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Canadian Programme on the Environnemental Impacts of Munitions

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DRDC | RDDC

Canada

ARMED FORCE READINESS DEPENDS ON TRAINING WITH LIVE AMMUNITION

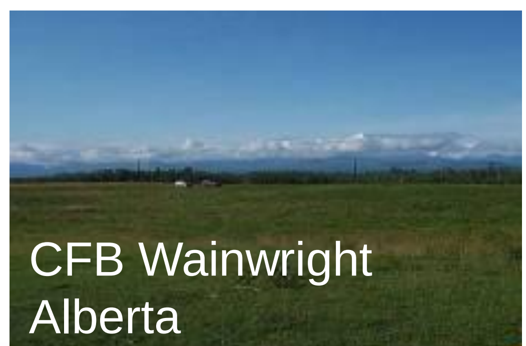
UNDERSTAND AND MINIMIZE ENVIRONMENTAL IMPACTS OF WEAPONS

Environmental Impacts of Weapons

Munitions Constituents (MC) Contamination

Source Terms
Fate and Transport
Toxicity

Mitigation,
Range Design &
Greener Munitions



What are the sources of munitions contaminants at impact areas ?

Deposition Studies

Type of detonation:

High-order
Low-order
Close-proximity
Field disposal by blow-in-place

Explosives

Close-proximity detonations: Rupture of UXOs

Low-order detonations

Explosives

UXO BIP using C4

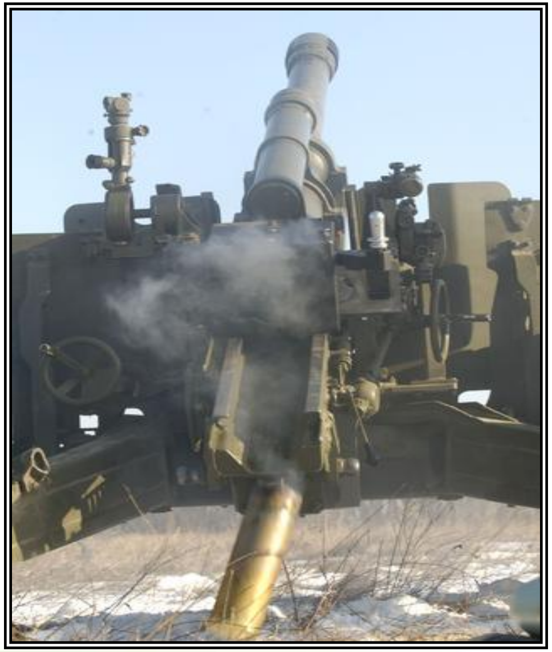
UXO corrosion

High-order detonations

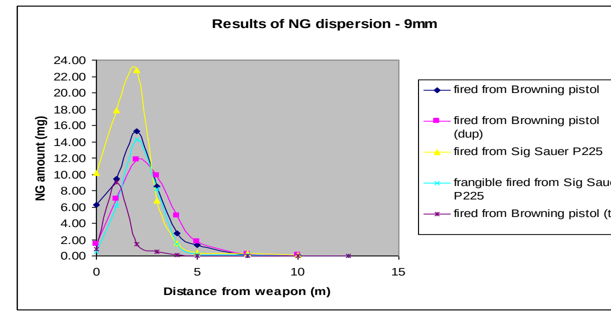
**100 000 high order =
one low-order detonations**

What are the sources of munitions contaminants at firing positions?

Incomplete combustion in guns



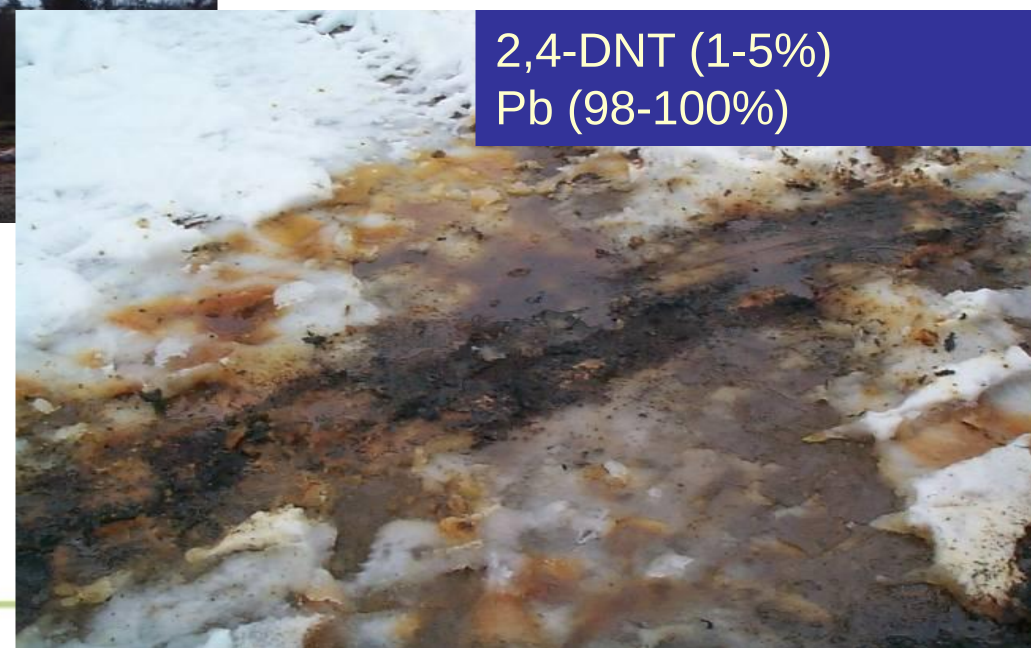
Deposition Studies



Results

Weapon	% of unburned EM
5.56-mm MG (NG)	0.7
7.62-mm MG (NG)	1.0
9-mm Pistol (NG)	2.5
12.7-mm MG (NG)	0.7
0.338 Cal Rifle (NG)	0.001
0.5 Cal MG (NG)	0.02
0.5 Cal Rifle (NG)	0.02
20-mm M61 (NG)	7×10^{-4}
40-mm Mk281 (NG)	0.6
40-mm M430 (NG)	8.0
60-mm Mortar (NG)	0.007
81-mm Mortar (NG)	3.3
120-mm Mortar (NG)	1.4
84-mm AT4 (NG)	73
84-mm Carl Gustav (NG)	14
66-mm M72 LAW (NG)	0.2
204-mm GMLRS (AP)	nd
203-mm MK-58 AIM-7 (AP)	3×10^{-7}
105-mm Howitzer (DNT)	0.05 - 0.3
155-mm British (NQ)	2×10^{-5}
155-mm British (NG)	3×10^{-5}
105-mm Tank (DNT)	0.003

Open burning of excess charge bags



2,4-DNT (1-5%)
Pb (98-100%)

Metals

Munition casings & hard targets : Pb, Sb, Cu, Zn, Sr, Cd.

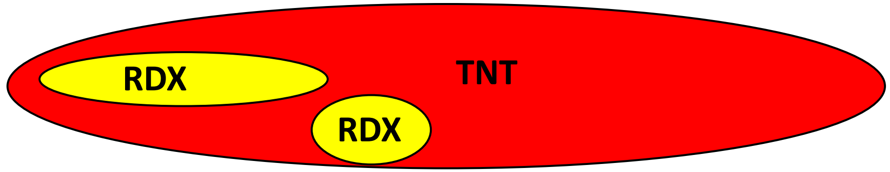
Sampling Objectives in Range and Training Areas

- Measure the surface soil contaminants that may:
  - Pose a threat to the health of users
  - Further be dissolved and brought to water bodies
  - Pose a threat to ecological receptors
  - Combination of all of the above

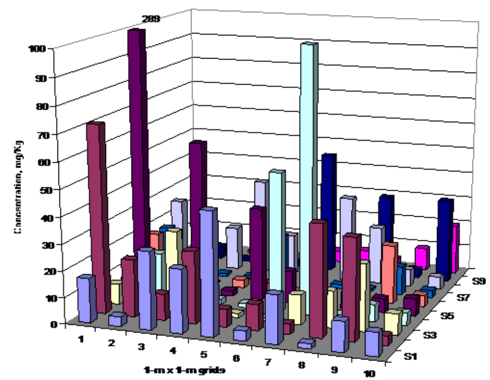
What are the nature and dispersion of munitions constituents ?

Dispersion of Munitions Residues

Compositional Heterogeneity: Fundamental Error (FE)



Distributional Heterogeneity: Segregation Error (SE)



Control over Heterogeneity

If the entire population is not well represented

Under or overestimation by orders of magnitude

↓

To minimize FE : greater sample mass

To minimize SE : many increments

↓

Sample treatment is as important as sample collection

Decision Units Definition

DUs for Various Objectives

- Risk-based human health

- Protection of surface or GW

- DU for risk-based ecological receptors

Results

Anti-tank Range Contamination

Energetic
HMX, TNT, RDX

Propellants
NG, 2,4 DNT

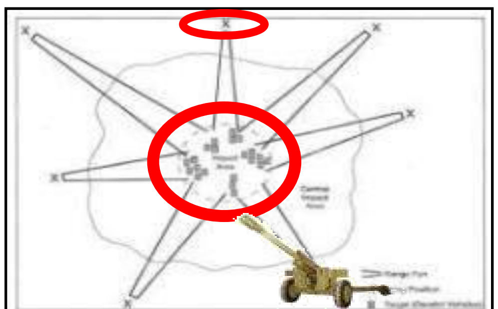
Metals
Pb

Artillery Range Contamination

Energetic
RDX, HMX, TNT

Propellants
NG, 2,4 DNT

Metals
Pb, Zn, Cu….



Small Arms Ranges Contamination

Metals
Pb, Sb

Propellants
NG

Demolition Range Contamination

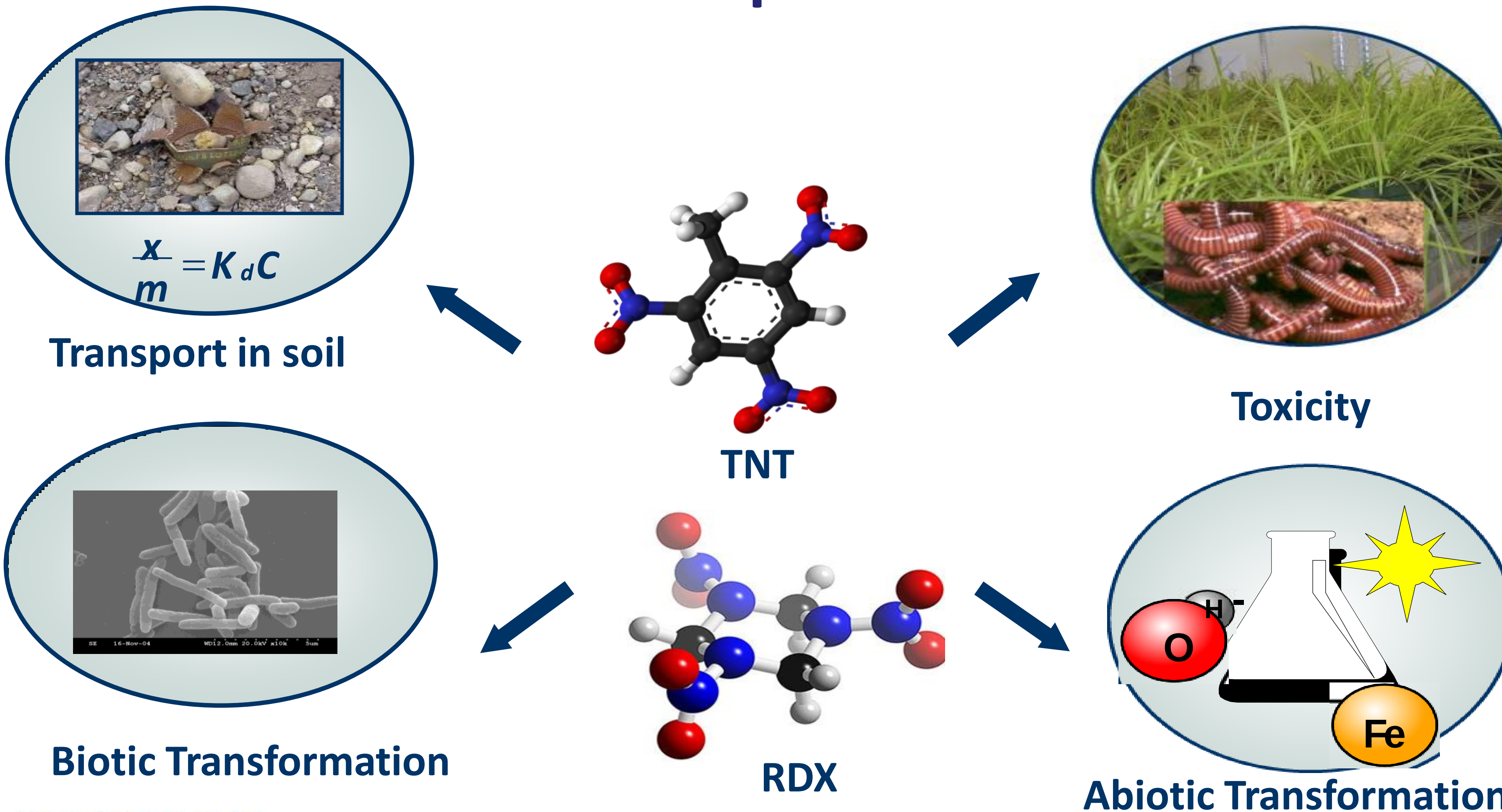
All types of ammo
Energetic : TNT, RDX
(low detonation)

Grenade Range Contamination

Energetic
RDX

Metals
Sb, As

Fate and Impact of EM



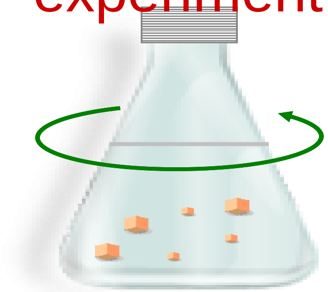
Aqueous dissolution of formulations

EC

Dissolution

EC in Water

Batch experiment



- Formulation (10mg) in 100 mL DW (T = 10, 25, and 30°C)

Dripping experiments

- Formulation (10 mg)
- DW (0.5 mL/min) at r.t.

Sorption on soils

Batch experiments

- Soil (1.5 g)
- Deionized water (10 ml)
- Energetic chemical (4-50 ppm)
- Static; aerobic; dark; r.t.

⇨ K_d values

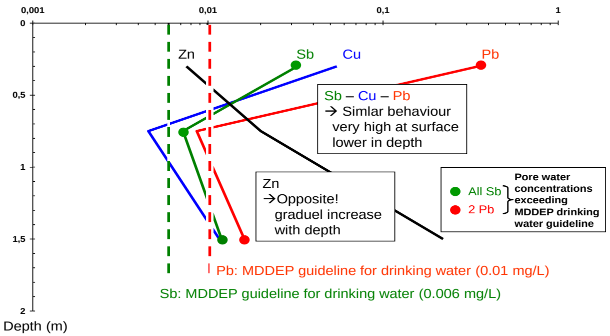
Column experiments

- Soil (90 g)
- Energetic formulation
- Flow rate: 0.4 mL/min, T = 22.5°C

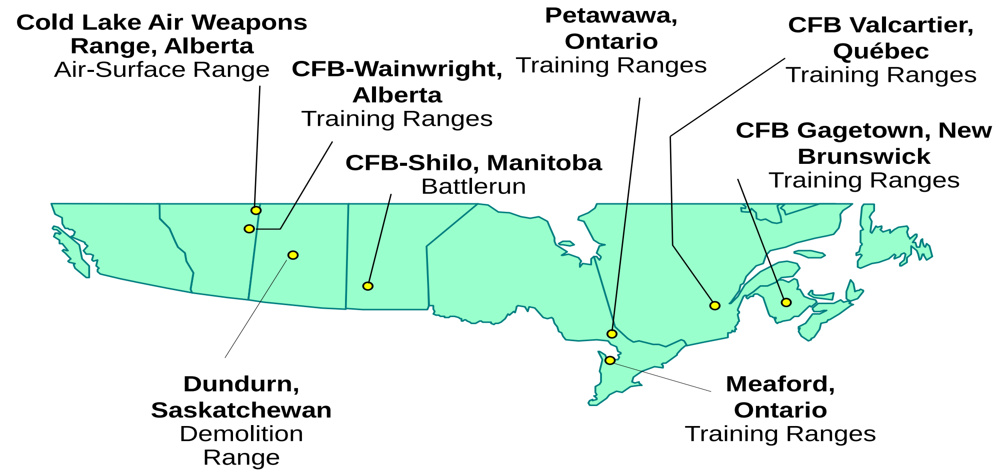
⇨ Breakthrough curves / transport modeling

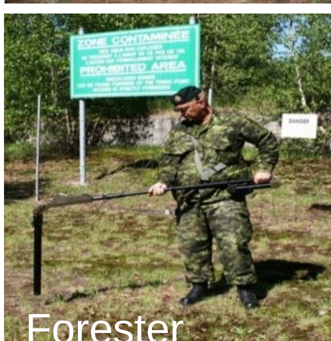
Lessons Learned on Fate, Transport and Toxicity

- RDX and AP : Toxic and bioavailable
- HMX : Much less toxic & bioavailable than RDX
- TNT : Toxic & soluble but non-bioavailable (through transformation/sorption)
- NG & 2,4-DNT : Toxic but low bioavailability (NC binding)
- NC : Neither toxic nor bioavailable
- Metals - Sb, Pb, Cd, Sr, toxic and bioavailable

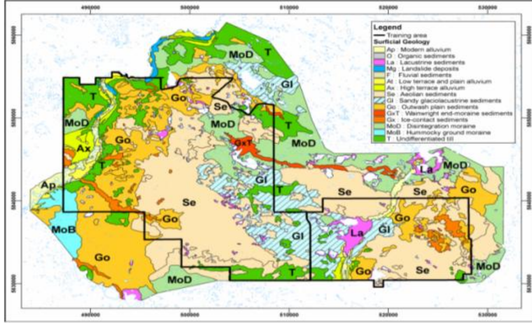


Large Scale Fate and Transport: Hydrogeological Characterization

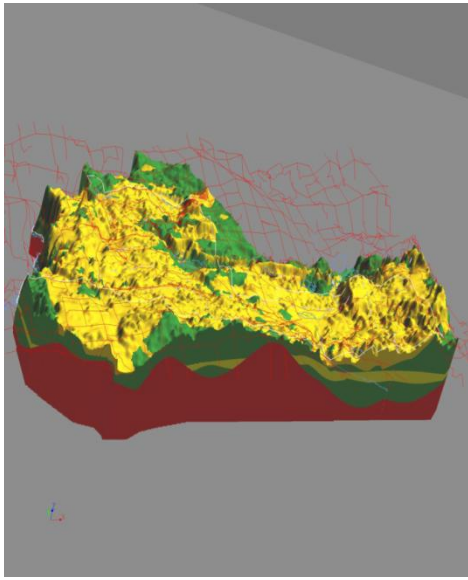


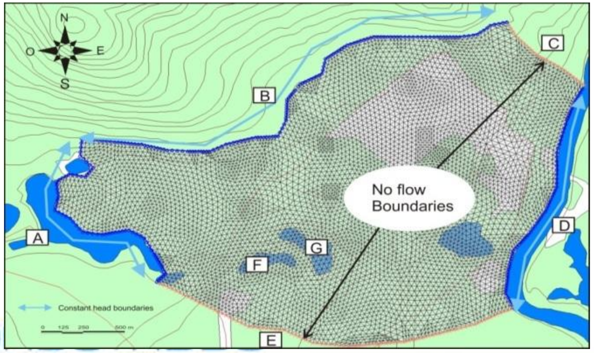


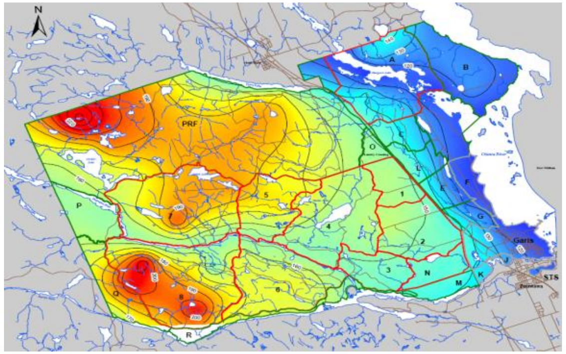
Hydrogeology



- Surveillance wells in major training areas
- Production of several thematic maps
- Modeling aquifer flow and direction
- Prediction of contaminants transport
- Surveillance programs

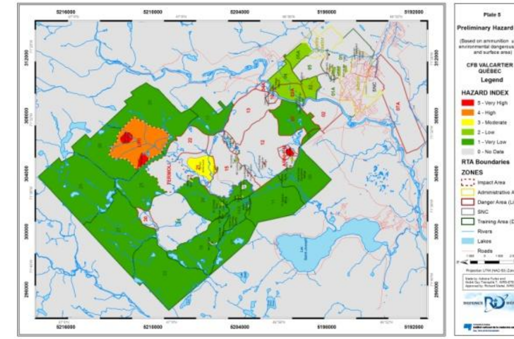




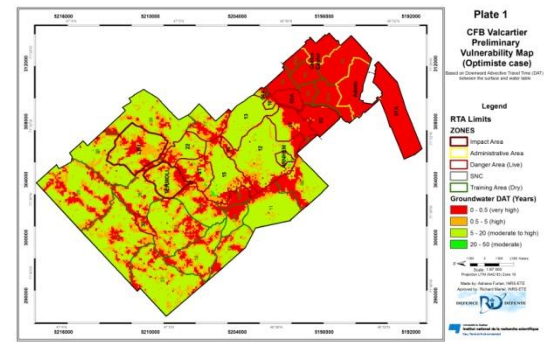


Hydrogeology / Risk Management Tool

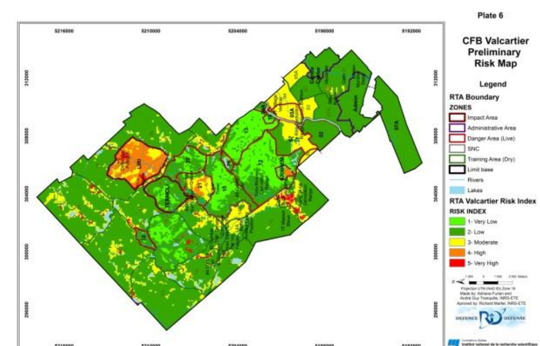
- Munition use logs/Surface sampling/ Deposition studies: Source terms **Hazard maps**



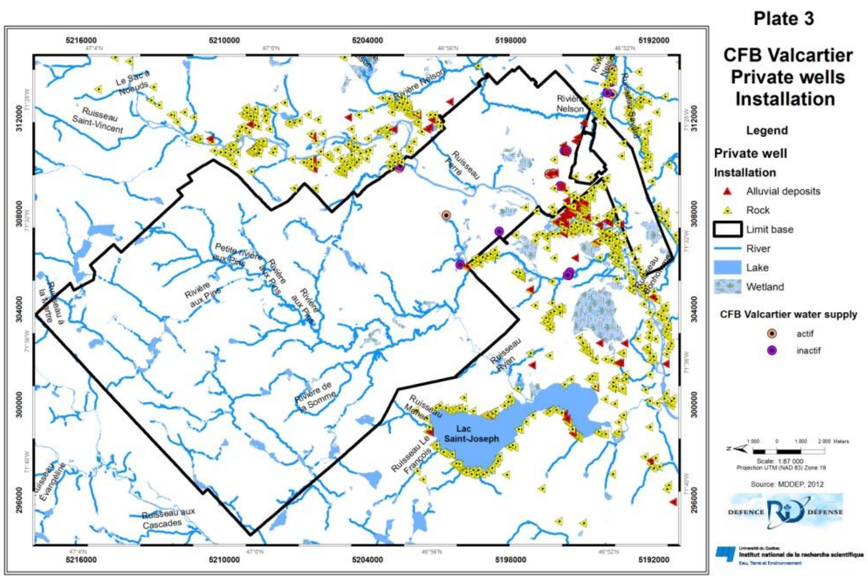
- Hydrogeological studies: Contaminant transport **Vulnerability maps**



- Combination of the vulnerability and hazard maps – **Risk maps**



Receptors & Surface water vulnerability



Futur work

- In situ analytical method for munition constituents in water samples
- Climate changes and their impacts of ranges and training areas
- Deployment in Arctic areas
- Fate and toxicity of emerging Insensitive Munition formulations

In situ monitoring using RAMAN spectroscopy: Theory

- Raman is a weak optical phenomena: Nanoparticles significantly improves the response (work conducted by Professor Masson, U. Montreal)

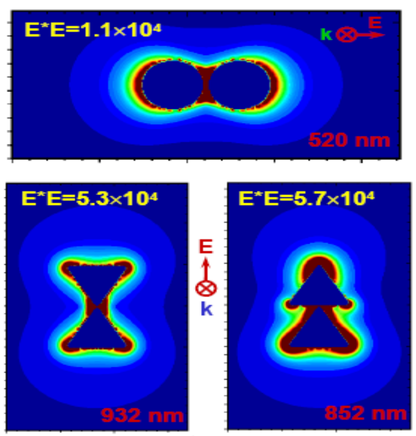


Figure 11. Contours of $|\mathbf{E}|^2$ for dimers of silver particles, including two spheres separation 2 nm) and two triangular prisms placed head to head and head to tai… nm, width 12 nm, snip 2 nm and separation 2 nm).

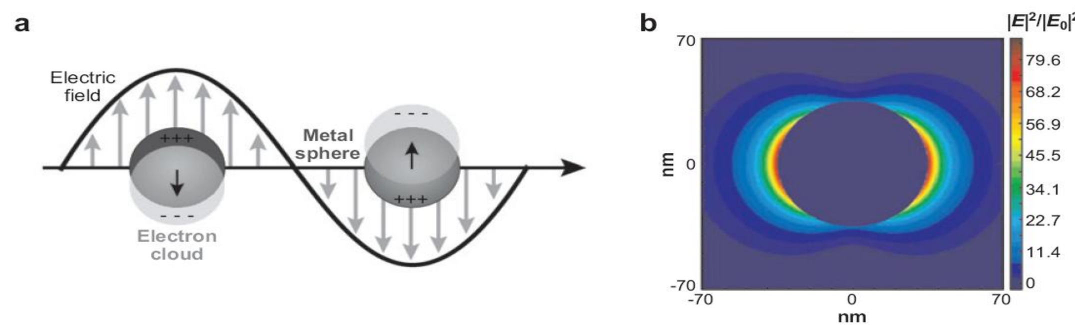


Figure 1

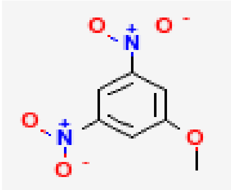
(*a*) Illustration of the localized surface plasmon resonance effect. (*b*) Extinction efficiency (ratio of cross section to effective area) of a spherical silver nanoparticle of 35-nm radius in vacuum $|E|^2$ contours for a wavelength corresponding to the plasmon extinction maximum. Peak $|E|^2 = 85$.

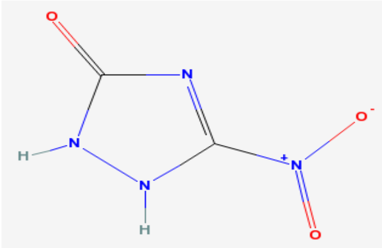
Climate change, Arctic deployment & Ecosystemic Values

- Climate changes: strong impact on contaminants fate and transport
- Canadian Army training ranges are located abroad Canada in various meteorological and geological settings
- A study will be initiated to predict potential problems in ranges and training areas related to climate changes
- Canada plans to open new ranges in Northern Arctic environment
- Live fire training must be conducted in a sustainable manner
- Ecosystemic value of our training ranges will be evaluated.

Future Work: Insensitive Munitions (IM)

- International pressure to develop IM
- New explosives and propellant ingredients:
  - Dinitroanisole (DNAN)
  - 3-nitro-1,2,4-triazole-5-one (NTO)
  - 1,1-Diamino 1,2-dinitroethylene (FOX-7)
  - Guanylurea dinitramide (FOX-12)
  - Ammonium dinitramide (ADN)
- Toxicity and fate ?





Munitions Formulations

Formulations already being used:

Octol (HMX/TNT); Comp B (RDX/TNT); PBX (HMX/Polyurethane/DOA/…);
M1 (NC/2,4-DNT/DPB/…); ….

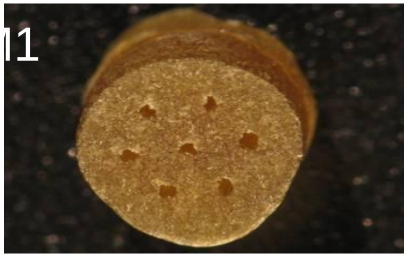
New formulations:

GIM (HMX/TNT/ETPE); IMX series (DNAN/NTO/…); PAX series (DNAN/…)
Helova (HMX/NC/ETPE/TEGDN/….); Green M1 (NC/TEGDN/…);
Triple Base (NC/TEGDN/NQ/…)

BX

GIM

1



Aqueous solubility and K_{ow} of traditional and new ECs

	Aqueous Solubility at 25°C (mg/L)	K_{ow} at 22 °C
TNT	137	39.8
RDX	55.5	7.94
HMX	4.80	1.46
TEGDN	7,430	6.17
NQ	3,200	0.21
DNAN	216	38.1
NTO	17,200	0.02

Future MC: What to Promote

Best scenario

- Non toxic, low water solubility, not bioavailable (e.g. NC)
- Favourable biotic and abiotic transformations
- High sorption to soil/humic material
- Low volatilization
- Benign gaseous emissions (e.g. nitrogen-based explosives)
- Non UXO producing munitions (high-order scenarios)
- Propellants: Modular charges !
- Design for demil
- Metals: Mitigation measures in ranges if unavoidable

Conclusions

- MC are dispersed heterogeneously in RTAs
- Composite systematic sampling must be used
- Treatment and homogenization are critical
- Fate and transport studies are critical
- Knowledge lead to risk management through mitigation measures
- Future IM are a challenge
- **Green component must be taken into consideration early in the development process**

The End - Thank You