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Teleprompter Script for Dr. Peter Haaland, Program Manager, Strategic Technology Office – The Warfighter Presentations

Chemical Mapping of Urban Environments

» **PETER HAALAND:**
As you landed in the
Los Angeles Basin, did you notice the chemical cloud that engulfed you?

Although your eyes and nose are now accustomed to the haze and fragrance, there are atmospheric traces that you neither see nor smell.

This profound ignorance of our chemical environment inspires my vision of a future in which chemical information is as accessible as the satellite images of Google Map.

Our forces now have detailed charts
with topographic, photographic, infrared, microwave, and
HUMINT features.

But their inability
to sense their
chemical environment
is unacceptable.

The current generation of chemical detectors focuses on the few dozen chemical agents subject to international treaties.

Does this list include chlorine gas?

No.

Where is Polonium-210?

Absent.

Dinitrobenzene?

Not there.

What about common
toxic materials like
hydrogen chloride, arsine,
or nitric oxide?

Missing.

The Merck index describes about ten thousand substances; most affect humans.

Over eighty thousand chemicals, many toxic, are commercially available on the Aldrich website.

And in July the Chemical Abstracts Service Registry contained **thirty two million** chemical compounds.

I want our forces to plan their actions using comprehensive chemical maps that highlight which of these buildings is a
chemical laboratory;

a Kindergarten;

or a weapons cache.

I want them to use chemical awareness to find targets whose capture or destruction gives them tactical superiority without collateral damage.

Today our forces plan using maps that display geospatial information with overlays of roads, buildings, radio emissions, and real-time troop locations.

Imagine how plans would differ if they had contours that highlighted trace concentrations of vapor from an explosive binder, hints of chlorine gas, or unnatural isotopes of krypton and xenon.

DARPA is looking for toolkits to revolutionize awareness of the chemical environment.

I'm going to share one vision of how to bridge the chasm from opportunistic sniffing of thirty-three materials to comprehensive mapping of thirty-three million.

We already have very clever microsensors for specific chemical traces.

Unfortunately, they only test our preconceptions.

Pentaerythritol is a
simple alcohol.

Nitric acid is also a common reagent.

But together they form a powerful explosive, PETN.

Mix it with trinitramine,

a naphthlyamine antioxidant,
an alkyl phthalate plasticizer,
and a styrene binder.

You get SEMTEX.

This symphony of chemical traces proclaims the presence of SEMTEX.

It can react with other gases like ozone or water, adding minor chords to the music of atmospheric contamination.

Can you hear this music?

Kerosene fumes in the air would be unremarkable, as would nitric acid vapor.

But detecting them together with tributyl phosphate at a remote location could herald extraction of plutonium from spent nuclear fuel.

Simple alcohols would not be alarming, but a combination of ethanol, amine, and acetic anhydride on an isolated mesa may signal production of heroin
from poppies.

And in any manufacturing of weapons there will be waste.

Carnivores track prey by the scent of their waste.

Shouldn't we be able to track the waste from weapons factories?

In short,
the Joint Forces need something like a Chemical Reconnaissance capability.

Maps of chemical anomalies must be anchored to atmospheric baseline conditions.

They must be placed in context; strategic meaning often increases as the baseline levels fall.

Nitrogen is the most abundant gas in our atmosphere.

Its background concentration of 78% is high and uniform, so small changes are hard to see.

Oxygen, at 21%, is the next most abundant.

Local fluctuations in its concentration are proportionately small and rapidly smeared by atmospheric motion.

Even so, they might signal respiration by personnel or combustion by diesel generators in an underground bunker.

Carbon dioxide
has a still lower baseline concentration, around three-hundred sixty parts per million.

Its abundance varies by more than 10% of this value, so a map of CO_2 levels has strategic value, revealing natural and anthropogenic signatures.

Now, consider the less abundant and more reactive compounds
that surround us.

Suppose a storage shed is tucked into a fenced yard and filled with a mixture of RDX and TNT.

Neither explosive is particularly volatile,
but the impurity dinitrobenzene has a significant vapor pressure.

Organic fumes also emerge from plasticizers, binders, solvents, and packaging materials.

They burp from the shed sporadically when windows, doors, or ventilation are changed.

Since their natural concentrations are
very small,
proportional changes and anomalies stand out.

Dinitrobenzene vapor is dense and diffuses slowly.

As it is wafted by surface winds it interacts with sunlight, moisture, tropospheric hydroxyl radicals, and other atmospheric gases.

These reactions convert the normally insoluble nitroaromatic to water-soluble amines or carboxylic acids that are entrained by rainfall and washed to the ground.

Evaporation, transport, reaction, and deposition
of materials other than
the explosive itself
make patterns.

Chemical Reconnaissance can map these patterns in space and over time.

Our forces need to understand chemical emissions from remote facilities, behind fences, across borders, or from underground.

Remote optical sensing has its place,
but tiny concentrations, propagation loss,
and uncooperative
optical properties
are problematic.

Chemical reconnaissance can merge analyses of reactions and micrometeorology with accurate maps to identify emitting sources.

This sounds easy;
plume models are available, and many have been tested with timed releases of tracer gases.

But the actual flow near the earth’s surface is complex.

This film clip, courtesy of Chris Carter at Johns Hopkins University, views the chemical emissions from a distant smokestack using Fourier Transform Infrared Spectroscopic imaging.

The billowy green plumes trace trajectories of chemical puffs as they are roiled by surface winds.

So the choice of where, when, and for how long
to sample is crucial.

Our current approach to sensing the chemical environment uses preconceived ideas and sensors designed to test our preconceptions.

Ion mobility spectrometers entombed as airport screening systems are a familiar example.

But the presumptive approach is impotent in the face of emergent threats whose mobility spectra are unknown, and the table of *known* threats holds a tiny fraction,
less than one in a million, of prospective compounds.

Chemical Reconnaissance will generate comprehensive chemical maps of the environment.

How?

One way,
but not the only way, is to replace sensors with samplers, to automate comprehensive chemical analysis,
and to orchestrate a parsimonious sampling strategy.

Here’s where we are today with sampling the atmosphere.

Bulky, heavy flasks and large, noisy compressors.

We can use nanotechnology to replace these bulky devices with simple tablets.

Start with a palette of nanoparticles whose surface structures and chemistries bind classes of molecular targets firmly but reversibly.

Blend these powders in proportions selected to ensure complete collection of noble gases, aromatic compounds, aliphatic hydrocarbons, amines, acid gases,
and the rest.

Use the nanomaterials’ active surfaces, thousands of square meters per gram,
by adjusting geometry and flow to rapidly extract everything but

nitrogen, oxygen, and water vapor from air.

Encapsulate these pristine tablets with helium or hydrogen gas – weakly binding molecules with high diffusivity.

Pack several hundred pills into a carousel and load the carousel into a puck.

What is a puck?

The puck is like a barnacle or a remora with a simple GPS receiver and a mechanism to index the carousel, exposing discrete tablets to ambient air as it is carried along
by a Hummer,
a Blackhawk, a Predator,
or a delivery truck.

The tablets can be indexed at specific times, or the GPS system can trigger exposure of a new tablet as waypoints are passed.

If the carousel falls into enemy hands
it wouldn’t matter.

The detection method, target molecules,
and sensitivities cannot be reverse-engineered
from a passive tablet.

When the puck is returned, its payload is identified by comprehensive, calibrated, and economical methods.

Today we examine collections as we used to examine moon rocks; with expensive, labor-intensive measurements.

I want to change that paradigm.

If samples are plentiful
we can emulate the medical community's blood assays.

Automate analysis and calibration.

Exploit microfluidics, and process in parallel.

Load the exposed carousel.

As GPS coordinates and time stamps are downloaded, unpack the tablets and queue them for analysis.

Strip adsorbed materials by heat, solvent, plasma, or laser ablation.

Chromatographically separate the slug of
mixed analyte.

As it emerges from the column conduct two nondestructive analyses: photoacoustic vibrational spectroscopy, and rotational spectroscopy by THz absorption.

Finish with a destructive assay using Fourier Transform Ion Cyclotron Resonance mass spectrometry.

For every trace molecule I've recorded its mass and empirical formula, how it vibrates, and how it twists.

In other words, each tablet yields a chemical handprint for the latitude, longitude, altitude,
and time recorded
by the puck.

Creating a system that will perform this analysis quickly and accurately will not be easy.

But think of what we'd learn if we could map the composition of a metropolitan region
in two days.

We'd find explosives,
gas leaks, toxic waste, and we'd see what might be common gases like chlorine or
hydrogen fluoride
in unexpected locations
or at unusual times.

Imagine conducting a site survey of a prospective forward-operating base
in a few hours.

Using the accurate baseline, commanders could deploy remote sensors to maximal effect.

And anomalous patterns of stable isotopes would help to find adversaries that were experimenting with nuclear or radiological materials.

If I had chemical maps and epidemiological data for thirty cities I could evaluate whether specific airborne chemicals are unhealthy.

I foresee a
chemical weather map, where inert compounds trace atmospheric flow fields and others react
as they move.

I’ve outlined one approach to comprehensive chemical mapping
that replaces sensors
with samples and automates their analysis.

There may be better ways, but the difficulty and expense of generating a single pixel in a chemical picture must be low.

Bridging the gap from a handful of prospective analytes to tens of millions will be hard,
but accurate insight into our chemical environment will be worth the trouble

Seurat discovered when painting Sunday Afternoon on La Grande Jatte that a pointillist approach can accomplish great things using only a handful of simple elements.

The fog of war,
indeed the fog of peace, will be penetrated in the future by chemical reconnaissance.

Breathe easier and
enjoy the atmosphere.

Thank you.

And now, to dig a bit deeper into strategic technology, I’d like to introduce Joe Durek.