Mask (MOPP IV)
- ~28°C/65% RH, indoors
- HR, Skin/Core temp, PSI
- System acceptability

Physiological Strain Index (PSI) (0-10 thermal-work strain)

Physiological Strain Index (PSI)

Strain Level	PSI	HR (bpm)	Core Temp (°C)
	0	71	31.12
None/Little	1	90	37.15
	2	103	37.35
Low	3	115	37.61
	4	125	37.77
Moderate	5	140	37.99
	6	145	38.27
High	7	159	38.60
	8	**175**	**38.70**
Very High	9		
	10		


A physiological strain index to evaluate heat stress

DANIEL S. MORAN,[1,2] AVRAHAM SHITZER,[3] AND KENT B. PANDOLF[1]

[1]United States Army Research Institute of Environmental Medicine, Natick, Massachusetts 01760-5007; [2]Heller Institute of Medical Research, Institute of Military Physiology, Sheba Medical Center, Tel Hashomer 52621; and [3]Department of Mechanical Engineering, Technion, Haifa 32000, Israel

Moran, Daniel S., Avraham Shitzer, and Kent B. Pandolf. A physiological strain index to evaluate heat stress. Am. J. Physiol. 275 (Regulatory Integrative Comp. Physiol. 44): R129–R134, 1998.—A physiological strain index (PSI), based on rectal temperature (T_{re}) and heart rate (HR), capable of indicating heat strain online and analyzing existing databases, has been developed. The index rates the physiological strain on a universal scale of 0–10. It was assumed that the maximal T_{re} and HR rise during exposure to exercise heat stress from normothermia to hyperthermia was 3°C (36.5–39.5°C) and 120 beats/min (60–180 beats/min), respectively. T_{re} and HR were assigned the same weight and functions as follows: $PSI = 5(T_{re,i} - T_{re,0})/(39.5 - T_{re,0}) + 5(HR_i - HR_0)/(180 - HR_0)$, where $T_{re,i}$ and HR_i are simultaneous measurements taken at any time during the exposure and $T_{re,0}$ and HR_0 are the initial measurements. PSI was applied to data obtained from 100 men performing exercise in the heat (40°C, 40% relative humidity; 1.34 m/s at a 2% grade) for 120 min. A separate database representing seven men wearing protective clothing and exercising in hot-dry and hot-wet environmental conditions was applied to test the validity of the present index. PSI differentiated indexes were derived, among them the wet-bulb globe temperature (29). A modified version of ITT was suggested in 1986 by Gagge et al. (9) that was based on more sophisticated heat exchange models (12). The ET indexes are widely applied to both assess and predict heat strain. However, they lack the capability to adjust for different levels of metabolic rate and different clothing, e.g., protective clothing (15, 24).

In 1937, Winslow et al. (27) developed the operative temperature index (TO), which considered the metabolic heat production ($M_{t,m}$), heat transfer between the body and the environment (E_{max}). Based on the TO capacity of the environment (1), heat exchange models have been developed, more than eight additional indexes have been developed (1). The best known of these is the heat strain index (HSI) suggested by Belding and Hatch (2). This index, which related $M + H_{t,r}$ [total evaporation required (E_{req})] to E_{max} is widely accepted because it combines environmental variables and body activity. However, according to Belding there were situations in

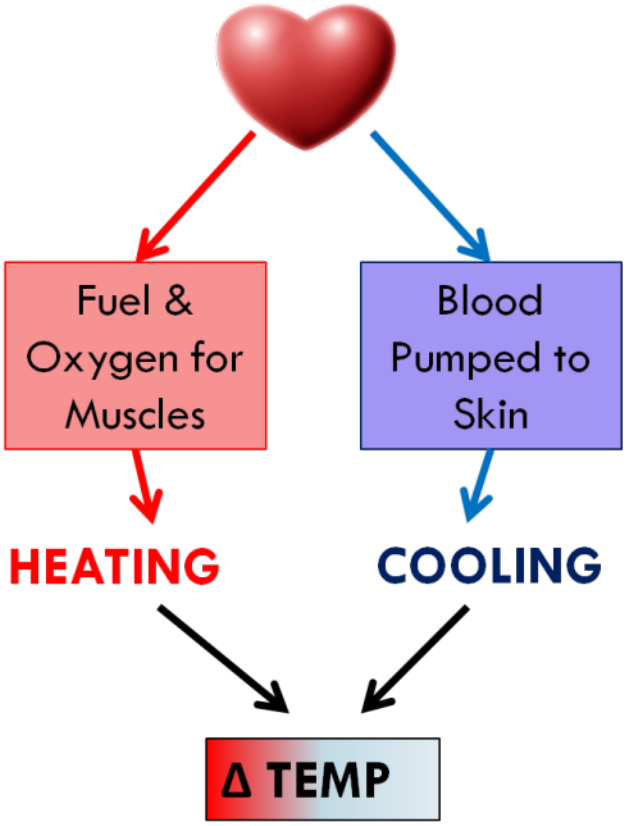
- PSI of 8 reflects a high thermal-work strain level; core temperatures above 38.5°C when encapsulated is associated with a significant risk of heat exhaustion

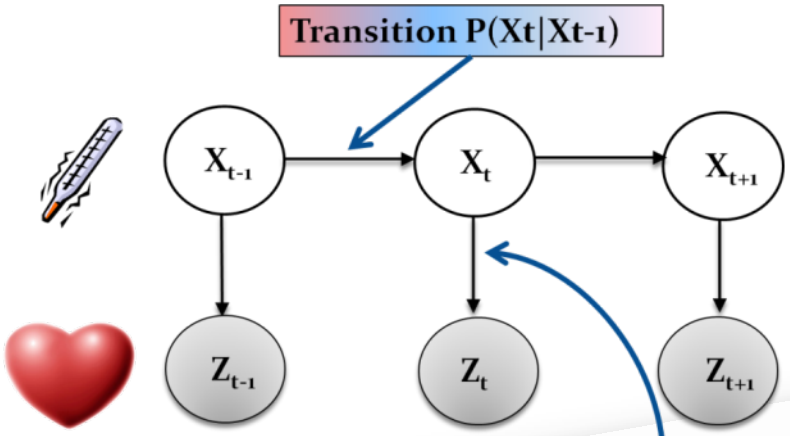
- PSI of 10 and above exceeds USARIEM Institutional Review Board (IRB) safety limits for heart rate (180 bpm) and rectal core temperature (39.5°C)

From Moran et al., (1998) A physiological Strain index to evaluate heat stress. *Am J Physiol Regul Integr Comp Physiol*: R239-R134.

Computational Physiology

HR "Noisy" Observation of Core Temp





IOP PUBLISHING
Physiol. Meas. 34 (2013) 781–798

Estimation of human core temperature from sequential heart rate observations

Mark J Buller[1,4], William J Tharion[1], Samuel N Cheuvront[1], Scott J Montain[1], Robert W Kenefick[1], John Castellani[1], William A Latzka[1], Warren S Roberts[2], Mark Richter[3], Odest Chadwicke Jenkins[4] and Reed W Hoyt[1]

[1] US Army Research Institute of Environmental Medicine, Natick, MA 01760, USA
[2] Defence Science and Technology Organization, Melbourne, Australia
[3] Marine Corps System Command, Quantico, VA 22135, USA
[4] Department of Computer Science, Brown University, Providence, RI 02912, USA

E-mail: mark.j.buller.civ@mail.mil

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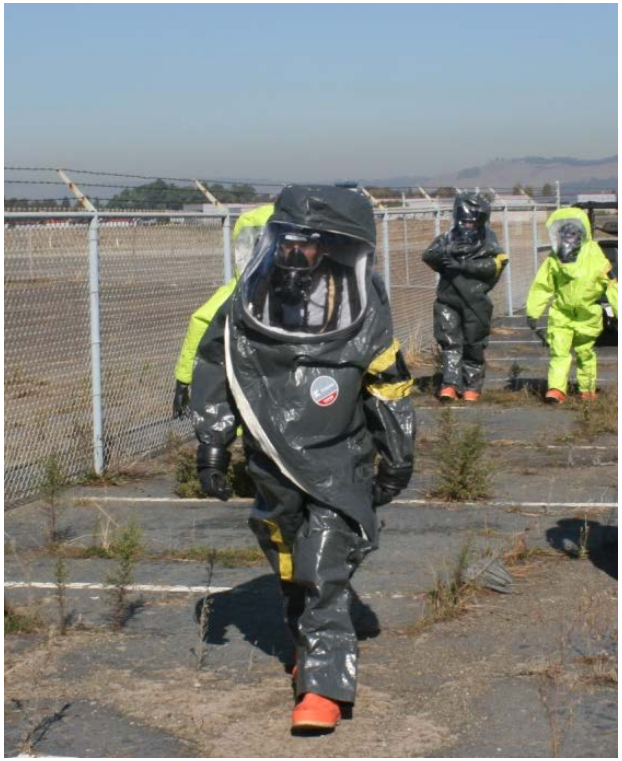
Thermal-work Strain During 95th CST-WMD CBRN Training

- Test Volunteers: 7 Experienced Soldiers from 95th Civil Support Team (CST), Weapons of Mass Destruction (WMD)

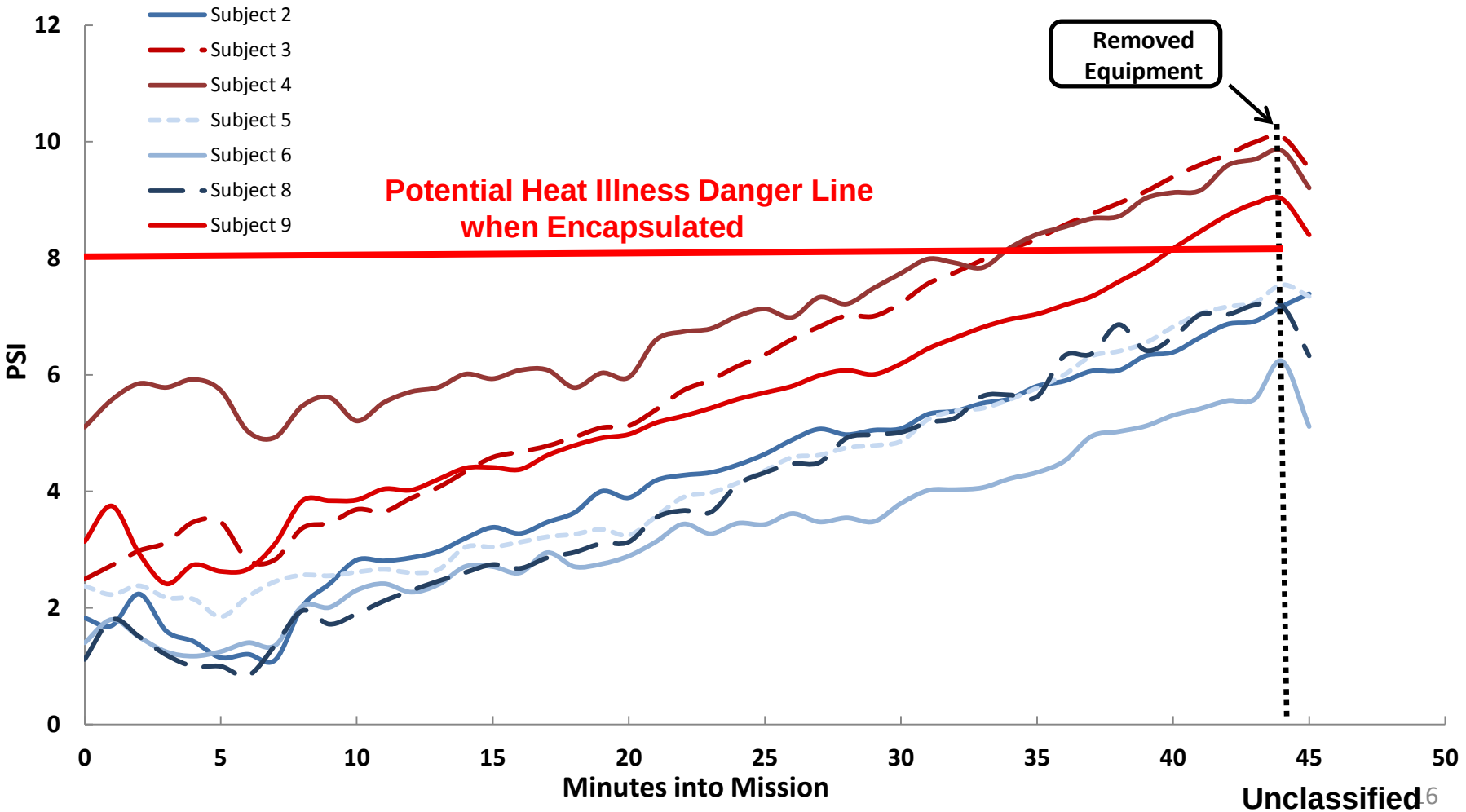
- Training Exercise: Self-paced approach march to a simulated chemical, biological, radiological nuclear (CBRN) incident site

- CBRNE Personal Protective Equipment: Level A with mask and Self Contained Breathing Apparatus (SCBA)

- Weather Conditions:
  - Full Sun (October)
  - Temperature: 22 °C
  - Relative Humidity: 36%

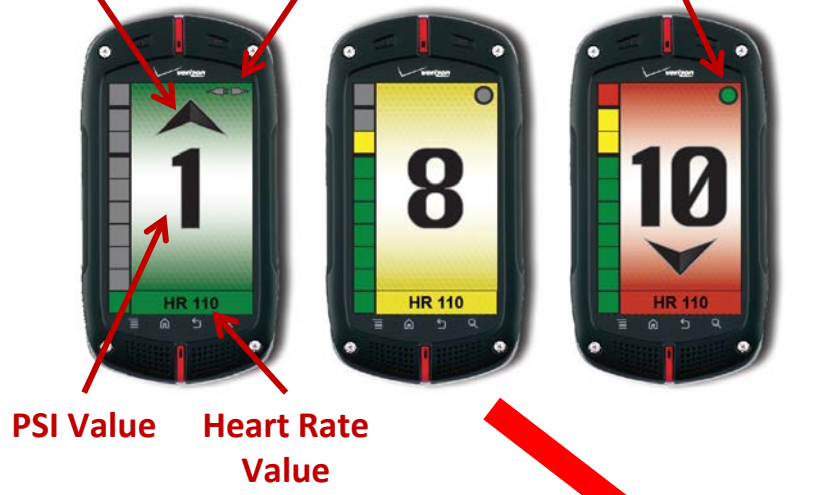


Varied Thermal-Work Strain Levels Among CST-WMD Soldiers Doing the Same Task

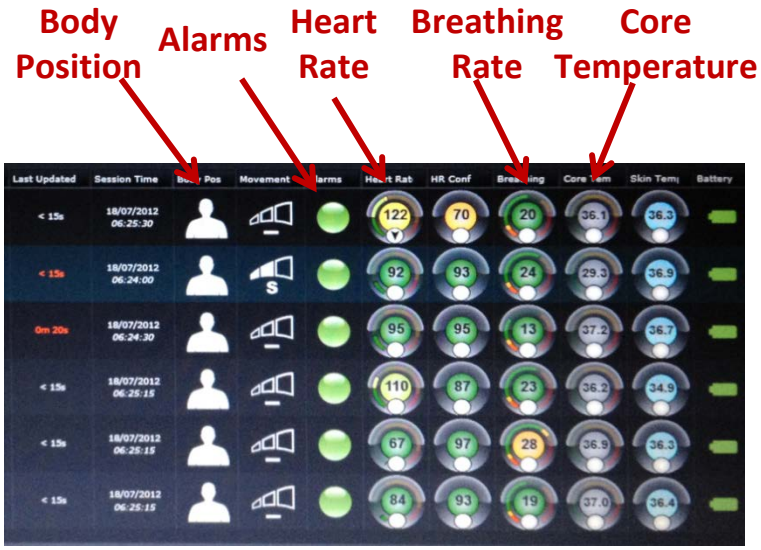


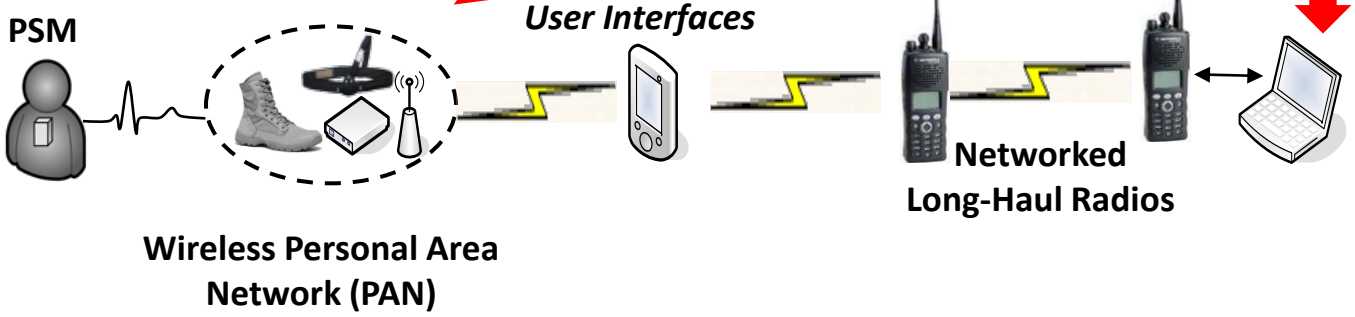
Actionable Information Display

On-Body (Hand-held) "Buddy" Display



Squad Command Post Display





Evaluation of a Buddy Display 1st CST-WMD CBRNE Training

Comment and % Agreeing

- Buddy Display would be useful in managing heat illnesses or injuries = 100%
- Understood what PSI is = 55%
- The heat strain number (PSI) on the Buddy Display was thought to be accurate = 100%
- PSI should be renamed (e.g., HSI for heat strain index) = 100%
- The amount of air left in the self-contained breathing apparatus should be shown on the Buddy Display = 100%
- Taping or attaching the Buddy Display to the outside the Level A suit is appropriate = 89%

WMD-CST Medical and leadership personnel stated there should be no Buddy Display; Information needs to go to Command Post for medical and mission decision making

Conclusions From Data Collected With WMD-CST Soldiers

- There were individual differences in heat injury/illness risk – illustrating the need for real-time monitoring
- Missions could be altered to allow an individual more at risk to do more sedentary tasks (e.g., radio communications)
- The term PSI should be changed to avoid confusion with pounds per square inch PSI of air left in the Self Contained Breathing Apparatus (SCBA) tanks; perhaps the term HSI for Heat Strain Index could be used
- Data from study should be used to guide future CBRNE PPE development

4. Acquisition Strategy

Acquisition Strategy Steps Taken

1. Utilize the COTS Modification (COTS-MOD) Process – For Rapid Acquisition
   - Joint Product Manager CBRNE Analytics & Response Systems

2. Procurement funds for purchase of physiological monitoring for all 57 WMD-CST teams was available with 30 September 2016 expiration

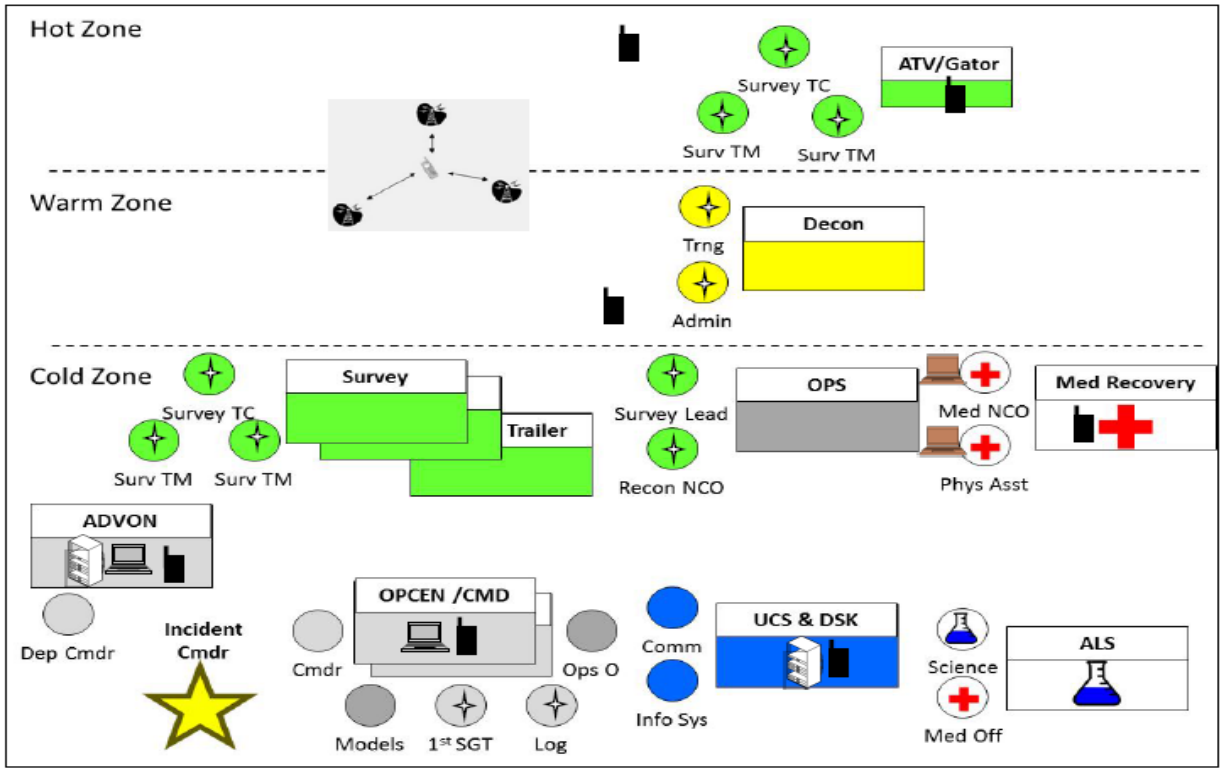
3. Evaluate potential commercial solutions
   - Equivital™ Life Monitor/Black Ghost System
   - RAE Systems/Zephyr Technologies Bioharness
   - Medweb Patch

4. Down-select a potential solution for hands-on testing and use with WMD-CST test teams

5. Define system requirements/specification in testable terms

6. Conduct operational field test by independent government test agency
   - Army Test and Evaluation Command

Incident Diagram for Concept of Operations (CONOPS) for WMD-CST PSM Use



Physiological Monitor / Mobile Device

Physiological Monitor Admin Node

Physiological Monitor SA Node

Physiological Monitor Server

Mesh Radio

Mobile Device / Cell Tower

[This diagram is an example of how the physiological monitor may be organized during the employment phase of a mission, but it is up to Commanders to gauge the situation and manage their assets accordingly. The NGR 500-3 and ATP 3-11.46 both contain extensive guidance regarding the employment phase.]

Understanding the CONOPS for Deploying PSM use is key as it can drive the selection of technology, cost of the technology and how it will be deployed

Requirements Document for RT-HSM for National Guard Bureau (NGB)

Real-Time CBRNE Physiological Monitoring Requirements for NGB CST

(*Finalized 21 October 2015*)

Overview:

While wearing appropriate Personal Protective Equipment (PPE), the National Guard Bureau's (NGB) Weapons of Mass Destruction Civil Support Teams' (WMD CST) mission is to support civil authorities at a domestic Chemical, Biological, Radiological, Nuclear, and High Yield Explosive (CBRNE) incident site by identifying CBRNE agents/substances, assessing current and projected consequences, advising on response measures, and assisting with appropriate requests for additional support.

The CSTs are currently authorized various levels of CBRNE PPE to fully complete their missions. Class 1 (NFPA 1991, fully encapsulating, vapor protective suit), Class 2 (NFPA 1994, non-encapsulating, non-permeable suit), and Class 3 (NFPA 1994, non-encapsulating, semi-permeable suit), and their associated NIOSH/OSHA/NFPA approved breathing apparatuses are worn during down-range missions. Wearing CBRNE PPE ensembles down-range increases the wearer's core and skin temperature, thereby increasing the risk of heat stress related incidents.

Integrated Product Team (IPT) That Wrote NGB Requirements Document

- CST – Working Group (CSTWG) Members for Physiological Monitoring
- Joint Product Manager Analytics & Response Systems (JPdM C-ARS) CBRNE Rapid Acquisition Division (C-RAD)
- U.S. Army Research Institute of Environmental Medicine (USARIEM)
- U.S Naval Air Systems Command (NAVAIR)

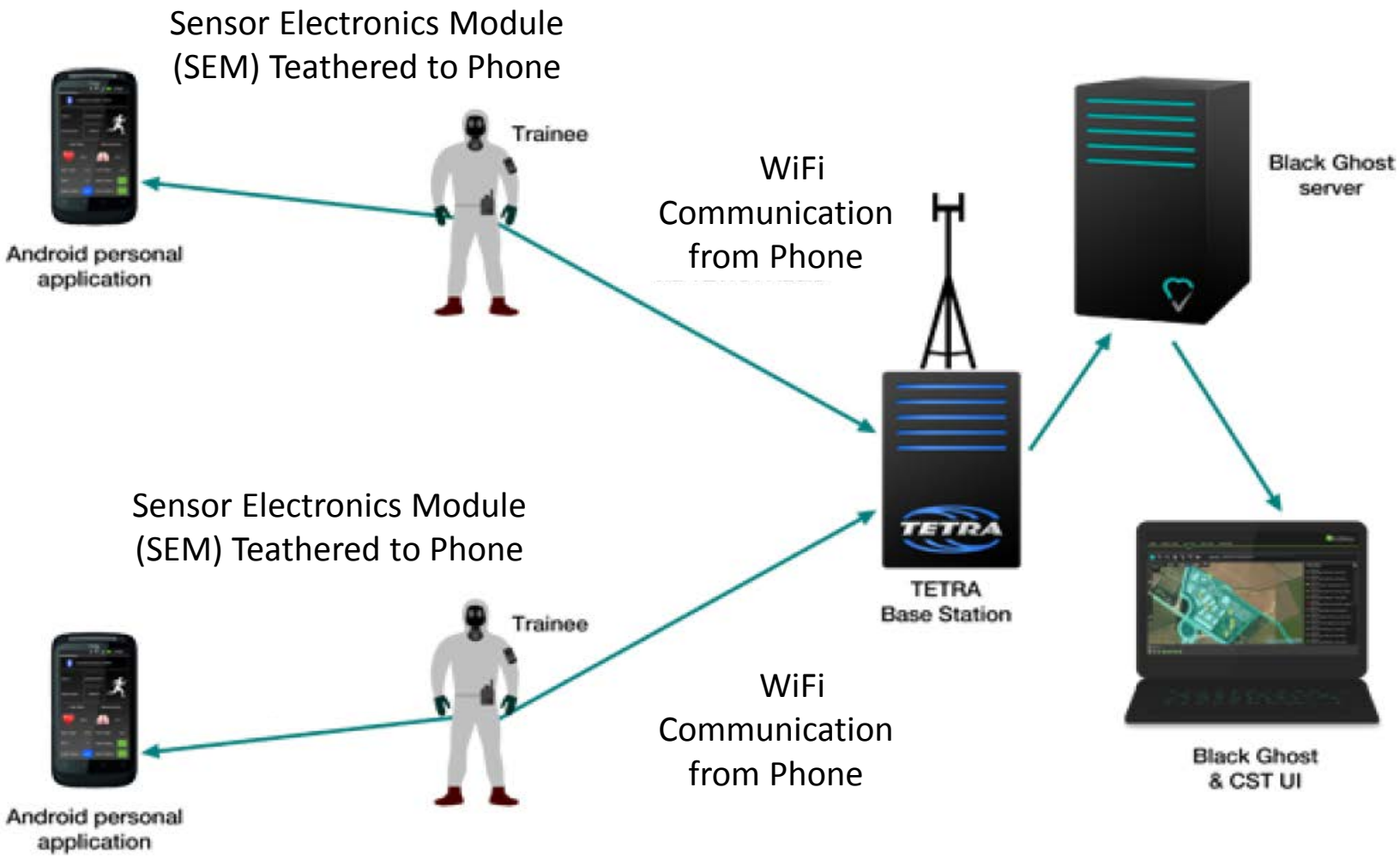
Testing Needed to Support Acquisition

- Conduct operational field test by independent government test agency
  - Army Test and Evaluation Command (ATEC)

- NAVAIR provided WMD-CST with the Unified Command Suit (UCS) and set up of “Breadcrumb repeaters and the Wifi network as would be used in WMD-CS operations

- Gather all supporting documentation to include ATEC Test report and other scientific and test documents to accompany a Acquisition Decision Memorandum (ADM) written by Joint Product Manager CBRNE Analytics & Response Systems

General Physiological Monitoring: Network Configuration



Unclassified

On Body PSM System Configuration

The Sensor Electronics Module (SEM) is hardwired to a cell phone which was attached to the arm or a waist belt

Phone on Arm

Phone on Waist

Final Steps for National Guard Bureau Procurement

- The ADM was signed by Joint Program Executive Office – Chemical and Biological Defense by the Assistant Secretary Deputy Program Executive Officer (Douglas Bryce) – July 2016

- Negotiate purchase with selected vendor; Execute and award contract by JPdM C-ARS with Equivital – September 2016

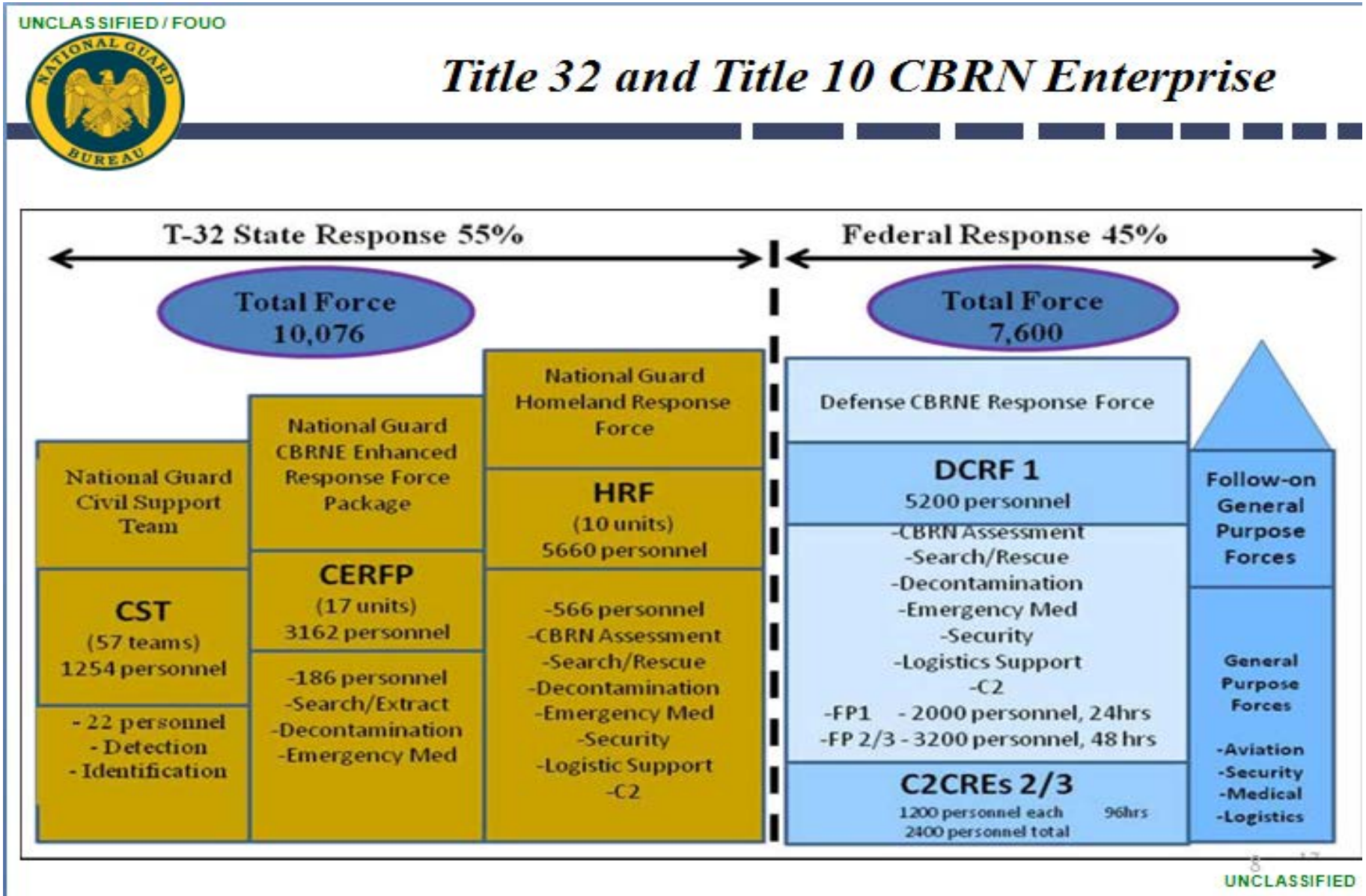
- Finalize Medical Technical Directive and Decision Matrix (Green, Amber, Red) recommended decisions by WMD-CST medical IPT and USARIEM – October 2016

- Finalize New Equipment Training (NET) for the system with the IPT – October 2016

- Begin delivering systems to select WMD-CSTs October/November 2016

5. Future Objectives – Address Other CBRN User Needs

Next Potential User Groups



Next Steps

- Understand CONOPS of new users' missions when employing PSM systems to protect Soldiers heat injuries as well as other injuries (e.g., chemical exposures)

  - Drives the use and choice of PSM system itself
  - Relates to the cost of the system especially the communication system

- Developmental efforts of PSM systems to:

  - Lower Cost
  - Lower Power Requirements
  - Enhance Tactical Capabilities
  - Make Simpler to Use

The Open Body Area Network – PSM (OBAN-PSM) system being developed by MIT-LL and USARIEM

Open Body Area Network (OBAN) – PSM System Tactical - Concept

Provide short-range (3-5m) data link from squad members to leader for 72-hour mission

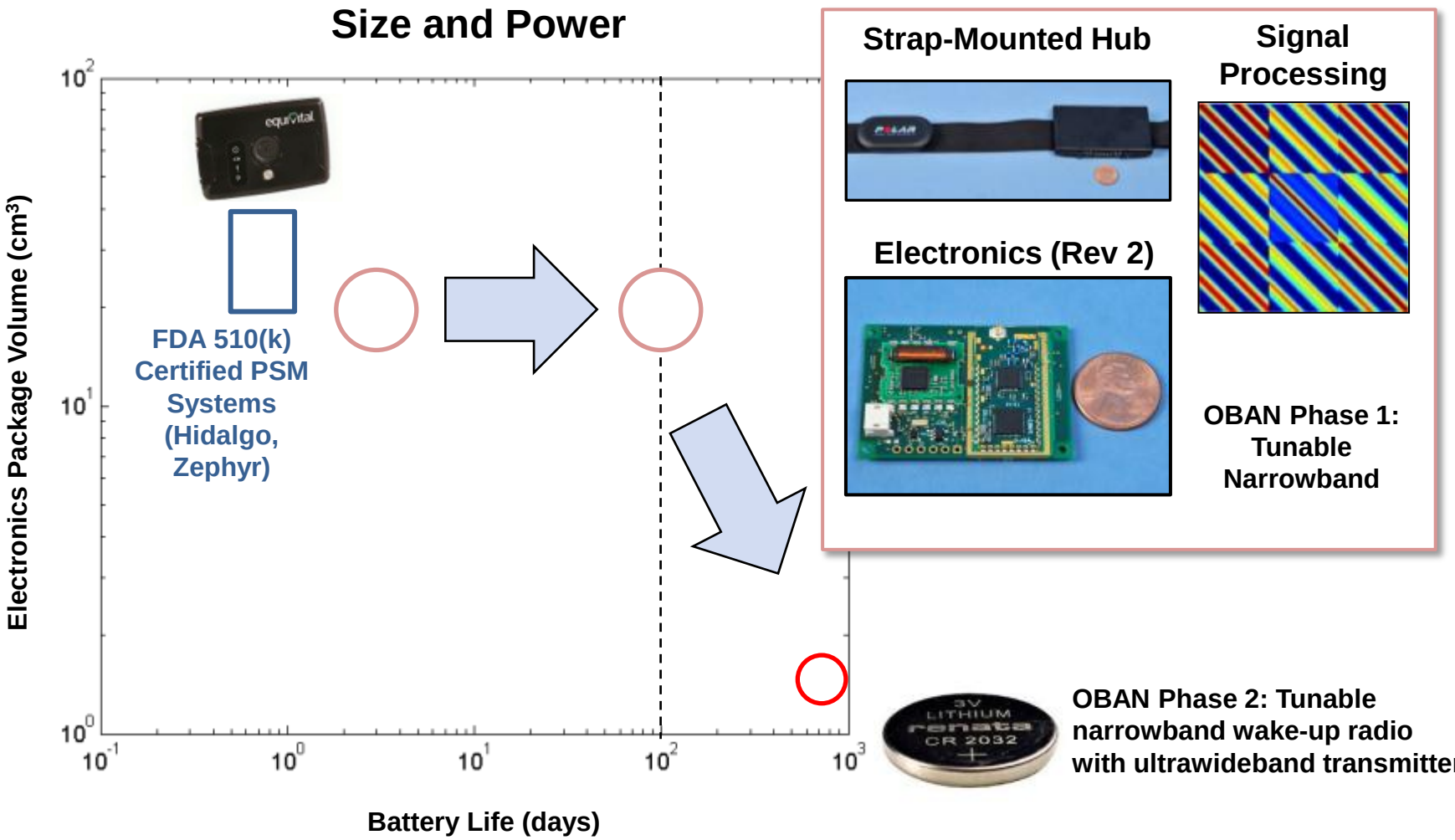
Squad Member
COTS Chest Strap with OBAN-PSM Sensor Hub

Low power wireless link

Leader or Medic/Corpsman
COTS Smartphone with OBAN-PSM Radio Dongle

Product is currently being matured by ODIC Inc.

Open Body Area Network (OBAN) – PSM System Phase 1 to Phase 2



Next Steps

- Work with WMD-CSTs in gathering data during their training and actual missions

  - Need to assess false positive rates associated with Decision Matrix Green, Amber, Red) of PSM system indices

  - Need to assess uses of the system in cold weather and whether core temperature algorithm might work when encapsulated in CBRN-PPE

  - Evaluate performance degradation and potential remedies through the the use of RT-HSM

Next Steps

- Integrate other sensor data (e.g., from air pressures from SCBA air tanks, CBRN environmental sensors)
  - Data integration to give a more accurate picture of operators condition
  - Sensor integration onto a common screen or platform (e.g., preliminary work was done with the Mobile Field Kit (MFK) system)

- Gather lessons learned from the WMD-CSTs deployment of the system
  - Share positive lessons with other potential users that need RT-HSM
  - Work to correct areas that need improvement for WMD-CSTs and other groups that need RT-HSM

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