COMPLEX PERFORMANCE EVALUATION OF PERSONAL PROTECTION ENSEMBLE

Pavel Castulik

CB 050 Vojenská chemie, toxikologie ochrana před vysoce toxickými látkami

Přírodovědecká fakulta Masarykovi university Brno

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The Royal
Wedding
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MILITÄR
POLIS

Personnel Safety

- Hazard Assessment
- Detection/warning means
- Protective Gear performance
- Personal decontamination means
- Communications
- Accountability during the response
- Training and education
- Human Factors & Fitness & Wellness
- Best Safety Practices

Levels of PPE Protection

Level A

Level B

Level C

Level D

Personal Protective Technology Priorities

- **Spectrum of hazards**
  - Chemical & Biological
  - Radiological
  - Ambient temperature & Workload
- **Respiratory protection**
  - Improve respiratory protection
- **Integration**
  - Component integration and compatibility
  - Improving gloves, footwear, hood, visibility and communication
- **Mission deployment**
  - Ease donning and doffing (limited assistance)
  - Improve mission operation and mobility
  - Ease of maintenance

Personal Protective Technology Priorities

- **Reduce physical/heat stress**
  - Improve garment breathability
  - Improve heat and moisture dissipation
  - Improve cooling systems
  - Improve hydration systems
  - Reduce equipment weight
  - Real-time personal physiological status monitoring
  - Anti-heat stress and wellness training program
- **Improve comfort**
  - Enhance ergonomic characteristics
  - Improve underwear
  - Ensure consistent and appropriate sizing of components
  - Improve quick-done-replacement of protective gloves and overboots

Personal Protective Technology Priorities

- **Testing and evaluation**

- Reliable and objective equipment performance assessment
- Implement testing technology for complexity and integrity of protective ensemble
- Implement outcomes for improvement of protective equipment design and utilization

Configuration Control

- Component Integration and Compatibility
- Eliminates bodily exposure at component interfaces
- Functional and safe interconnectivity of masks, hoods, gloves, boots/overboots with protective gear
- The standardized specification dimensions and interfaces of protective ensembles components

Testing System in Systems

PP ENSEMBLE

- Suit
- Hood
- Mask
- SCBA
- Underwear
- Gloves
- Boots/Overboots
- Cooling
- Communication

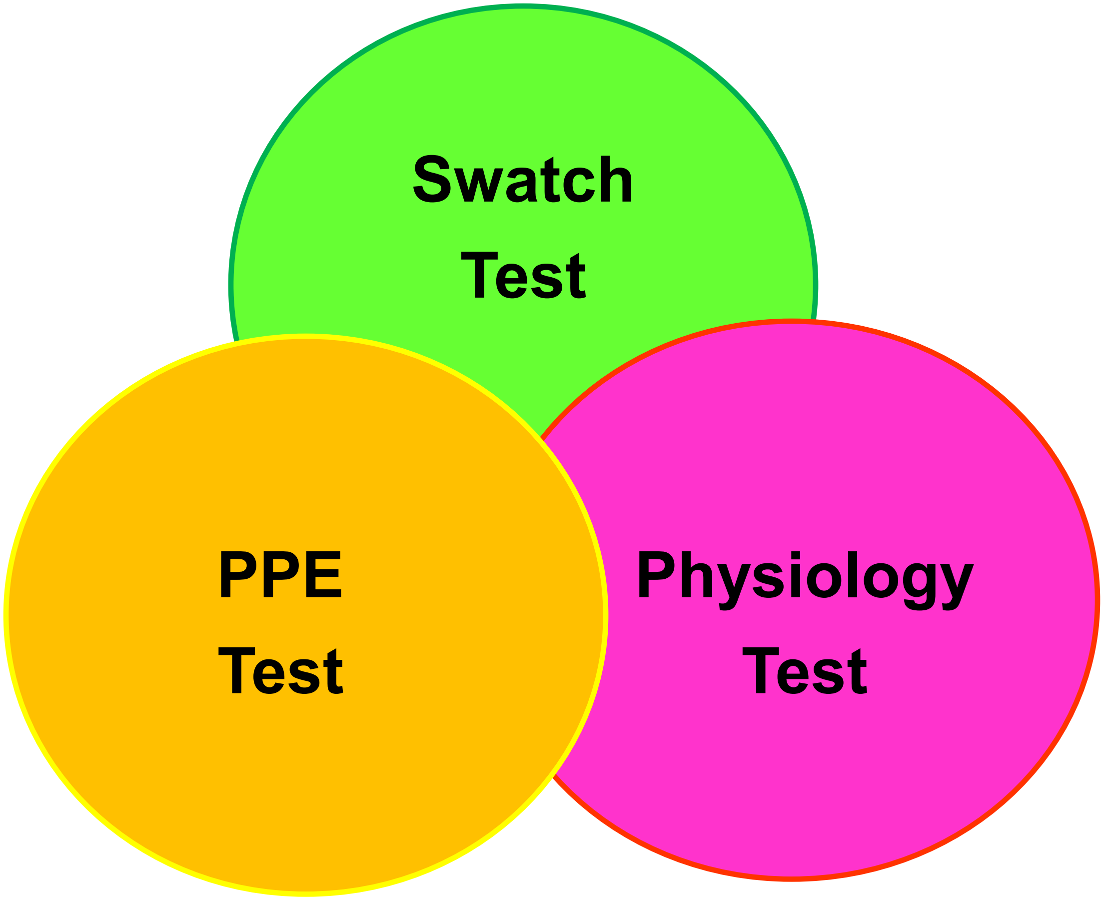
MISSION PERFORMANCE

- Protection Factor
- Mission operability & effectiveness
- Comfort and
- Friendly use

Rationales for Evaluating Protective Ensemble

- When a protective suit is constructed from a suitable material (swatch test passed), however, the final product can no longer be considered homogeneous and continuous
- The suit is fabricated from many panels that are stitched, bonded, or otherwise held together, which creates discontinuities
- In addition, the suit must be integrated with other protective gear, such as a hood, a mask, gloves, and boots, which create additional discontinuities in the overall ensemble

TRINITY TESTS



Testing and Evaluation of PPE

Tier 4
SYSTEMS TESTING

Tier 3
Physiology Testing

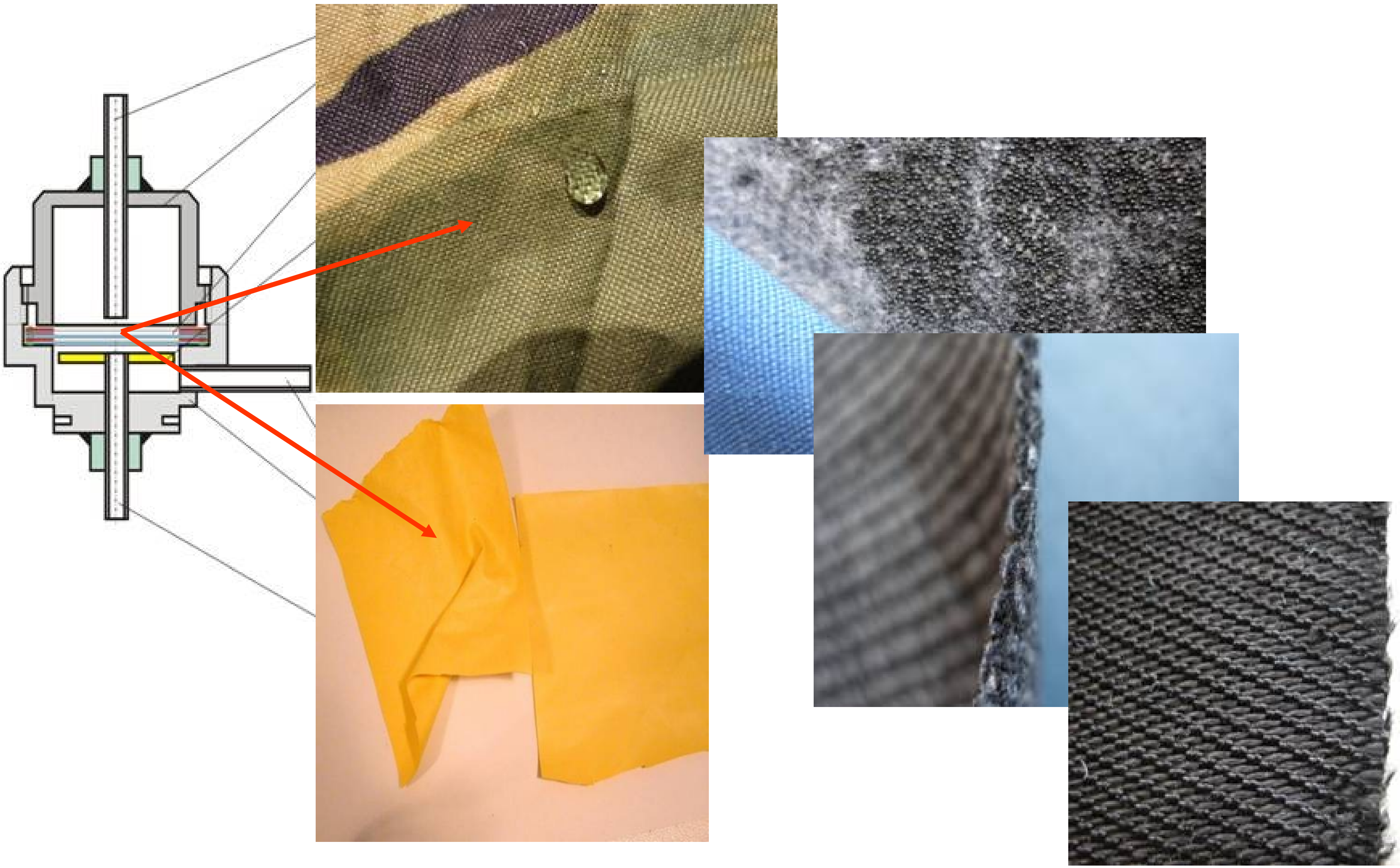
Tier 2
Component Testing
[Masks, gloves, boots, Filters, etc.]

Tier 1
Materials Testing
[Swatch materials Barrier/Filtration]

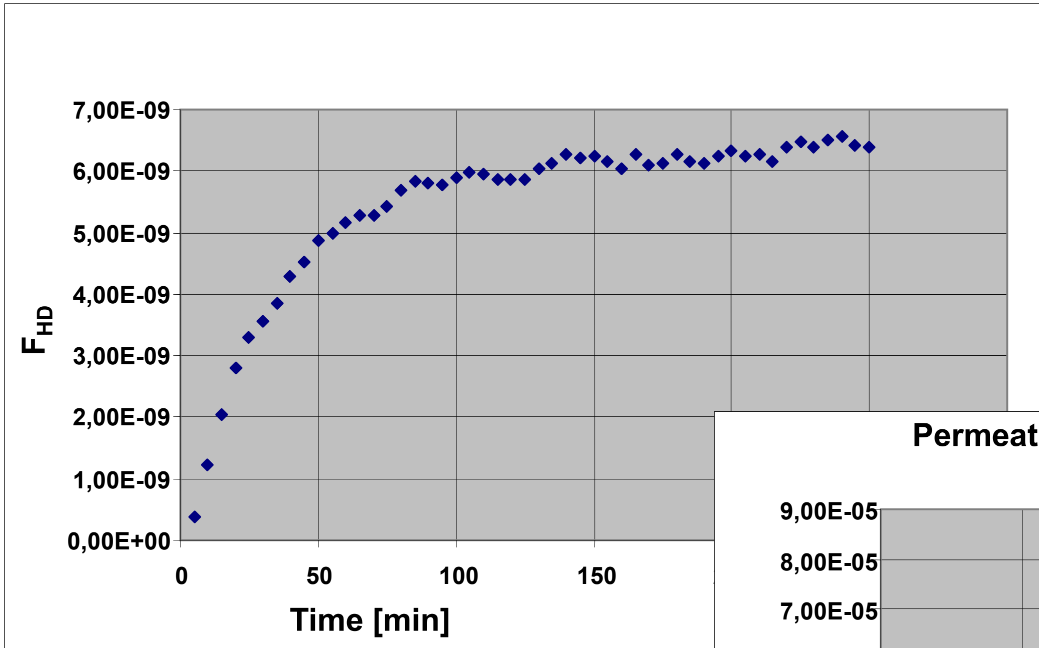
Part I

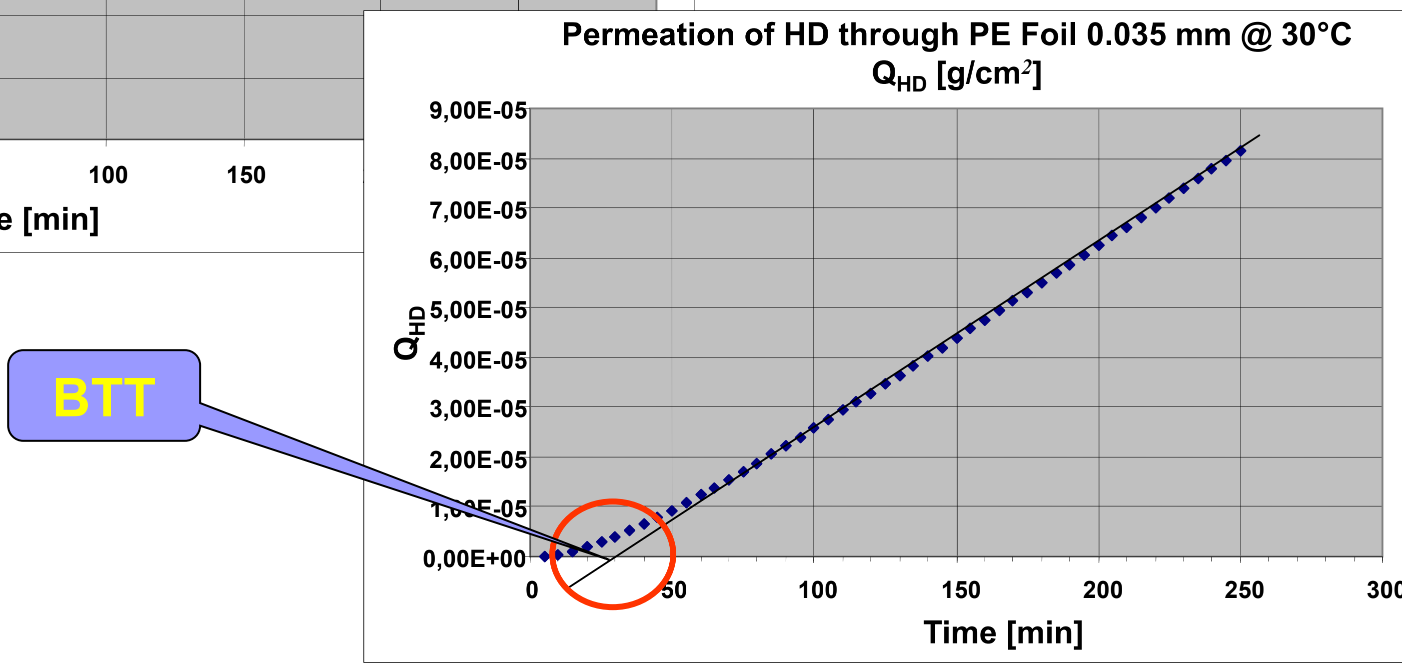
SWATCH TESTING FOR PPE

Swatch Testing with Permeation Cell



Swatch Permeation of HD

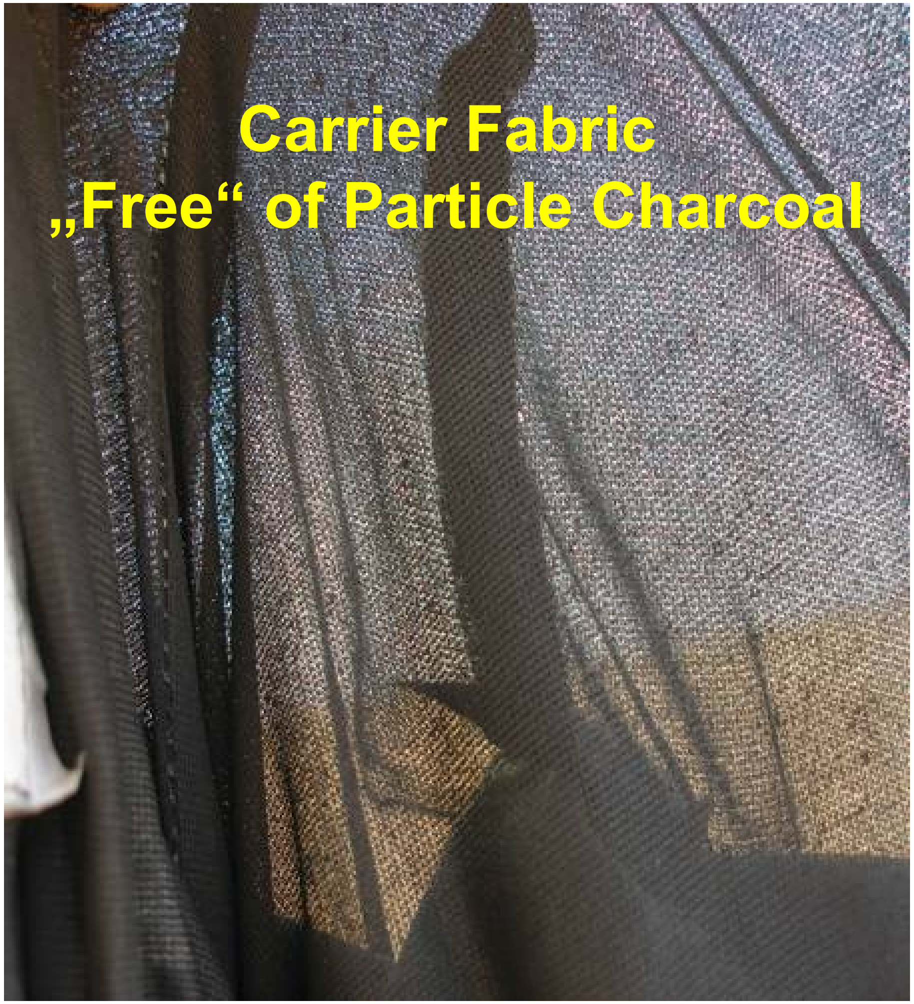


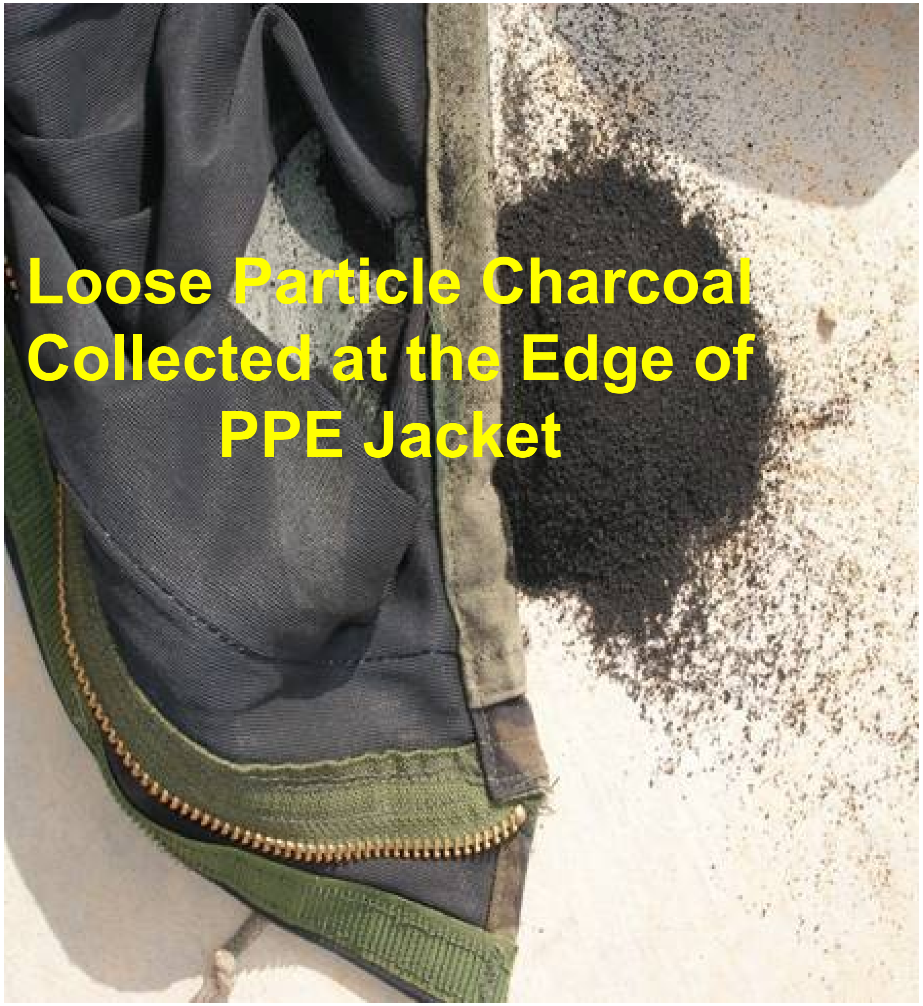


Degradation of Rubber Protective Fabric with High Concentration of Chlorine

Technology Failure
Particle Charcoal Fallen Apart from Carrier Fabric

Technology Failure
Particle Charcoal Fallen Apart from Carrier Fabric





PPE Performance Evaluation

CURRENT STATUS

- Design material and components for PPE are meeting/exceeding standards
- Evaluation/testing is primarily focused on swatches and components, thus….
- Current garment **certification** testing focuses primarily on the material properties of the individual components

IMPROVEMENT

- Implementation of full-body testing of protective ensemble in dynamic conditions as a part of a new rigorous certification
- An example: New method **„V-MIST“**

Visual-Man-In-Simulant-Test

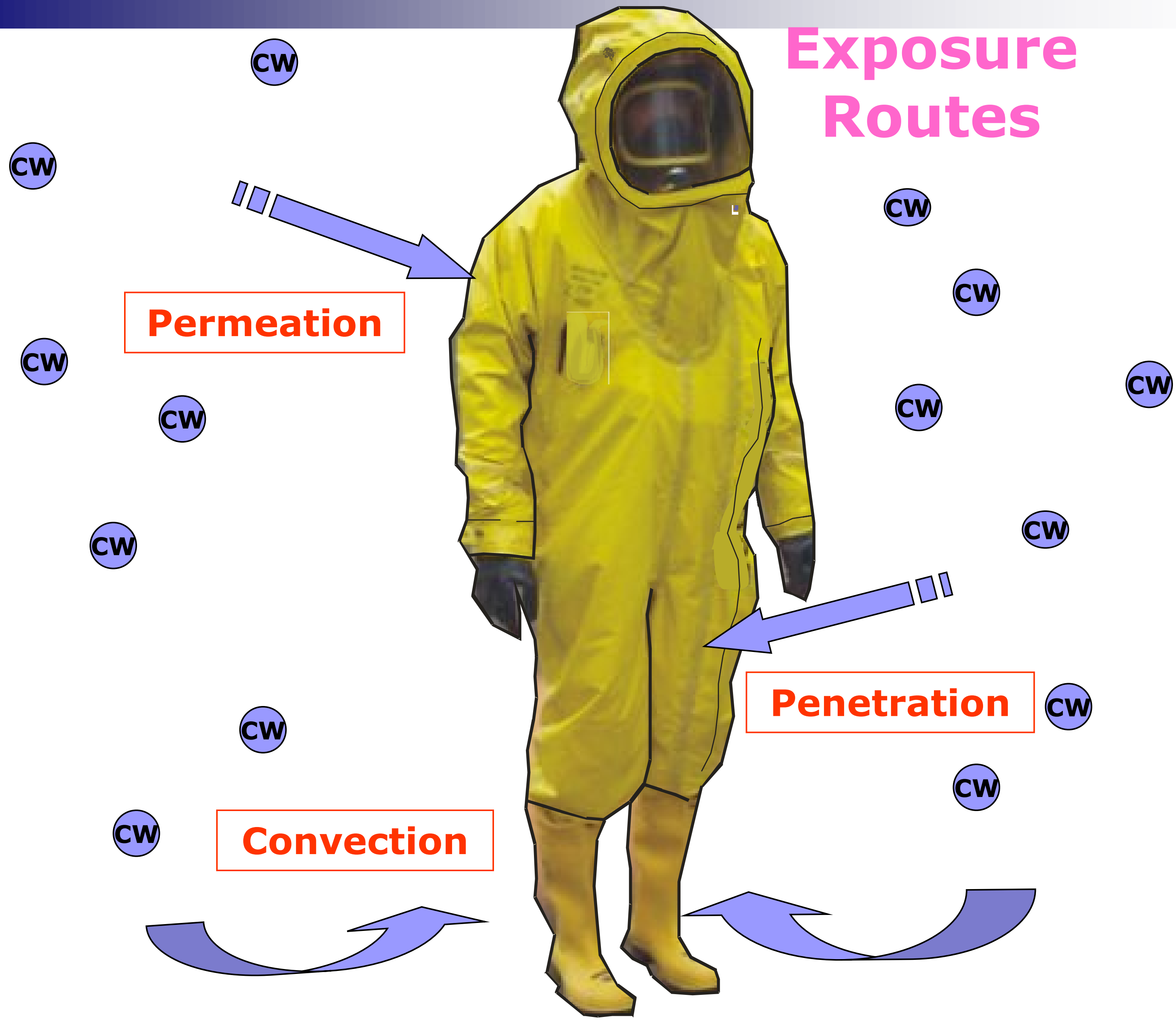
and

Workload Climate Tests

Part II

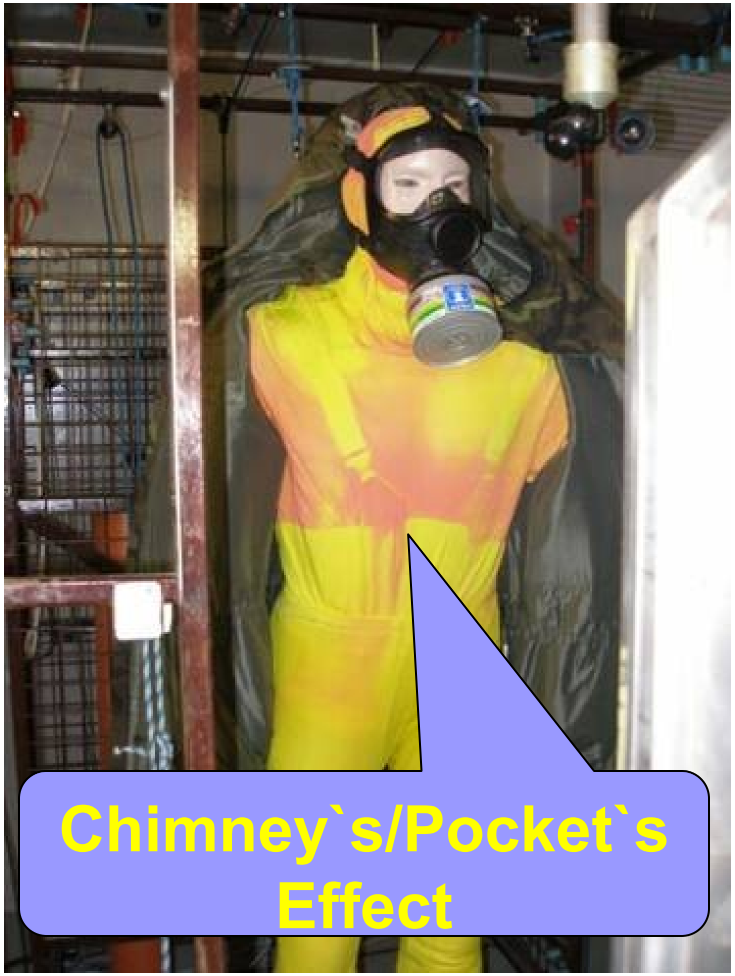
VISUAL-MAN-IN-SIMULANT TEST FOR INTEGRITY EVALUATION OF PPE

Exposure Routes



„Bellows“ Effect of Under-suit Exposure

Mannequin „Golem" in PPE and V-MIST detection of Chlorine penetration



„Chimney“ Effect of Legs Exposure when Trousers are Worn over Boots

Improper Donning of PPE

Integrated Seals of Hood & Arms & Legs

Improvised Sealing of PPE

- Mask with Hood
- Closures/Zippers
- Gloves with Sleeve
- Boots with Trouser

Protection Factor of PP Ensemble

Protective Suit + **Protective Mask**

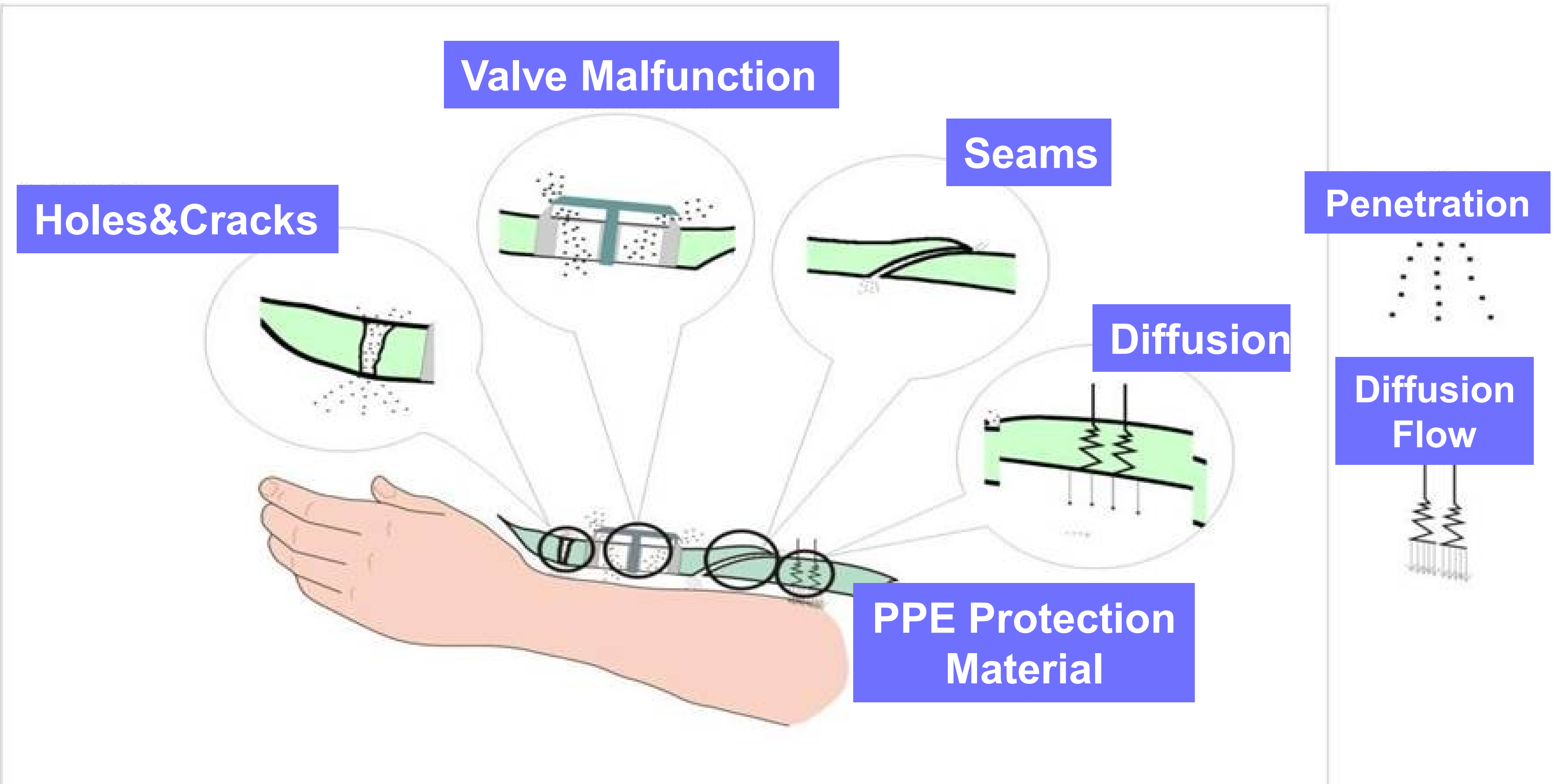
$$PF_{PS} = \frac{C_0}{C_{PS}}$$

$$PF_{PM} = \frac{C_0}{C_{PM}}$$

Complete Ensemble

$$PF_{COMPL.} = \frac{C_0}{C_{PM}} = \frac{C_0}{\dfrac{C_0}{P_{PM} \cdot P_{PS}}} = PF_{PM} \cdot PF_{PS}$$

Shortfalls of PPE Design, Manufacturing and Exploitation



Rationales for Evaluating Protective Ensemble

- In addition, CB protective suits may also be subject to wear and damage during service, potentially under extreme operation conditions
- Perforations, punctures, and tears in the suit material will create further discontinuities, including malfunction of closures (zipper) and/or outlet valves
- For the reasons outlined above, evaluating the performance of a CB protective ensemble under realistic, dynamic conditions is far more complex than only relying on evaluating of construction and component materials

Rationales for Evaluating Protective Ensemble

- PPE system is required to function under dynamic conditions and physical motion of individuals

- These conditions are affecting protective properties of PPEs resulting in
  - „Bellows“
  - „Chimney“ and
  - „Windshield “ effects

Testing PPE with Volunteer Individuals in Gas Test Chamber

Testing PPE with Semi-robotic Mannequin in Gas Test Chamber

Illustration of Golem's motion

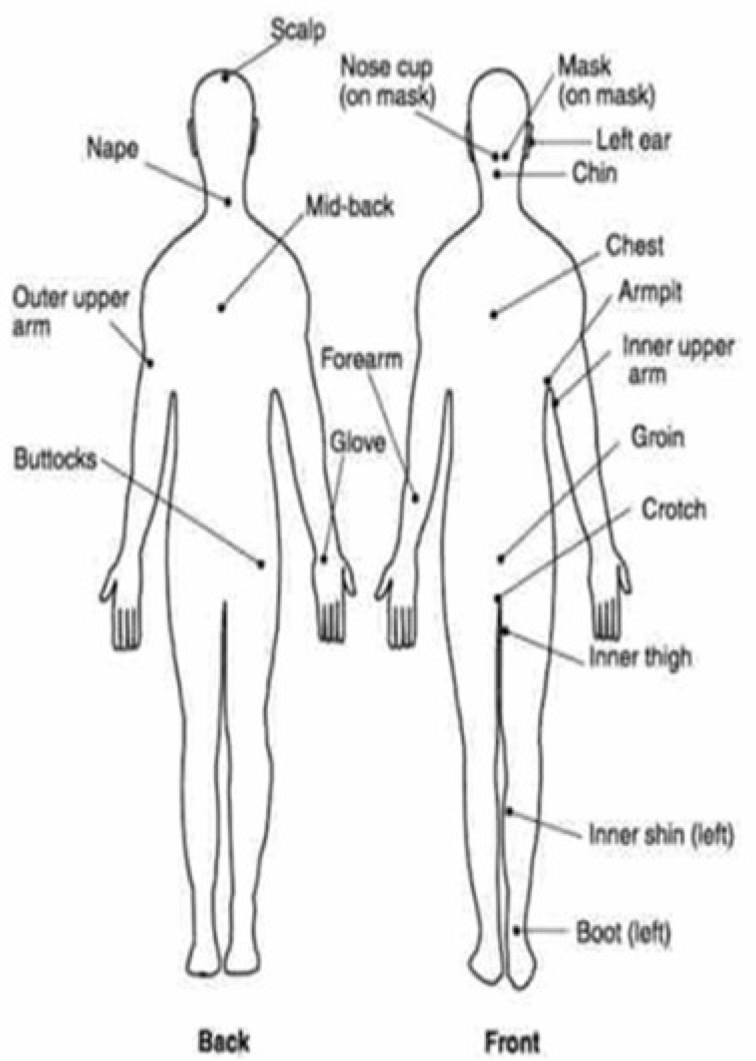
Human Body Motion Simulation

- Walking with the arms motion (up to 5 km/h)
- Stretch arms upwards
- Forward bend
- Knee-bend
- Sitting
- Head turning (synchronised with arms movement optional)
- Breathing

Man-In-Simulant Test „MIST“

- Chemical Vapour and Aerosol System-Level testing of chemical/biological protective suits.
- The test individuals/mannequin are outfitted with passive sampling detectors (PAD) on their skin, that absorb the chemical compound when and if it penetrates the protective suit system.
- The sensing PADs are positioned at various places on the body and are analyzed at the conclusion of the test procedure.

Placement of Passive Adsorption Devices of the MIST



- 19 pcs PAD (size cca 1,5x1,5 cm = 2,25 sq.cm) represents 43 sq.cm
- Human Body Surface = 19,000 sq.cm
- 19 PADs represents only **0,22 %** of a body total surface

What about remaining

99,78 %

of body surface ?

- This is the task what V-MIST can do

V-MIST

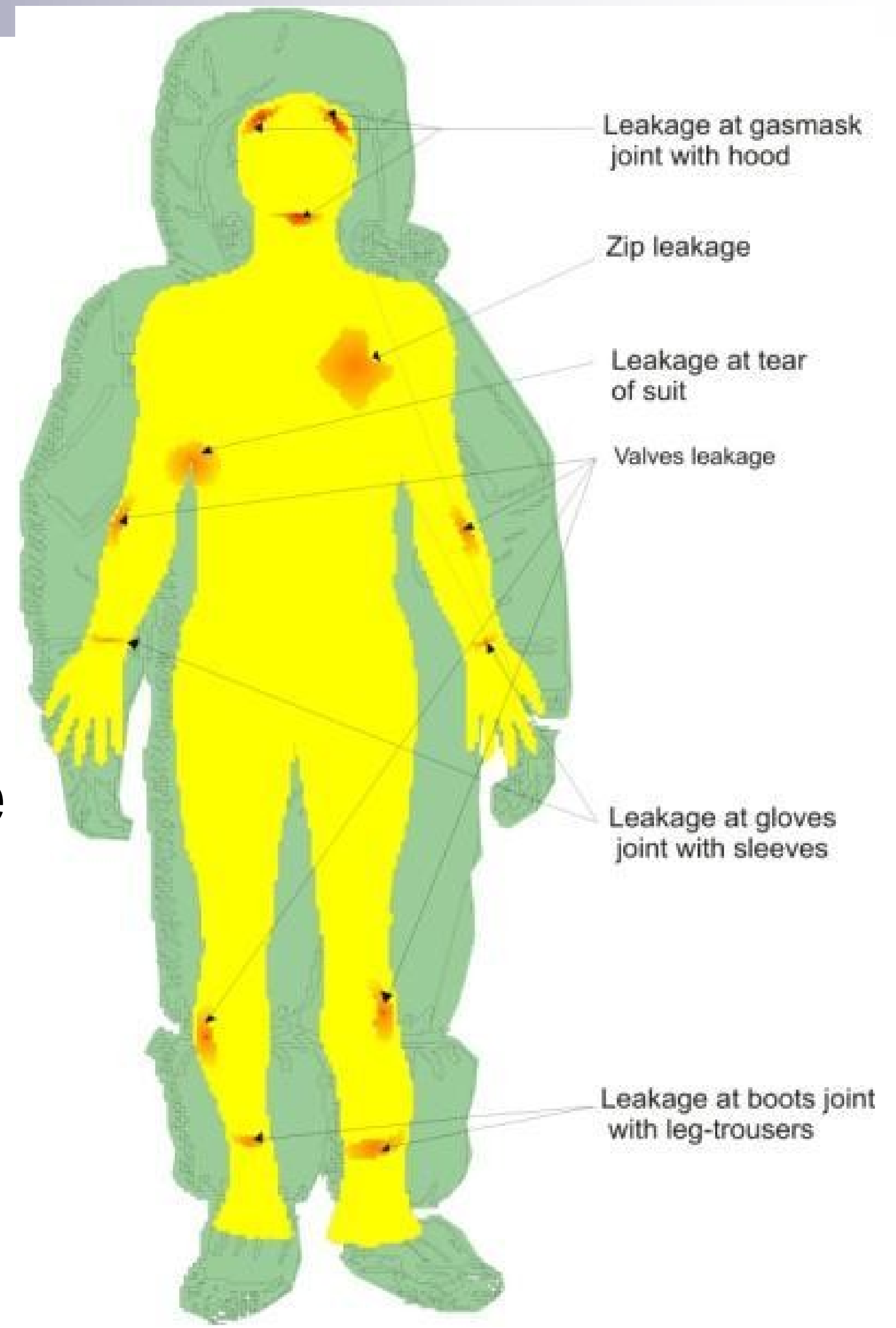
Visual

Man-In Simulant-Test

is enable

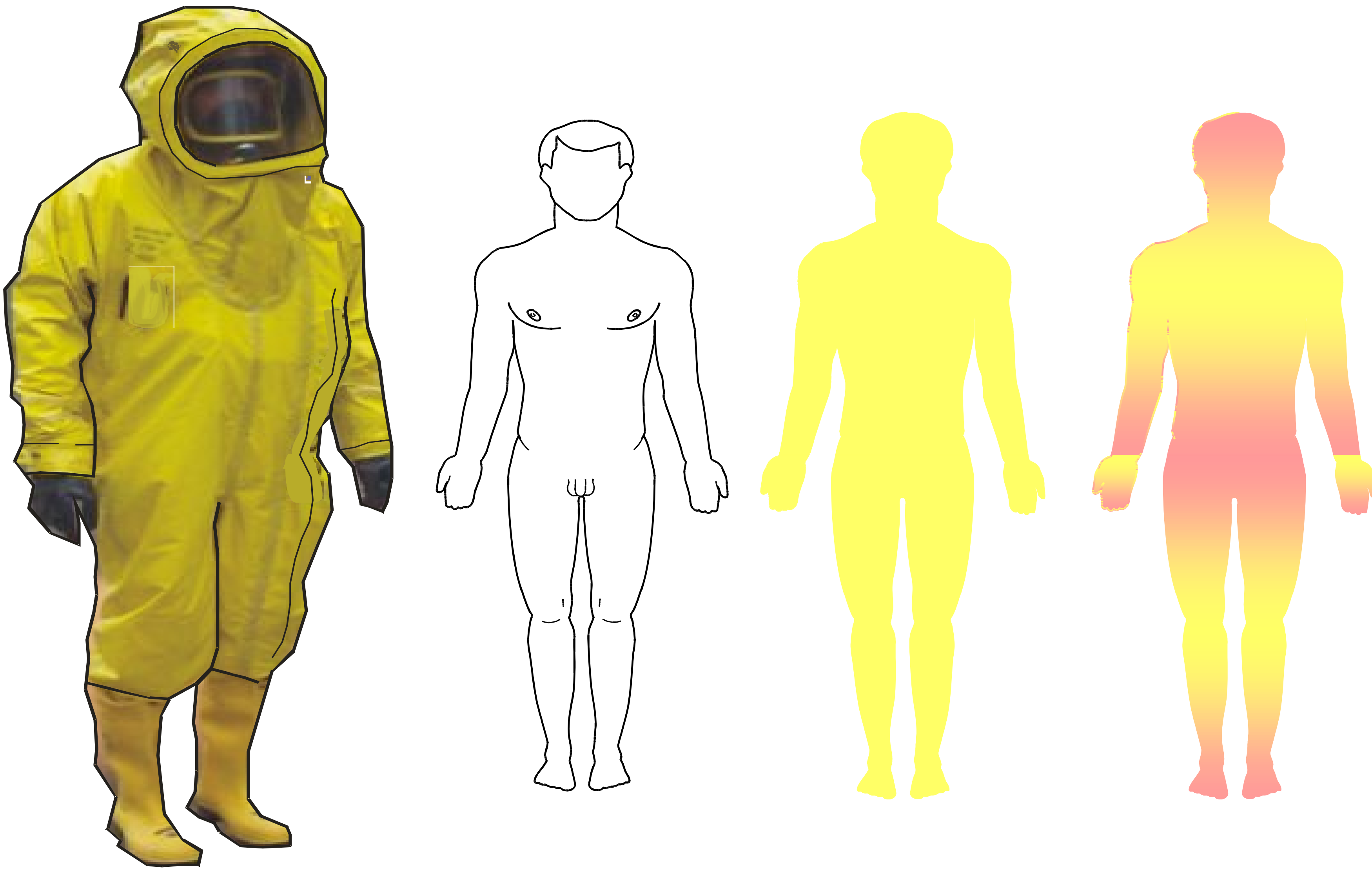
precisely and objectively identified penetration of challenge agents/simulant

through deficiencies of personal protective ensembles



Why V-MIST ?

- Data usually obtained by means of discrete samplers do not distinguish precisely the place/areas of breakthrough (permeation/penetration), spreading under protective suit and moreover, the proper detection and subsequent evaluation of such data is very time consuming
- Even if the results of MIST are undoubtedly correct in quantity, the user, in fact, would not know whether he/she donned the suit correctly and whether all parts of the equipment are sufficiently leak-tight and functioning properly
- V-MIST technique allows to evaluate
  - whole body surface,
  - calculate Dermal Dose exposure and
  - the Protection Factor of a PPE



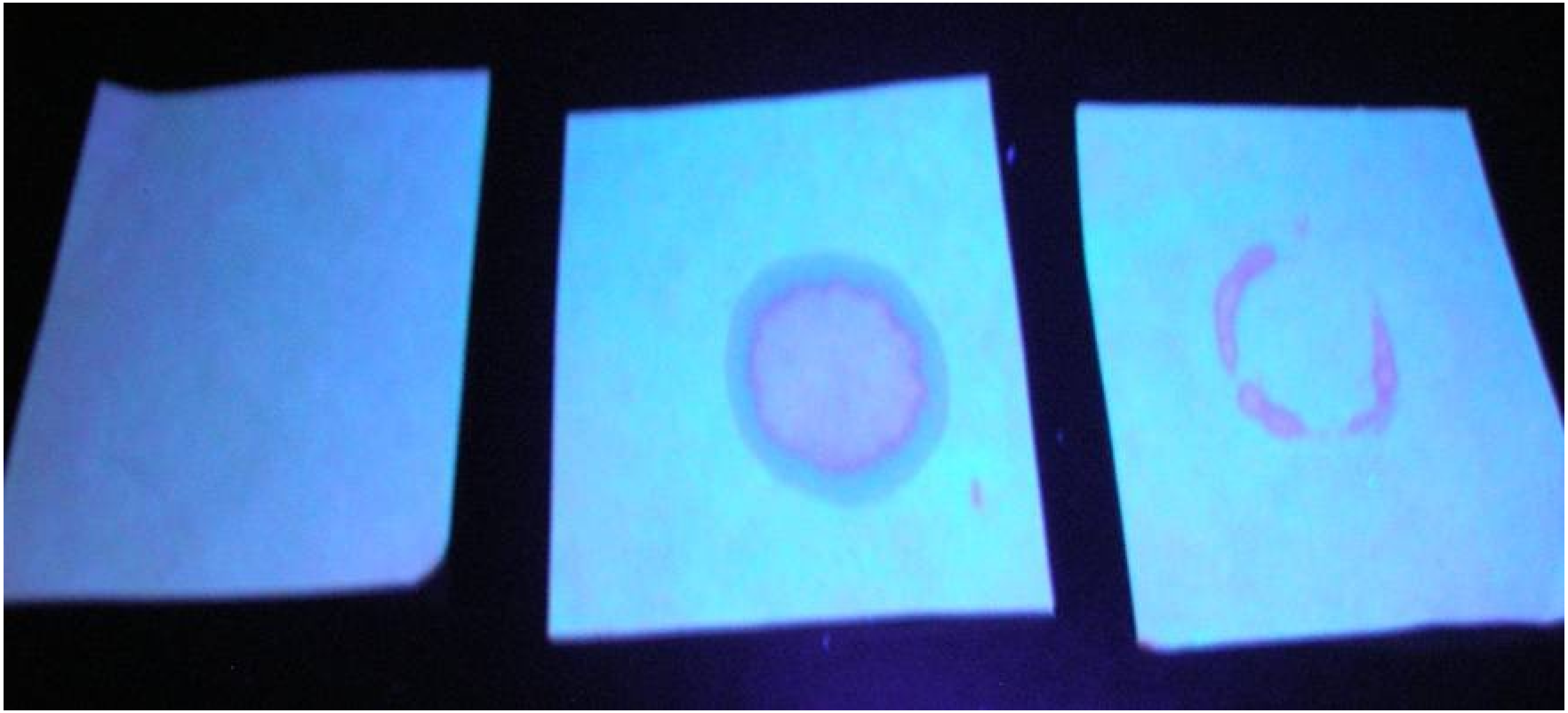
Options Color Detection with different Agents

Benzoylchloride

Chlorine

Sulphur Mustard

Sarin (GB) detection with fluorophore oxime sensible to UV light



Test of PPE Gas-tightness in GTCh

Dynamic movements:

Breathing

Walking

Knee-bending

Etc.

Time of test: 30min

Test gas:

Chlorine

Benzoylchloride

S-Mustard

Mannequin System

PPE Assembly

1st Level

Protective Cape

2nd Level

Chemical

Protective Suit

3rd Level

Chemical Sensing Underwear

Example of Test outcome Data

Exposure 30 min of exercise

Body Surface

$$\sum_{1}^{5} S_d = 19230{,}64 cm^2$$

Total Dose

$$\sum_{1}^{5} D_c = 190{,}5 \mu g$$

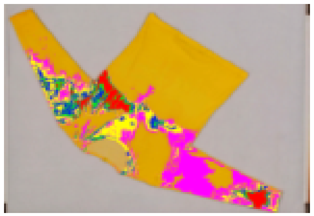
Protection Factor

$$PF = \frac{35{,}65 \cdot t \cdot C_k \cdot \sum_{1}^{n} S_d}{\sum_{1}^{n} D_c} = 970{,}6$$

Correlated Doses for

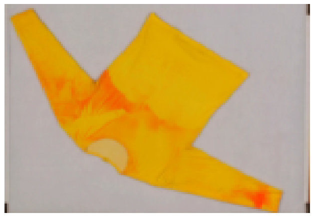
HD	**432**	**µg/cloth**
	241	**µg/cap**
	191	**µg/shirt**
	0	**µg/trousers**
GB	**381**	**µg/cloth**
	212	**µg/cap**
	168	**µg/shirt**
	0	**µg/trousers**

How it works



poznámka:
typ obrazu: pseudocolor
název obrázku: FOP 96 - 1 - bunda - přední

název oděvu: FOP 96
číslo figuranta: 1
část oděvu: bunda
strana: přední
datum:
plocha části oděvu: 4887.5
délka: 643.21
průměrná testovací koncentrace v ppm: 2,8
délka pobytu v komoře v min.: 30



poznámka:
typ obrazu: original
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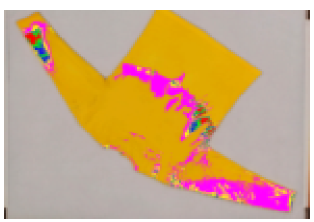

poznámka:
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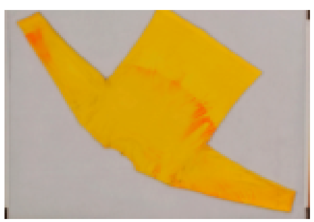
název obrázku: FOP 96 - 1 - bunda - zadní

název oděvu: FOP 96
číslo figuranta: 1
část oděvu: bunda
strana: zadní
datum:
plocha části oděvu: 4892.3
délka: 293.54
průměrná testovací koncentrace v ppm: 2,8
délka pobytu v komoře v min.: 30



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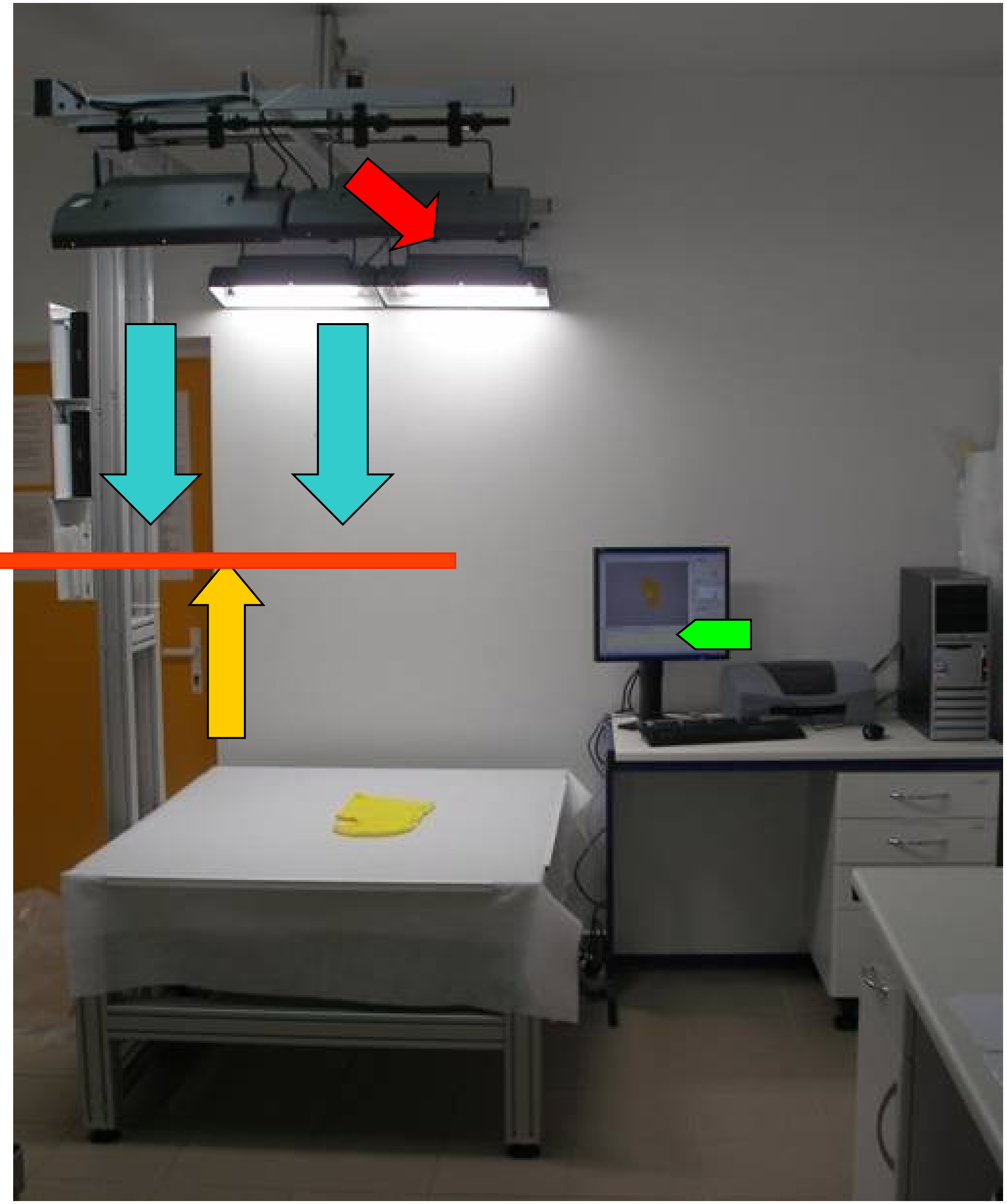
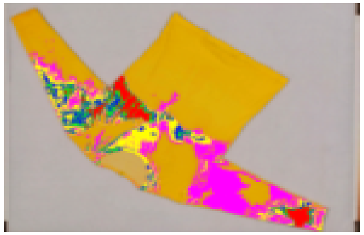


Test Protocol Information



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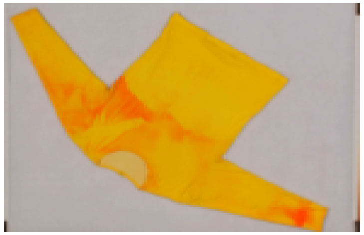

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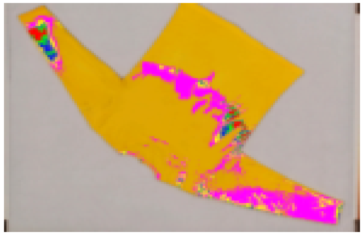

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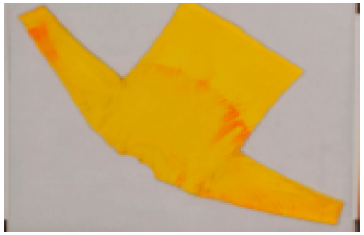

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Type of PPE:	FOP
Date:	06.04.09
Figurant:	# 1
Part of PPE:	Jacket
Side of Item:	Front
Challenge Conc. [ppm]:	2,8
Time of Expo. [min]:	30
Area of Item [cm^2]:	4887,3
Doses [μg]:	643,21

Pseudo-color Scale Concentration

Chlorine
[µg/cm²]

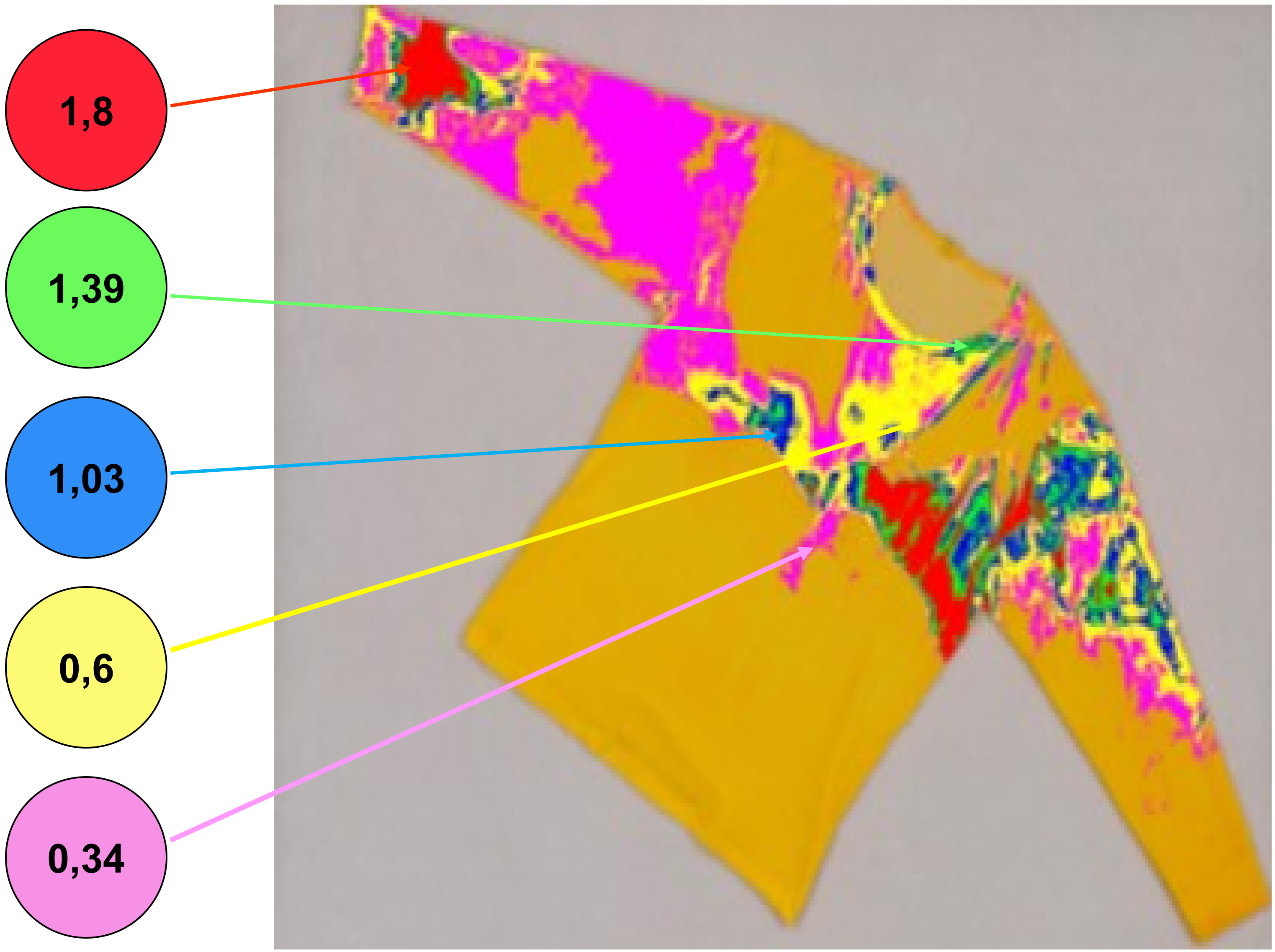
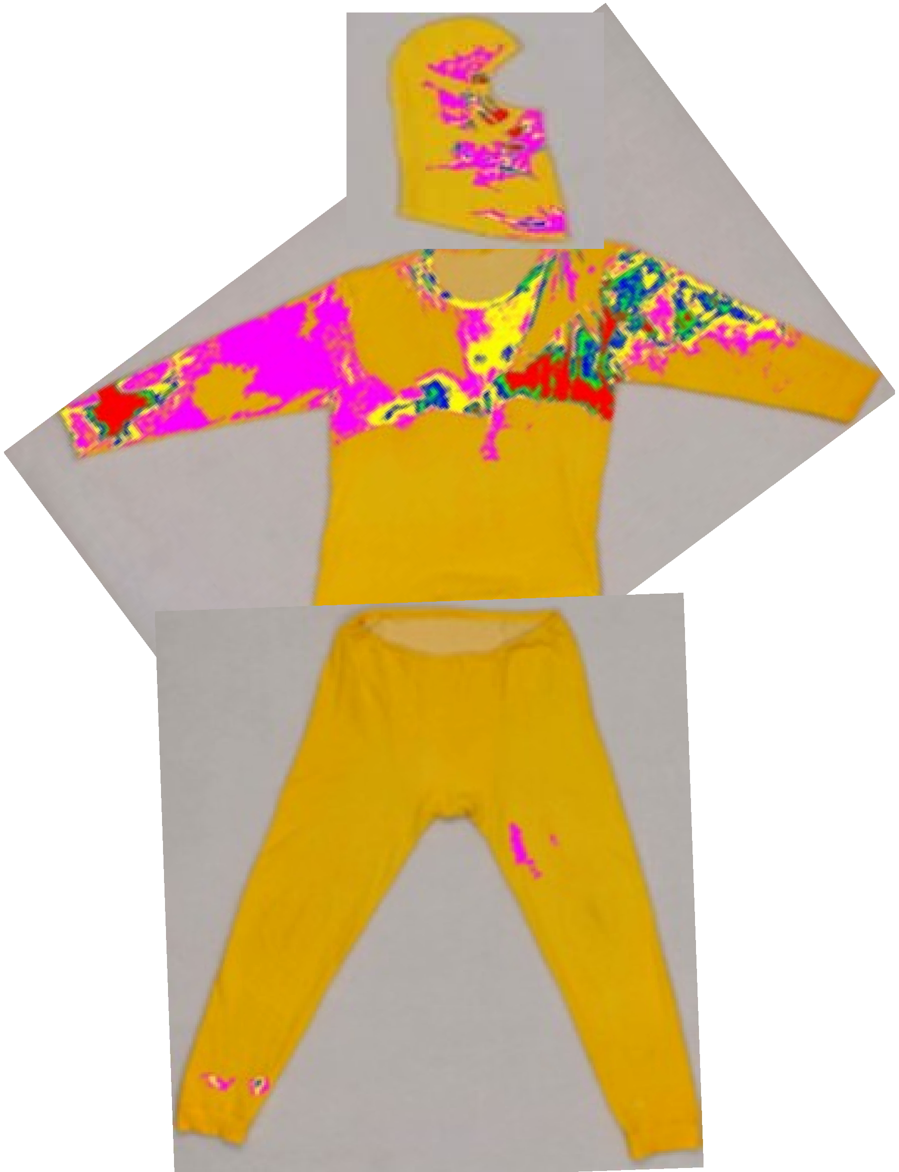


Image of Whole Body Exposure



WHOLE BODY
S=18322 cm^2
D= 1022 µg

Part III

IMPROVEMENT OF

PPE PROTECTION FACTOR THROUGH ARTIFICIAL VENTILATION

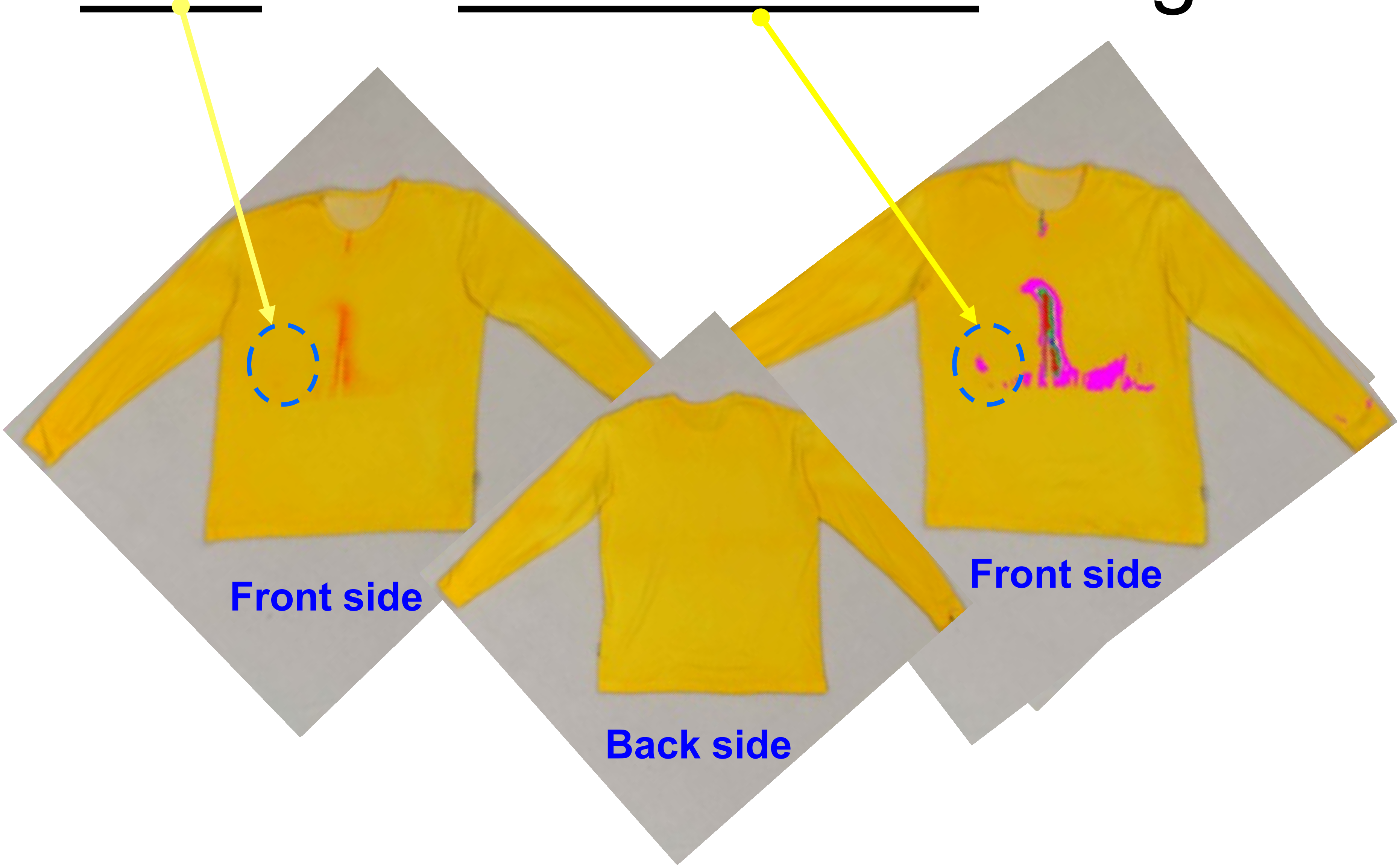
AGAINST „WINSHIELD EFFECT“

„Wind Shield“ Penetration Effect

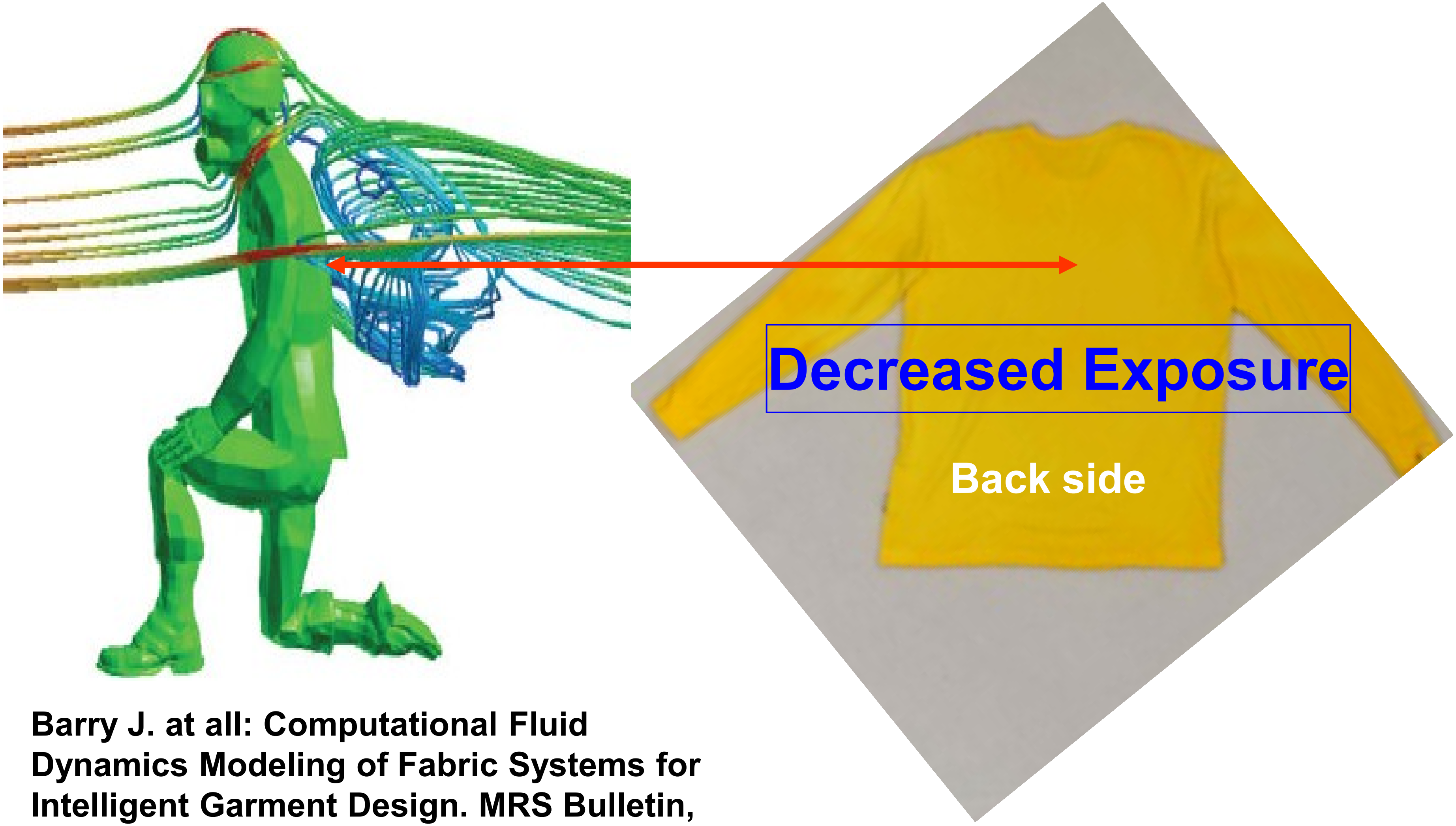
Sub-millimeter hole (0.9mm)

Penetration „signature“ through the hole

Real and Pseudo-color Images



Aerodynamic Flow-Windshield



Barry J. at all: Computational Fluid Dynamics Modeling of Fabric Systems for Intelligent Garment Design. MRS Bulletin, August 2003

Outflow Air

$\boxed{F_{AMB} = D \times C \times A \times \Delta t / h}$ $\boxed{F_{INT} = \nu \times C \times A \times \Delta t}$

$$\boxed{F_{INT} \geq F_{AMB}}$$

$$\boxed{\nu \geq D/h}$$

$D \cong 1.10\text{-}2\ cm^2/s$

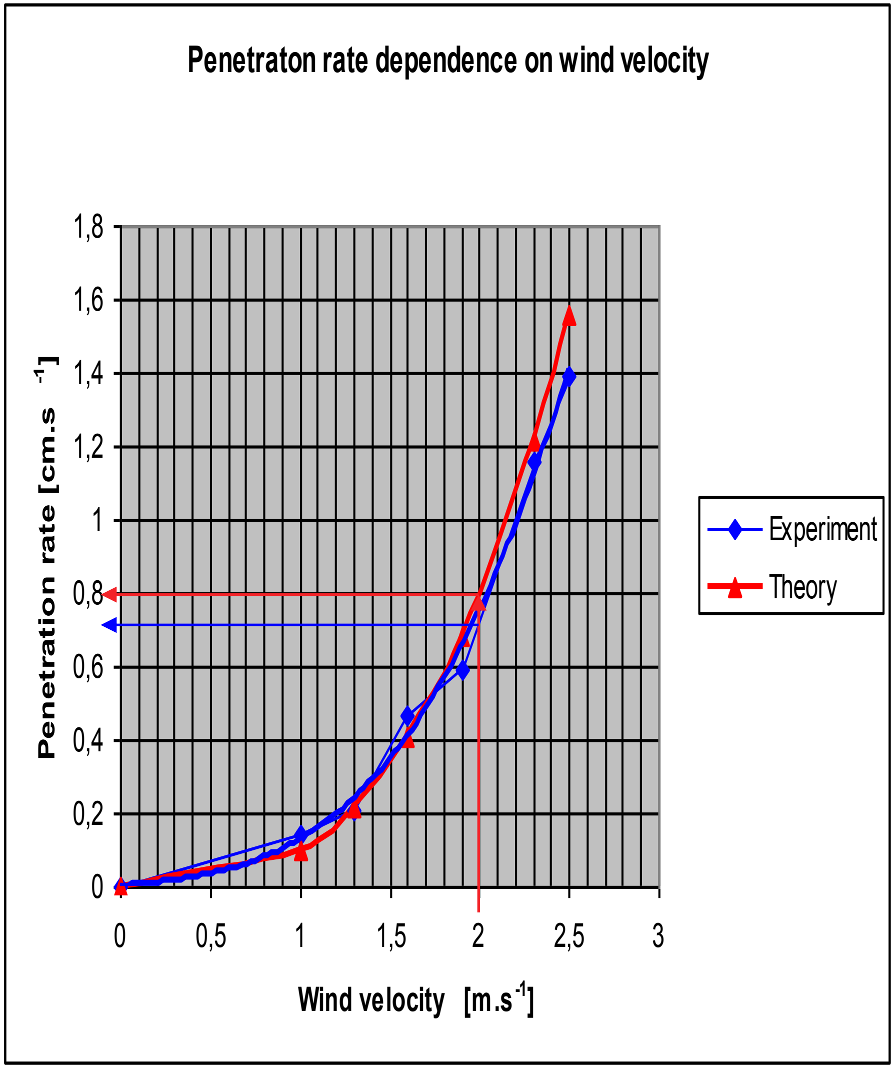
$h = 0{,}02\ cm$

$$\boxed{\nu \geq 0{,}01/0{,}02 \geq 0{,}5\ [cm/s]}$$

$$\boxed{\nu \geq D/h + \nu_p}$$

$\nu_w \rightarrow$

Penetration Flow *versus* Front Wind



$$\nu_p = 0,1 \,.\, \nu^3_w$$

- where ν_p is penetration flow (cm/s) and
- ν_w is wind velocity (m/s)
- $\nu_p = 0,72\ (0,8)$

@ ν_w 2 m/s

Outflow Air

$$\boxed{\nu \geq D/h + \nu_p}$$

ν_p = 0,8 cm/s
@
ν_w = 2,0 m/s

$$\boxed{\nu \geq 0{,}5 + 0{,}8 \geq 1{,}3\ [cm/s]}$$

$$\boxed{F_{INT} = \nu \times C \times A \times \Delta t}$$

Ventilation-leakage

Body Motion	Outflow from a suit through (m/s)						
	Hood Valve	Hood	Zipper Closure	Wrists Right	Wrists Left	Ankles Right	Ankles Left
Static	0,04-0,06	0,12	0	0,06	0,4-1,5	0,72	0
Knee-bending	13,8	0,88	1,0	1,8	21	6,8	3,5

Blower hose with airflow 100 l/min

Outflow Air

Soupy bubbles indicating outflow of ventilated air from protective ensemble

Part IV

THERMOVISION SURVEY
OF HUMAN BODY THERMAL BEHAVIOR
IN PPE

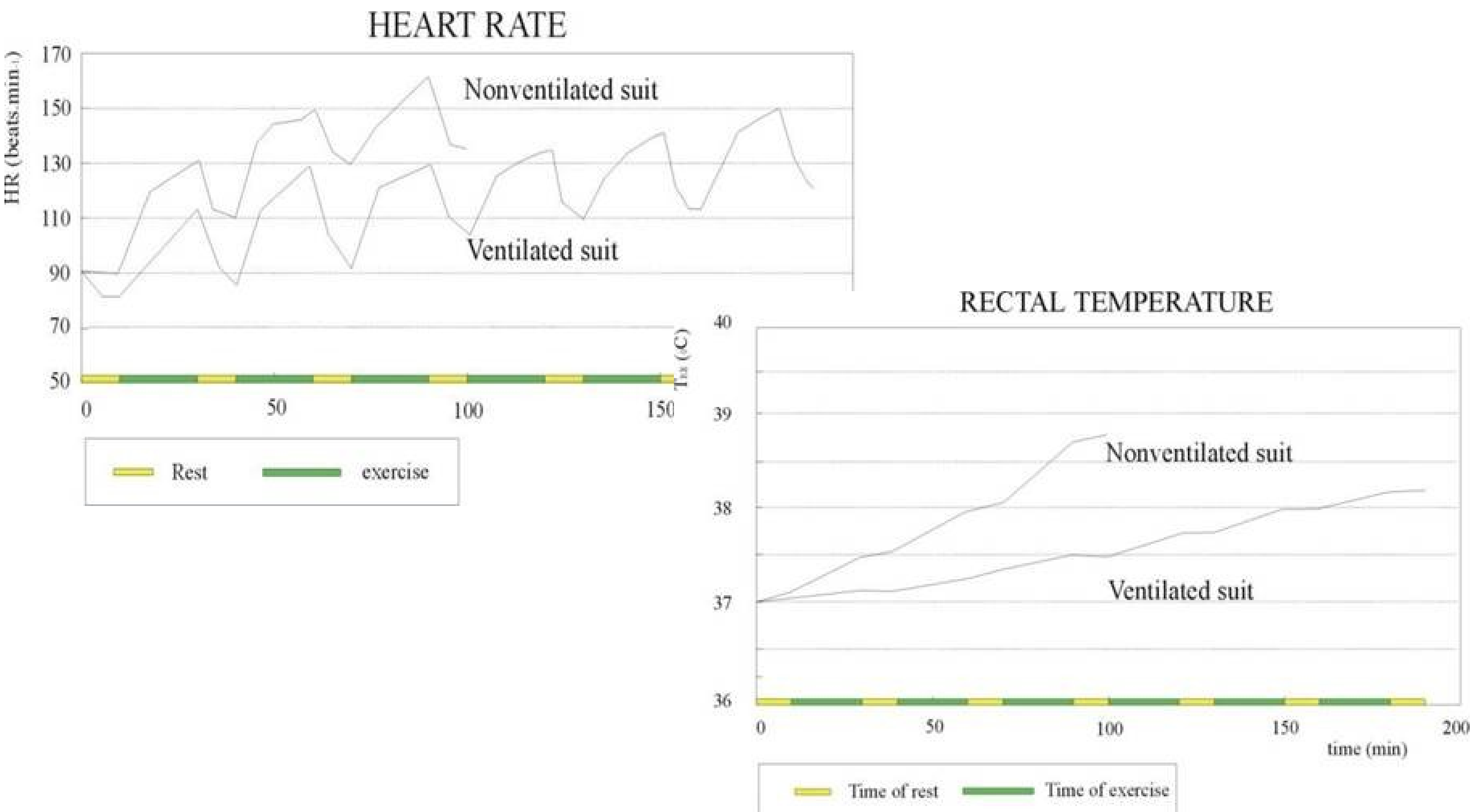
Physiology evaluation in Climate Test Chamber

Response of human body to workload in PPE

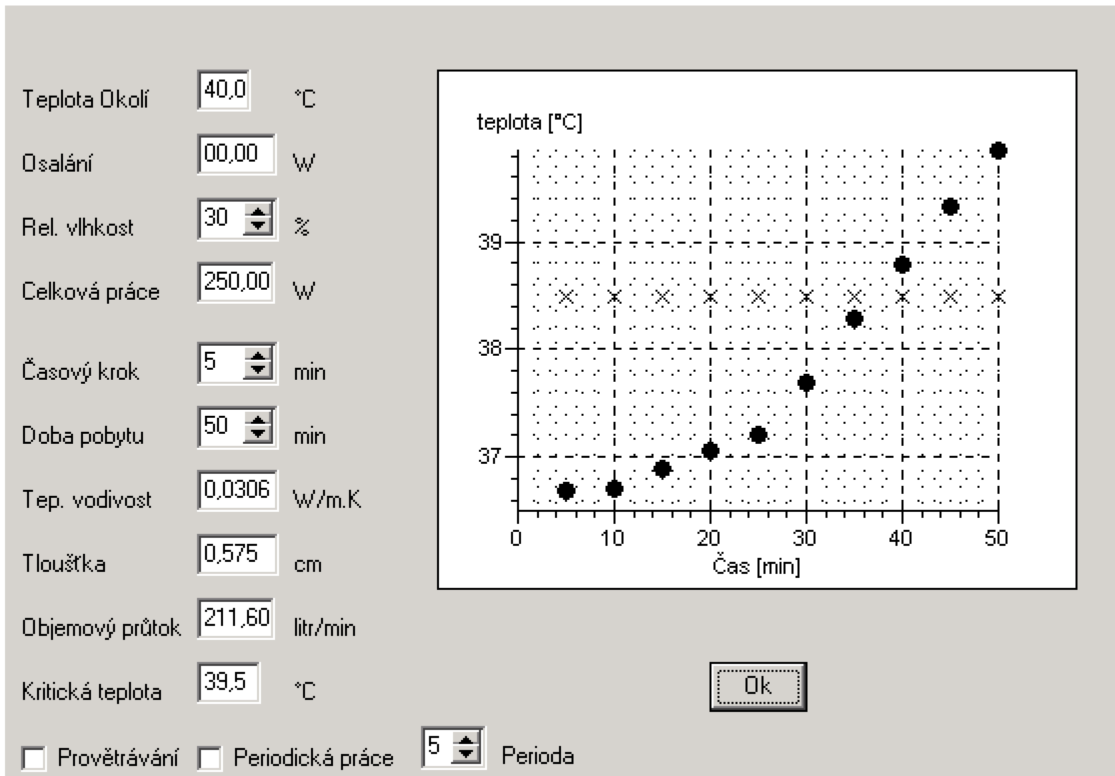
- The goal is to calculate permissible time of a person's deployment in a PPE under particular environmental conditions and workload scenario
- Key controlled parameters are ambient temperature, humidity, heat radiation, workload (watts), time exposure, the core body temperature (in rectum), heart frequency and loss of body fluids (perspiration, urine), psychomotoric response

Heat Workload and Ventilation/Cooling Evaluation

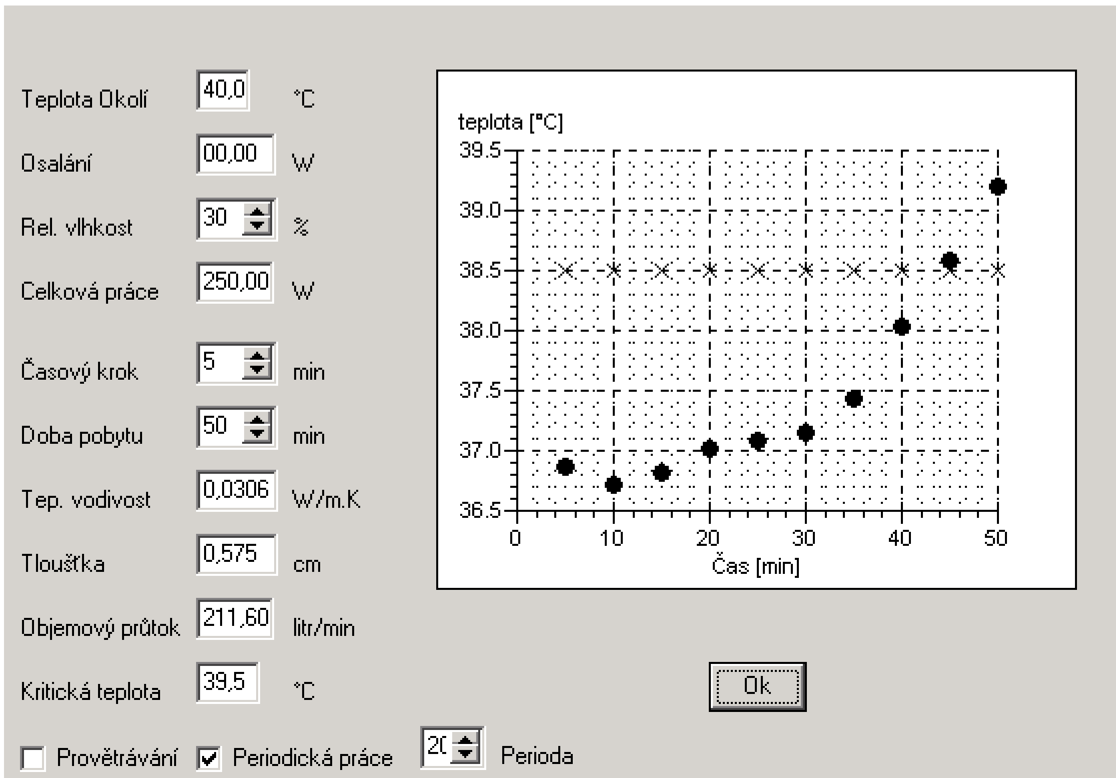
Body Heat Stress Response



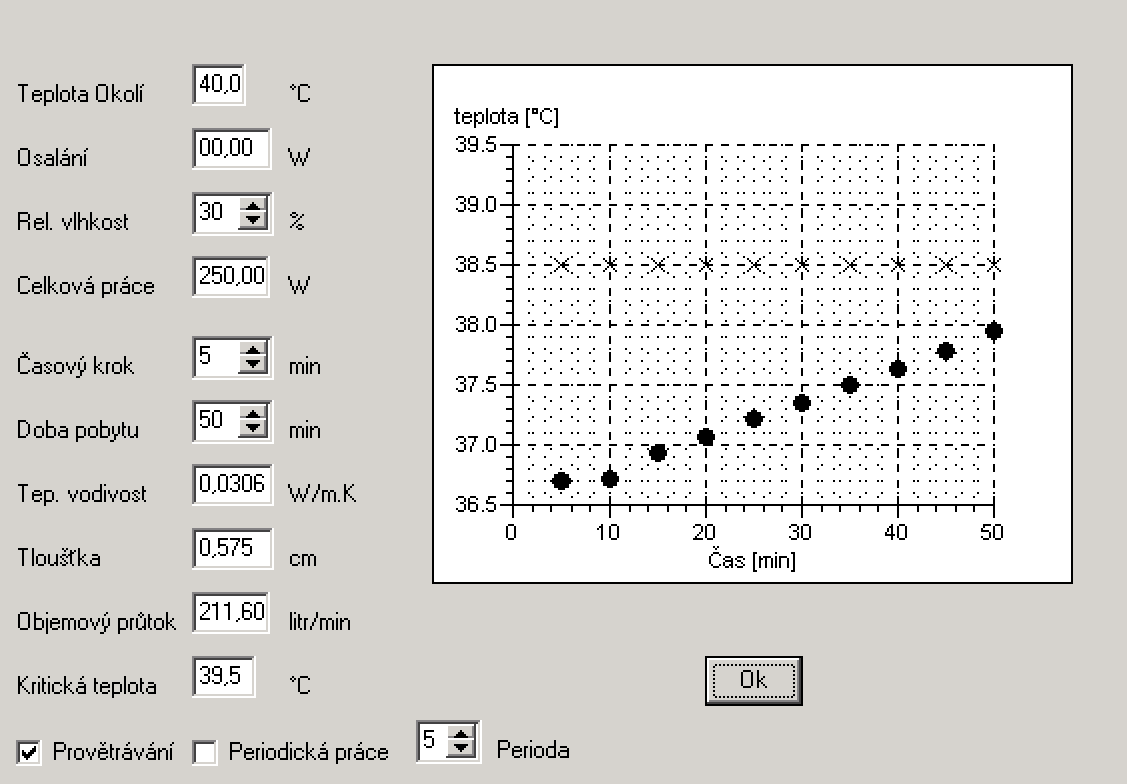
T_{rectal}= f (t) for continuous workload



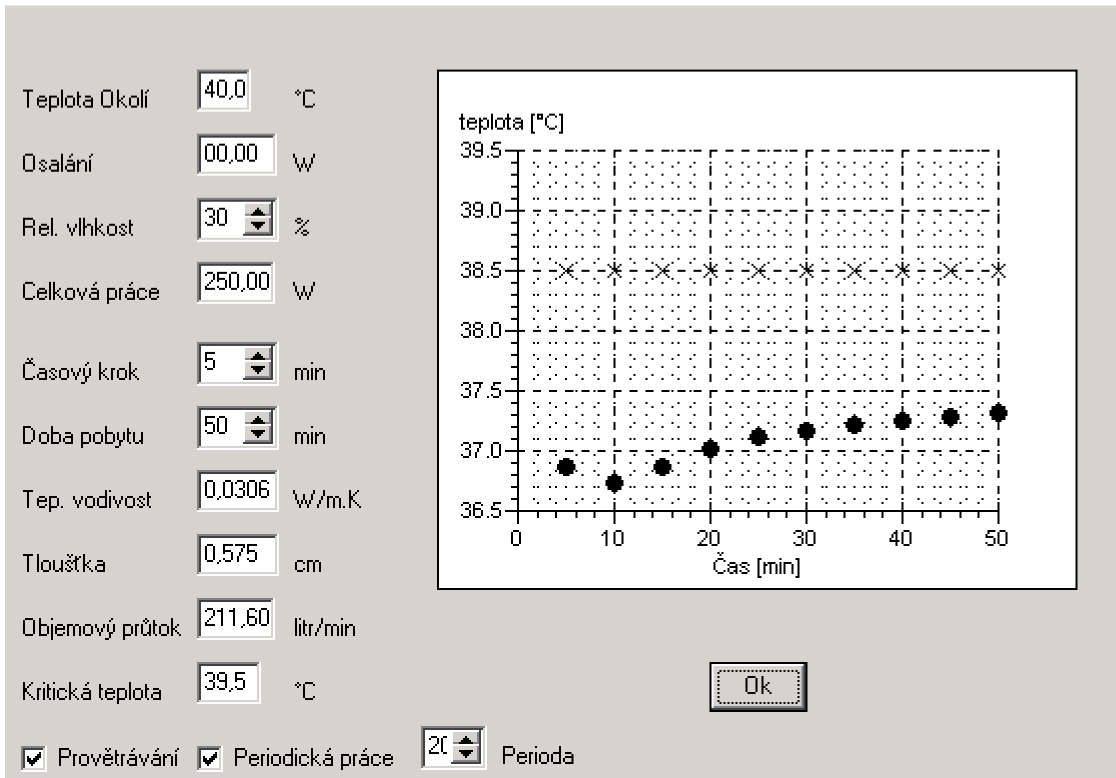
T_{rectal}= f (t) for periodical workload (work and rest)



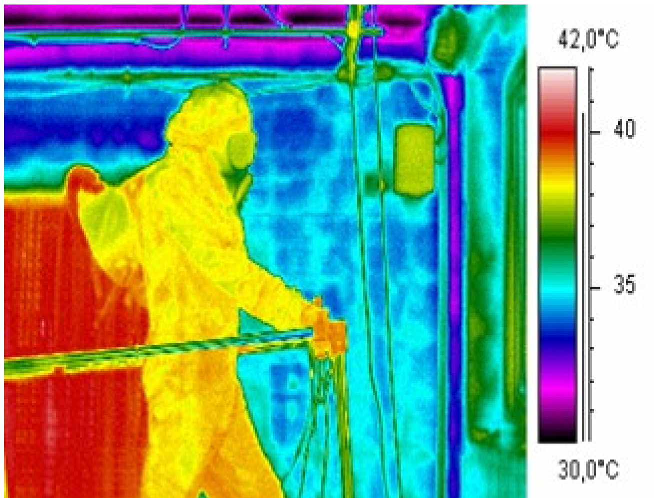
T_{rectal}= f (t) for continuous workload with ventilation

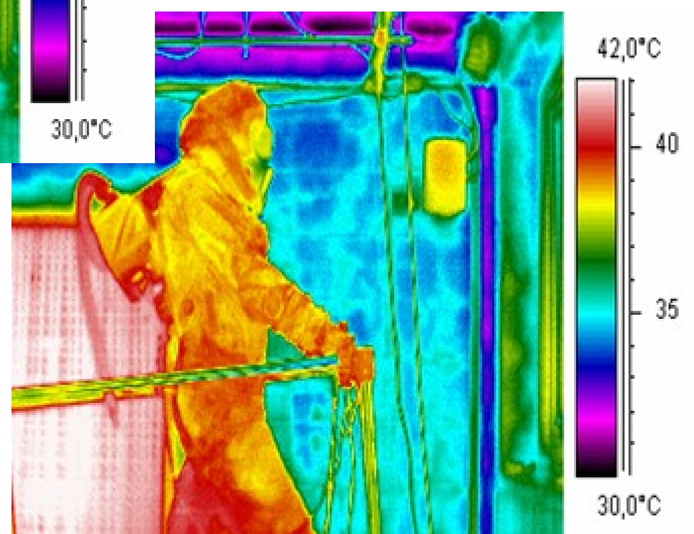


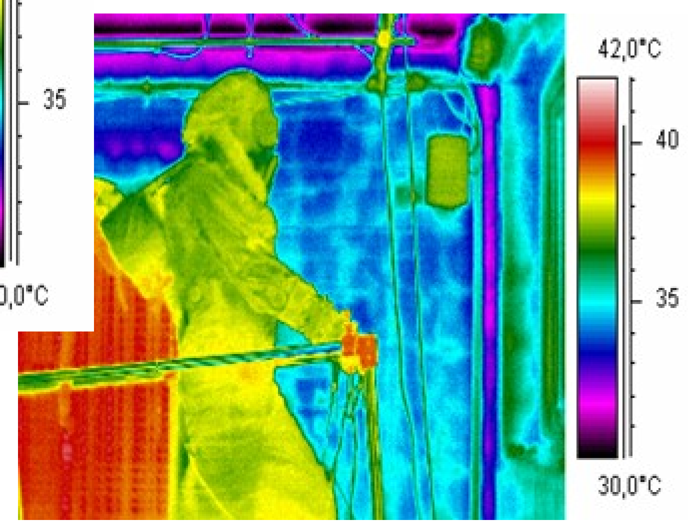
T_{rectal}= f (t) for periodical workload with ventilation



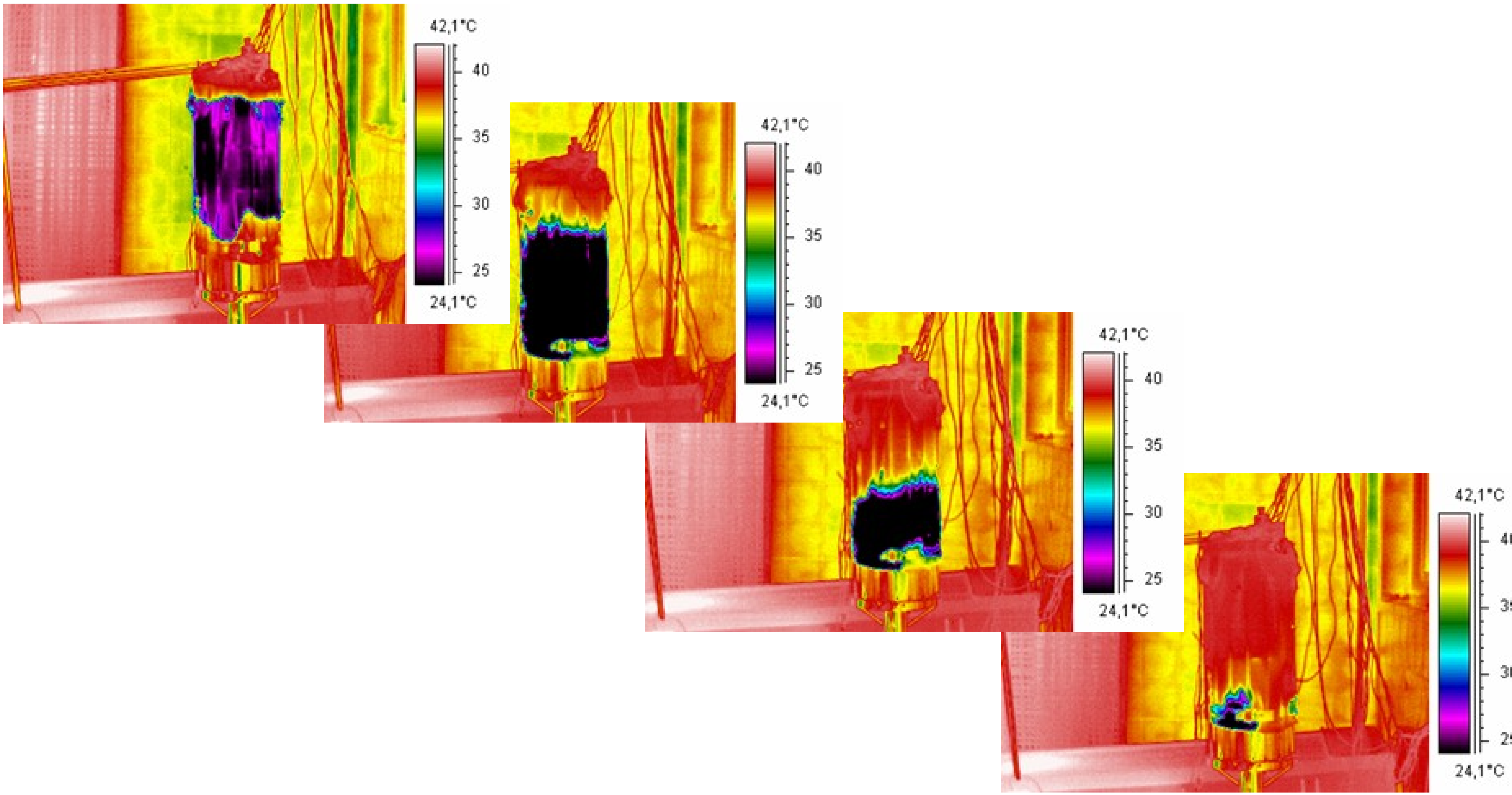
Thermo-imaging of Heat/Cooling Dissipation







Cooling Evaporation Effect



Conclusions

- Swatch testing represents only precondition for requested properties of PPEs during their design, development and manufacturing
- Visual-MIST represents high fidelity and fast testing technology for comprehensive evaluation of protective ensemble in dynamic condition
- Utilization of V-MIST as standard test technology for determination of PPE`s Protection Factor would require also revisions and the improvement of protection standards
- Heat stress properties of a PPE and workload response of a PPE users have to become the standard
    - Collaboration is welcome

Jiri Slabotinsky, Stanislav Bradka,
Lukas Kralik, Petr Smitka, Marketa Weisheitelova

National Institute for Nuclear, Biological and Chemical Protection v.v.i.,
Kamenna 79, 262 31 Milin, Czech Republic, *www.sujchbo.cz*

Petr Navratil*,

*VOP 026 Sternberk s.p.-Military Technical Institute of Protection,
Veslarska 230, 637 00 Brno, Czech Republic www.vtuo.cz

Pavel Castulik**

**CBRNe Consultant, Mikulaskovo sq. 17, 625 00 Brno,
Czech Republic
E-mail: *pcastulik@yahoo.co.uk*

CV Dr. Pavel Castulik

- Education: University of Defence, Chemical Engineering and NBC Defence, Dipl. Eng., PhD
- Commander of NBC Battalion
- PhD Thesis on Decontamination
- Head of Research & Development Decontamination Department
- Head of R&D Chemical and Nuclear Protection Division
- Destruction of CWs in Iraq
- Development of the Technical Secretariat of the Organization for the Prohibition of Chemical Weapons
- Head of Training at the OPCW
- Head of Chemical Weapons Demilitarization at the OPCW
- Chief Inspector at the OPCW
- University lecturer
- Consultant on CBRNe