DEFENCE R&D DÉFENSE

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Who is Defence R&D Canada ?

- Agency within the Department of National Defence with the mandate to provide S&T advice to the Canadian Military

Research Centres

Defence R&D Canada - Suffield

Chemical Biological Defence Section

- Preventive Medicine Group
- Molecular Biology Group
- Biological Detect/Ident Group
- Medical Therapy Group
- Chemical Synthesis and Analysis
- Chemical Detect/Ident Group
- Simulation and Modeling Group
- Decontamination Group
- Soldier and System Protection Group


Functional Materials
for CB Protection
Against the
Asymmetric Threat

What do we mean by…

“Functional materials for the asymmetric threat ”

Starting position … existing CB protective materials were developed for the "Cold War"

- Not functional …
  - thick, heavy, stiff
  - task restrictive
  - inefficient permeability
- Result …
  - over protection (not optimised)
  - high burden
  - integration issues
  - poor moisture management
  - many commanders decision issues

Outcome …

Protective clothing and equipment drives the mission

What do we want from a functional material ?

- A material, that when incorporated into a system, will contribute to **a measurable improvement in capability** provided by the system, and …
- will result in a **distinct operational advantage for the users of that system**

The Canadian approach

- Asymmetric threat different from Cold War
  - Alteration of Force Planning Scenarios
  - Change in Conduct of Operations

- Cold war protection and sustainment requirements are reduced by **matching level of protection to threat**
  - enabling superior warfighting capability, survivability and maintenance of op tempo

Capitalise on difference to develop materials that are more functional

Situate the context of use …

- **Cold War**
  - “history” – enemy was known
- **Asymmetric threat**
  - “now and future” – rogue nations/terrorist groups acting against national and global interests

Cold War battlefield

- Defensive operations in Central Europe - defend in-place “terrain denial”
- Large CB weapons stockpiles - warfighter faced possible large scale use of CB agents
- Fighting “dirty” for extended periods
- Wide range of delivery systems (aircraft, missiles, MLRS etc)

Asymmetric Threat battlefield

Very different from Cold War …

- Highly mobile battlefield
- Availability of CB weapons is much smaller
- Reduced capability to deliver and sustain attacks
- Asymmetric attacks – enemy avoids Force on Force, minimise technological advantage – enemy seeks disproportionate effects
- Attacks less massive, but less predictable - unconventional delivery
- Real time intelligence – greater situation awareness
- Greater ability of coalition Forces to dictate Op Tempo
- NATO and Coalition Air superiority

Define protection requirements for Conduct of Operations (in the Asymmetric battlespace)

- Enemy with reduced capability; less massive, less contaminated footprint; well defined operation and exit strategy
  - **Chemical protection required for <u><2 h</u>**
  - **Biological protection required for <u><30 min</u>**
- Liquid contact/vapour penetration
  - **<2 µg total in 2 h**
- Direct vapour challenge
  - **Ct of <50 mg min m^{-3} in 2 h**
- Aerosol penetration
  - **>90% reduction over existing**

Integration of the Threat into Design

Threat and hazard scenarios

- CB agents
- Delivery means
- Challenge levels (spatial and temporal)

Protective materials design

- Acceptable levels of exposure
- Exposure durations
- Physiological burden
- Task/performance functionality

Material requirements

- “Tailored” protection – toxic effects have negligible impact on military task performance
- Low physiological burden (thermal, weight)
- High task functionality

Outcome

	Protective Posture					
	Combat Uniform	MOPP 1	MOPP 2	MOPP 3	Asymmetric Threat Posture	MOPP 4
Body	X	√	√	√	√	√
Feet	X	X	√	√	√	√
Hands	X	X	X	√	X	√
Head	X	X	X	X	X	√
Respirator	X	X	X	X	X	√

X – no protection

√ – protection

Asymmetric Threat Posture

- Applied in the appropriate theatre of operations…
  - well defined level of protection <u>all</u> of the time
- Rather than…
  - no protection (combat uniform)
  - logistical burden of too much protection that is not need most of the time

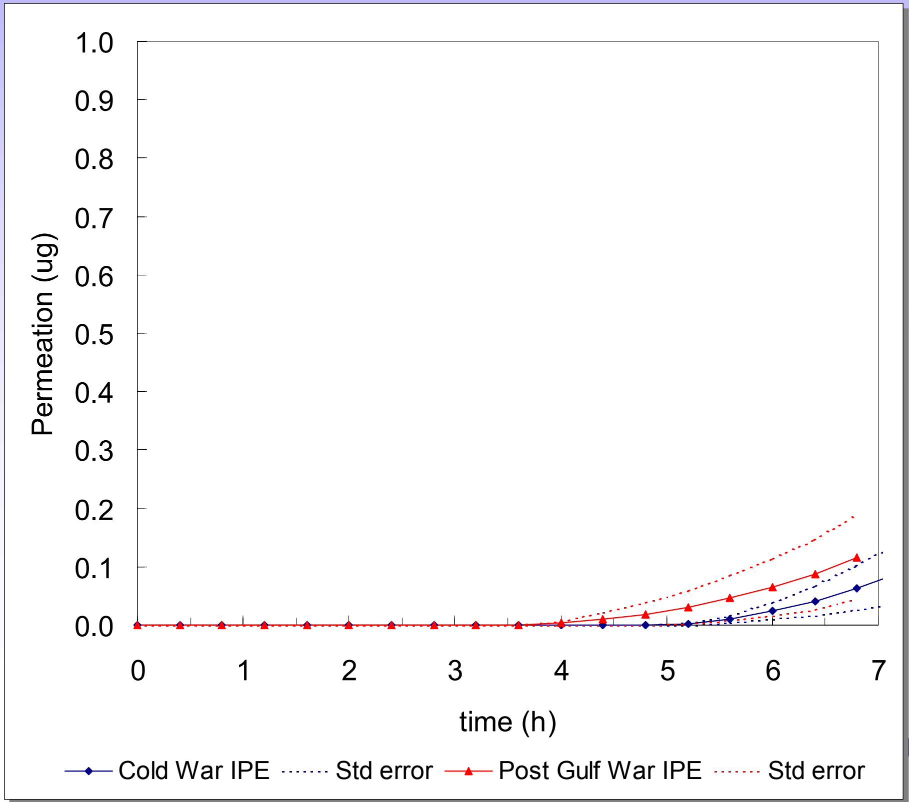
Functional materials

Examples of R&D effort at DRDC Suffield

- Fabric based protective systems
  - chemical
    - liquid
    - vapour
  - aerosol
  - biological

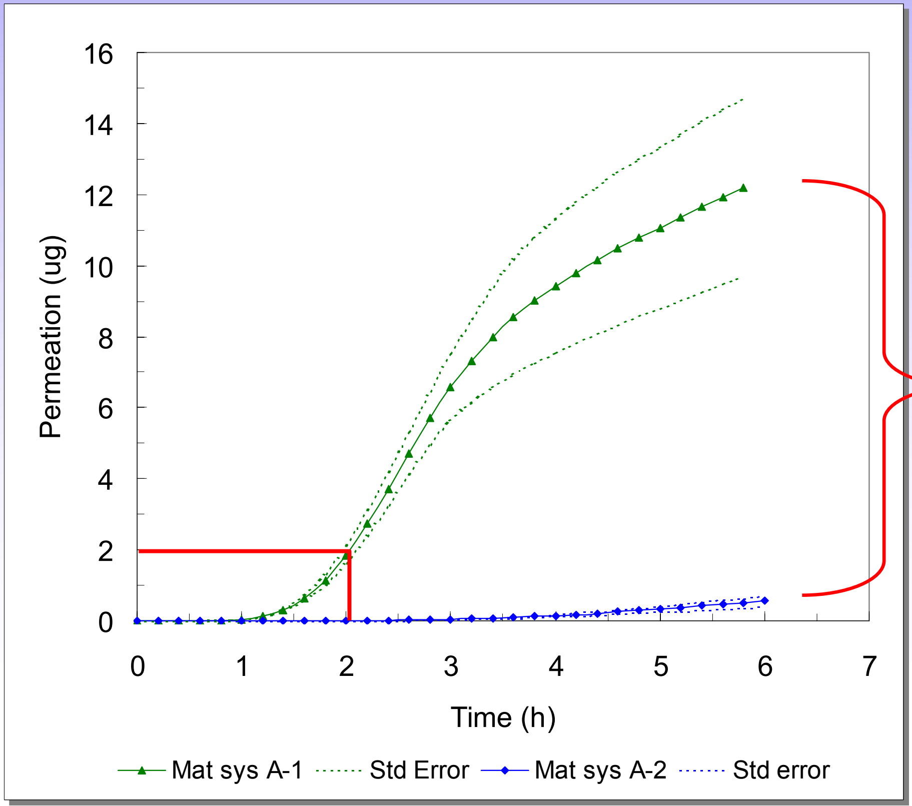
Current IPE materials

- Cold War IPE (legacy) – blue curve
  - Mass: 482 g m^{-2}
  - Air Permeability: 25 cm^3 cm^{-2} s^{-1}
  - Thickness: 2.35 mm
- Post Gulf War (Horizon 1) – red curve
  - Mass: 400 g m^{-2}
  - Air Permeability: 18 cm^3 cm^{-2} s^{-1}
  - Thickness: 1.10 mm



Asymmetric Fabric Systems (A)

- System A-1 (green curve)
  - Mass: 200 g m^{-2}
  - Air Permeability: 43 cm^3 cm^{-2} s^{-1}
  - Thickness: 0.59 mm
- System A-2 (blue curve)
  - Mass: 259 g m^{-2}
  - Air Permeability: 48 cm^3 cm^{-2} s^{-1}
  - Thickness: 0.83 mm

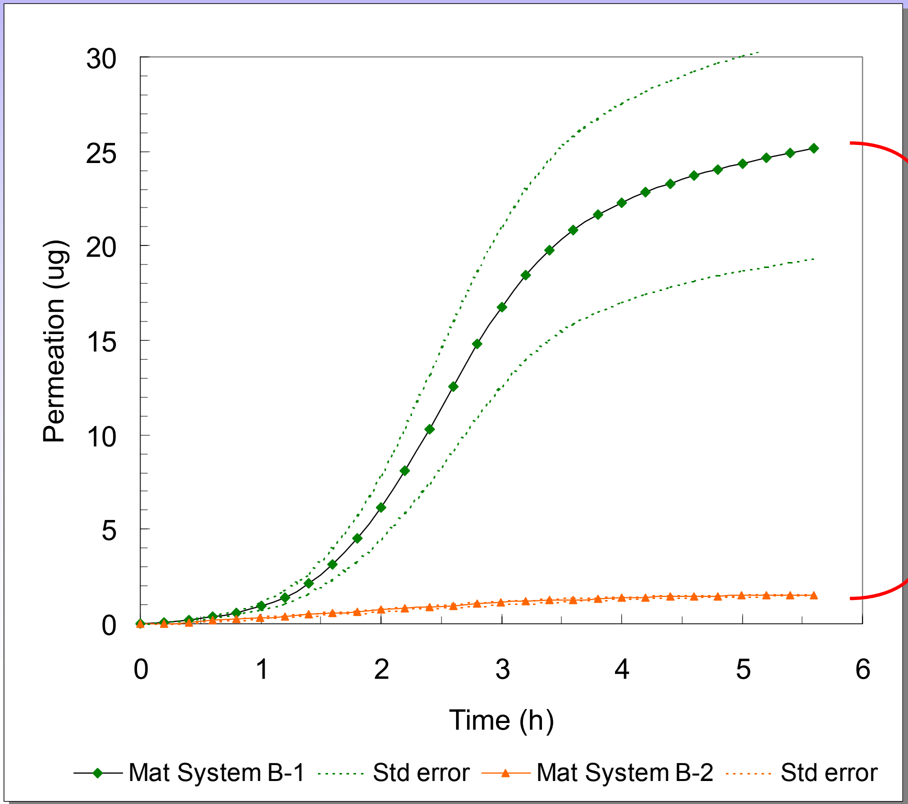


Systems have the same barrier A

Difference due to outer shell

Asymmetric Fabric Systems (B)

- System B-1 (green curve)
  - Mass: 316 g m^{-2}
  - Air Permeability: 36 $cm^3\ cm^{-2}\ s^{-1}$
  - Thickness: 0.79 mm
- System B-2 (orange curve)
  - Mass: 375 g m^{-2}
  - Air Permeability: 52 $cm^3\ cm^{-2}\ s^{-1}$
  - Thickness: 1.02 mm

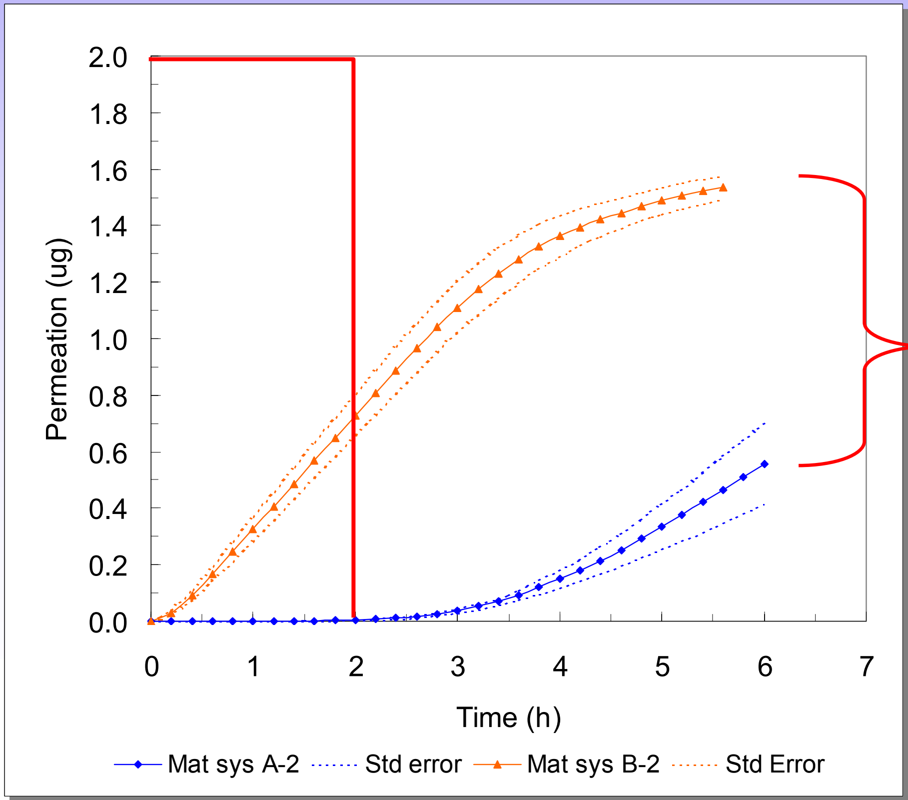


Systems have the same barrier B

Difference due to outer shell

Comparison of Asymmetric Fabric Systems A-2 and B-2

- System A-2 (blue curve) and B-2 (orange curve)
  - Mass difference: A-2 (-116) g m^{-2}
  - Carbon loading ratio: A-2/B-2 (2.0)
  - Air Permeability: A-2 (-4) cm^3 cm^{-2} s^{-1}
  - Thickness: A-2 (-0.19) mm

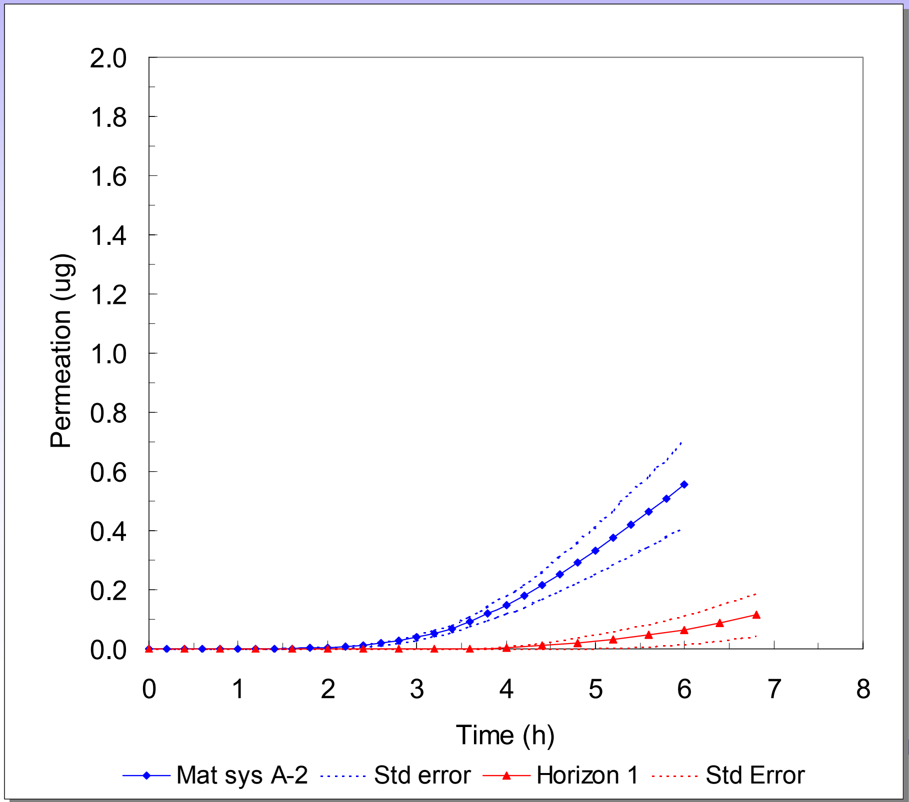


Systems have different barrier

Difference due to barrier layer

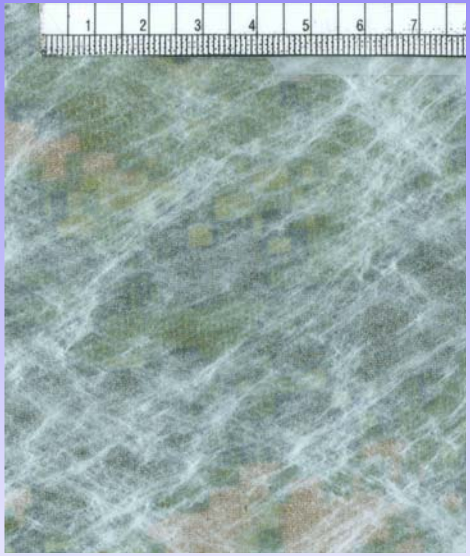
Comparison of New Asymmetric Fabric System A-2 and Current Horizon 1

- A-2 System (blue curve) and Horizon1 (red curve)
  - Mass difference: A-2 (-140) g m^{-2}
  - Carbon loading ratio: A-2 /Horizon 1 (1.0)
  - Air Permeability: A-2 (+30) $cm^3\ cm^{-2}\ s^{-1}$
  - Thickness: A-2 (-0.27) mm



Enhancement of performance against vapour

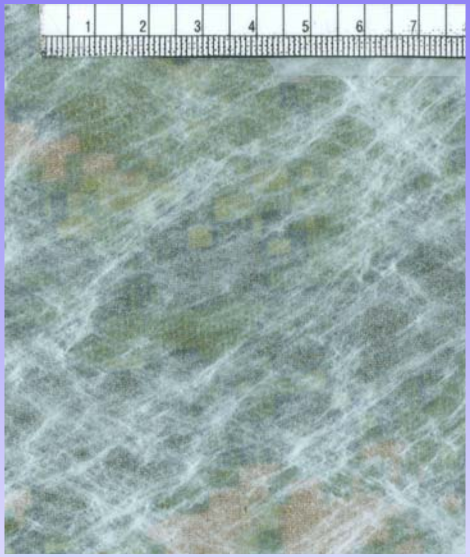
- Improve by introducing an aerosol web (AW) into material system
  - System A-2: change in material properties due to AW
    - Mass (increase): from 259 to 267 g m^{-2}
    - Air Permeability (decrease): from 48 to 9.5 $cm^3\ cm^{-2}\ s^{-1}$
    - Thickness (no change): 0.83 mm
  - Challenge dosage to material at 2 h
    - 1320 mg min m^{-3}; 5 m s^{-1} wind speed



Fabric System	Cumulative penetrated dosage (mg.min.m^{-3})		
	1h	2h	6h
System A-2	55	124	922
System A-2-AW	3	**9**	78

More than factor of 10 reduction of Ct

Enhancement of performance against aerosols



- Improve by introducing an aerosol web (AW) into material system
  - System A-2
- Challenge
  - *Staphylococcus Aureus* ATCC# 6538
  - Concentration 10^6 CFU mL^{-1}
  - Aerosol size: 3 µm
  - Flow Rate: 30 LPM

Fabric System	Filtration efficiency %
A-2 outer shell	< 1
A-2 outer shell with AW	98.938

Enhancement of performance against bacterial contact

- Introduce an antimicrobial finish on outer shell
  - System A-2
- Organism:
  - *Staphylococcus aureus* ATCC # 6538
- Concentration: 10^6 CFU mL^{-1}
- Time Exposures: 24 h

Fabric System	Log_{10} reduction
A-2 outer shell	-
A-2 outer shell with treatment	>4.87

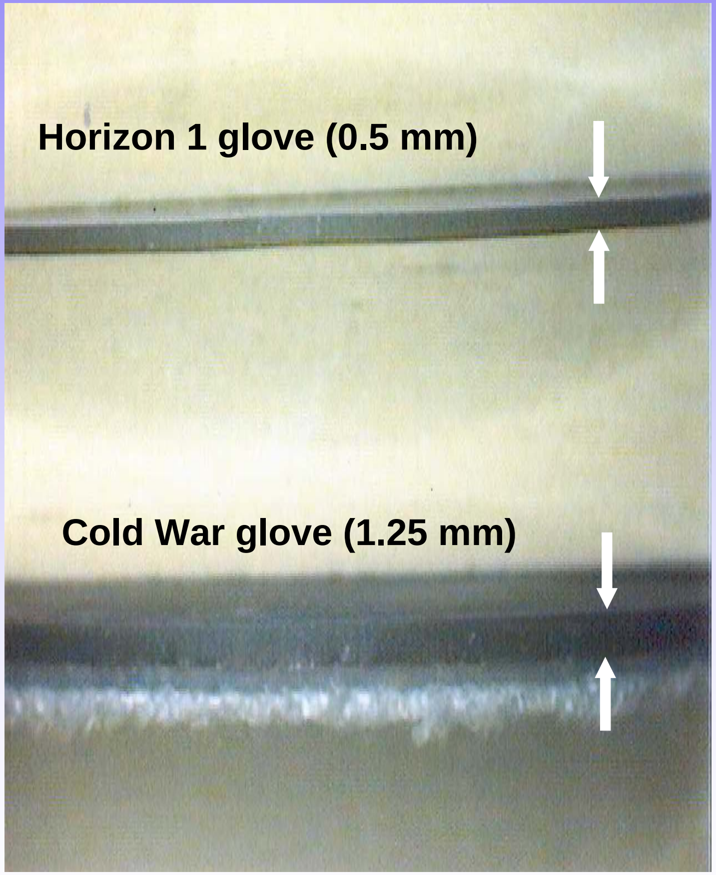
Summary

- We are developing protective fabric materials with properties more conducive to higher functionality
  - lighter (35%)
  - more air permeable (166%)
  - thinner (25%)
  - aerosol web that improves protection against
    - direct vapour challenge
    - penetration of aerosols
  - anti-microbial coatings to protect against contact bacteria

These improvements in the context of the Asymmetric Threat

- Enemy with reduced capability; less massive, less contaminated footprint; well defined operation and exit strategy
  - **Chemical protection required for <2 h**
  - **Biological protection required for <30 min**

Functional materials: Polymers

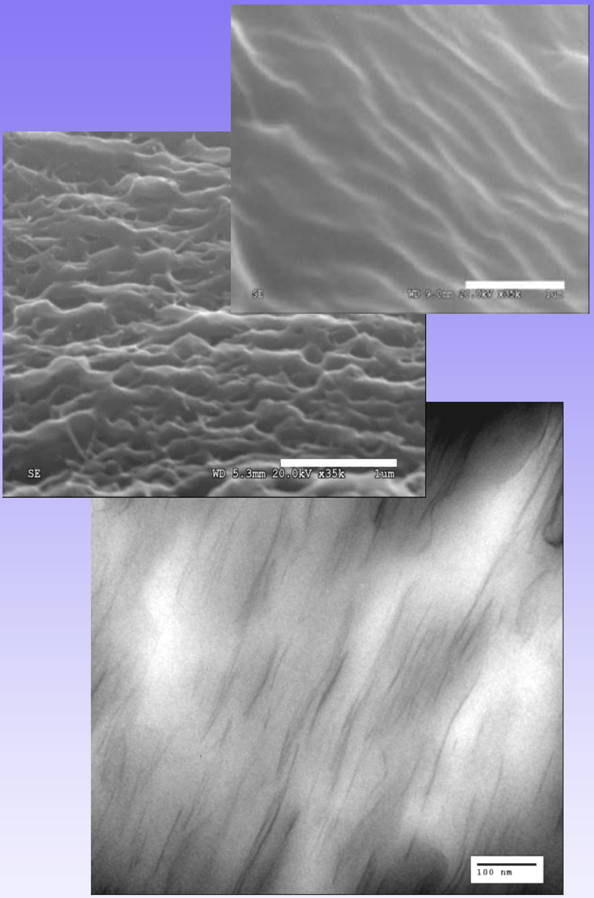


- Typical thickness of polymer-based materials used in current in-service military protective equipment
  - 0.50 mm (the chemical protective glove)
  - >2.0 mm (the facepiece of the C4 respirator)

Polymer Nanocomposites

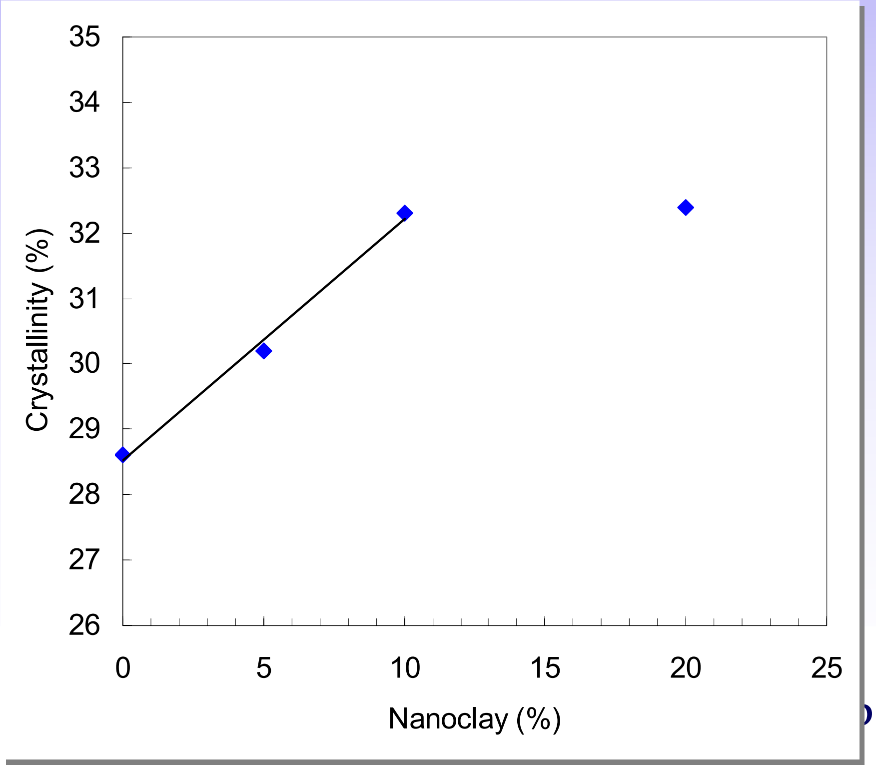
- Aim is to develop micrometer thin CW agent impermeable TPE polymer films
- Nanocomposite materials successfully developed into films ~25 µm in thickness
- Benefits – replace polymers in existing CB protective equipment – reduce burden and improve functionality

Polymer Nanocomposites

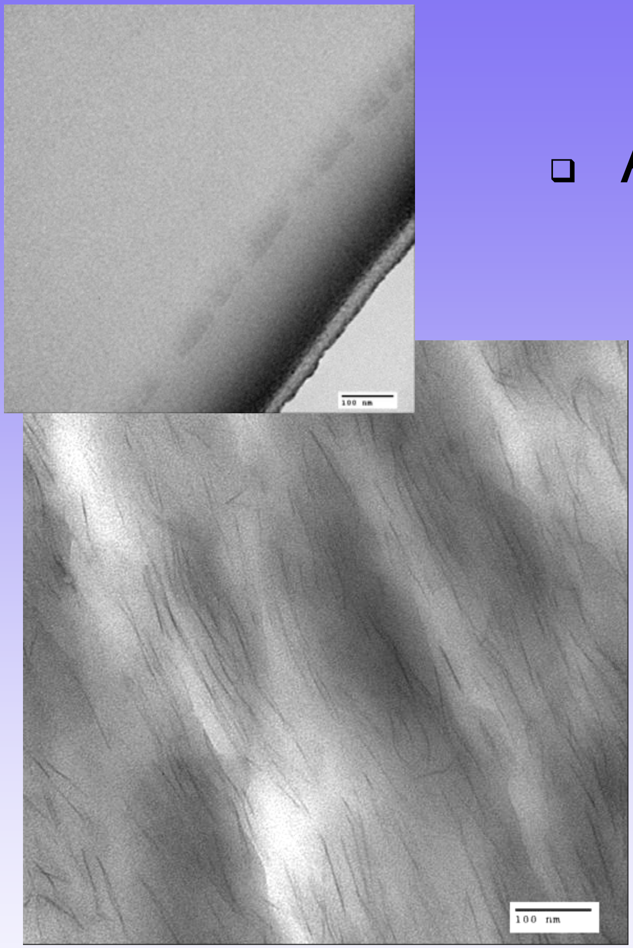


Addition of nanoclay to polymer system

- increases crystalline fraction
- improves physical properties
    - Tear strength (+15%); uniaxial strength (no change); modulus (+50%)

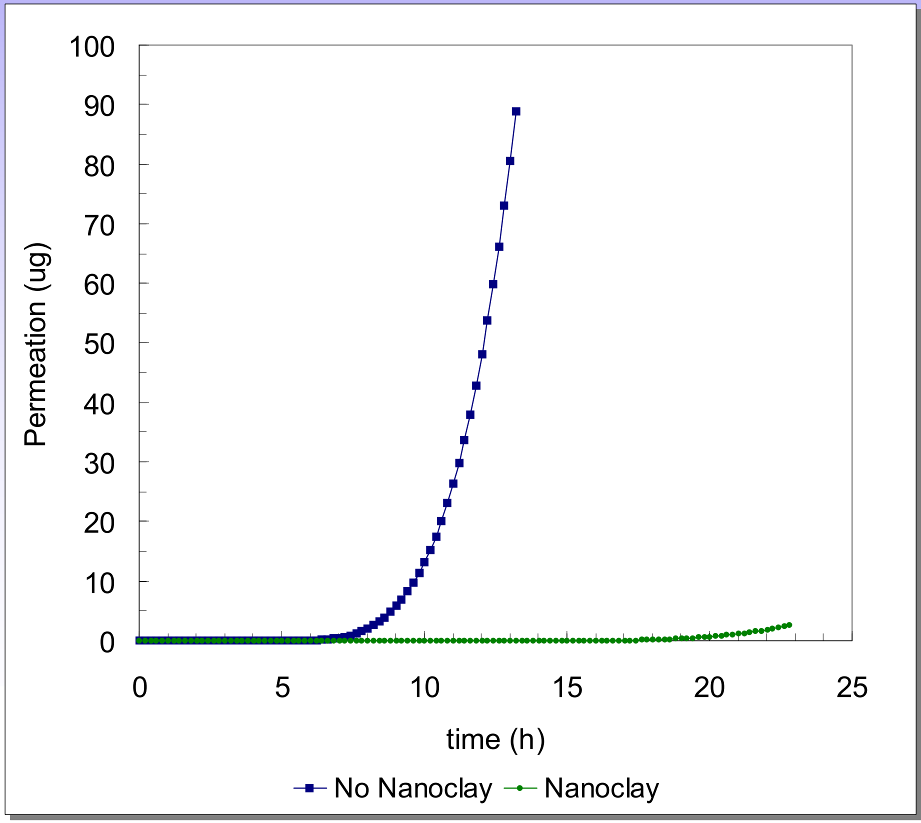


Polymer Nanocomposites



TEM, 200000 x magnification

- Addition of nanoclay to polymer system
  - increases diffusion path (tortuosity)
  - **improves chemical resistance**

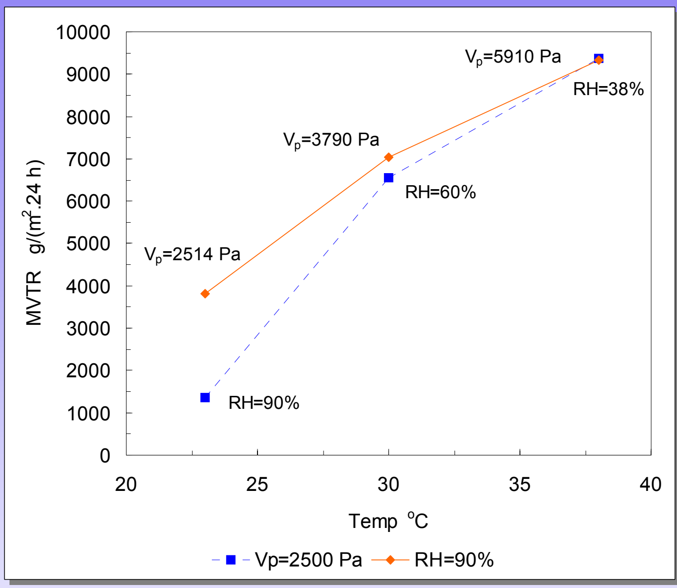


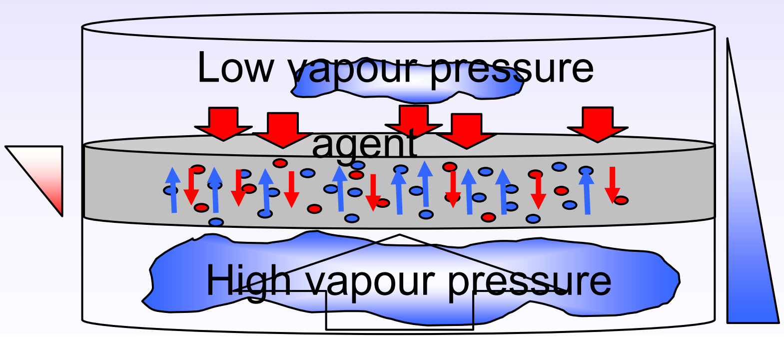
Selectively Permeable Membranes

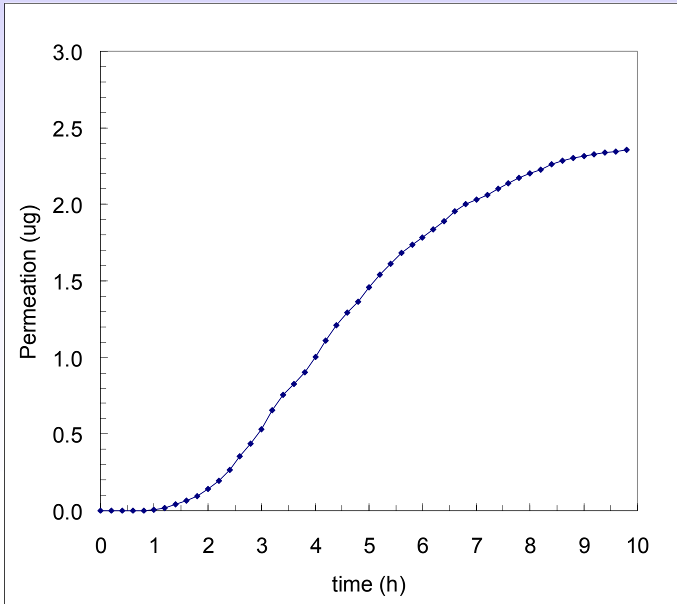
- Objective
  - develop micrometer thin water vapour permeable CW agent impermeable polymer films

Moisture vapour permeable (agent impermeable) monolithic membranes

- Two phase polymer membrane
  - Water diffusion
    - inverted cup method
  - Permeation (simulate high water vapour pressure next to skin)
    - open cell; agent (drop-wise) 5 g m^{-2}; T=30 ^{o}C
    - ΔH_2O v_p= 3400 Pa across membrane
      - no permeation through
    - ΔH_2O v_p= 1500 Pa across membrane



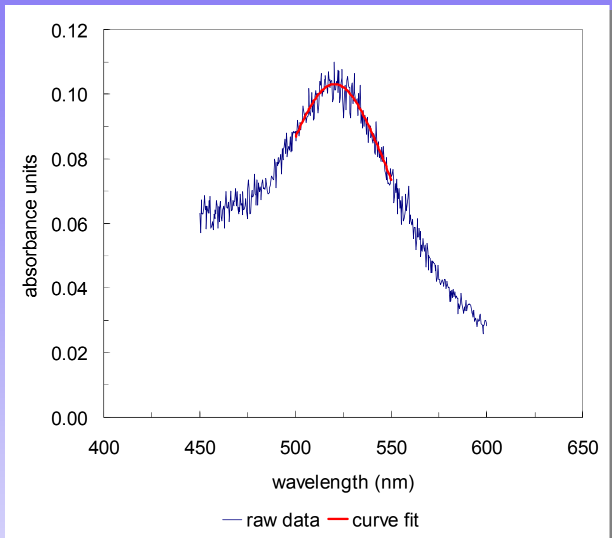




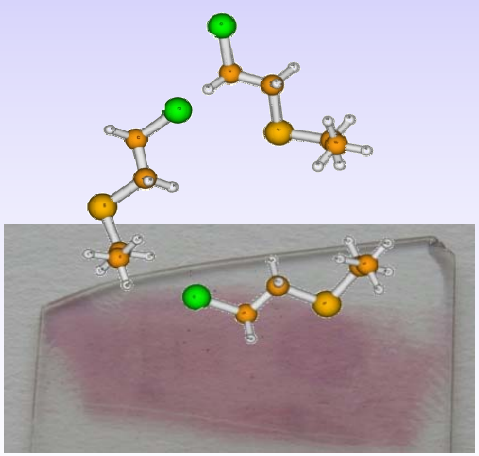
Nanoparticle complexes

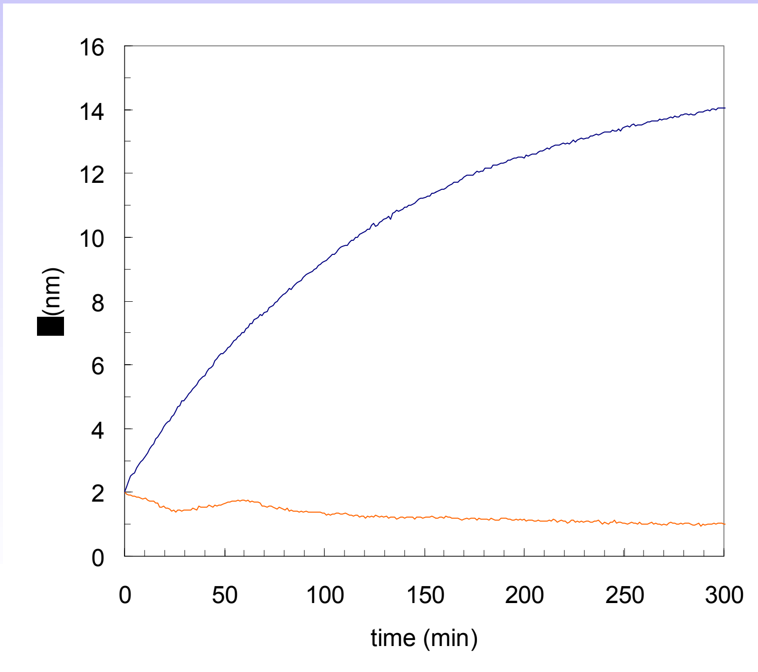
- Objective
  - Develop nano-ordered materials/ complexes
    - control material properties to affect specific outcomes or responses
    - study of uptake of organics, reversible/irreversible adsorption, colorimetric detection, reactivity / degradation / functionalisation properties

Nanoparticle film sensing



- Surface plasmon resonance (SPR) absorption band observed in the absorption spectra of many metallic nanoparticles
    - Au particles 5-15 nm have maximum absorbance near 520 nm
- Expose Au nanoparticle film to organic vapour and monitor shift in SPR peak with time





Summary

- Conducting operations in Asymmetric Threat environment demands different approach to protecting the soldier
- Integrate threat into design and match protection requirements to threat level
- Shorter duration protection requirements allow development of protective materials with properties more conducive to higher functionality
- Progress being made on thin nanocomposite films and thin moisture vapour permeable membranes (~25 μm)
- SPR-based sensors have real-time capability

Motto

Well defined, short duration protection available all of the time…

… is more effective than too much protection that is not needed most of the time