APPLICATIONS OF HIGH POWER ACCELERATORS TO CARGO INSPECTION

North American Particle Accelerator Conference

Steve Korbly

Passport Systems, Inc.

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Outline

- Overview of Passport Technologies
  - Effective-Z 3-D (EZ-3D™)
  - Prompt Neutrons from Photo-Fission (PNPF)
  - Nuclear Resonance Fluorescence (NRF)
- Overview of Passport Scanner
  - Scanner Capabilities and Features
  - Port of Boston Project
- Sources Requirements
  - Existing commercial sources
  - Source requirements

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Passport Systems Overview

- Proprietary detection and identification technology
  - Passport's technology allows prompt, thorough, and precise cargo screening
  - Identifies cargo by what it is made of - not by how it 'looks'
  - Passive, scalable, bi-directional sensor network for wide area surveillance
- Passport's strong intellectual property originates from MIT
  - Passport patents on core detection technologies, HW and applications
  - Unique automated threat detection algorithms
- $85+ million invested in Passport to date
  - Major funding from U.S. Department of Homeland Security ($50M)
- 2 products being launched
  - Cargo Scanner
  - Networked Radiation Detection Systems
- Experienced management team with proven track record

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What are the goals related to cargo screening?

- Materials of interest:
  - Radiological and Nuclear materials
  - Explosives
  - Contraband (Drugs, tariff avoidance, etc)
- Shipping scenarios (cross-section dimensions)
  - Packages, hand and checked baggage (< 1 x 1 m) – **Relatively mature technology**
  - *Air cargo (1.5 x 1.5 m x 1.5 m)*
  - *Shipping containers (2.4 x 2.4 m x 6/12 m)*
- Throughput requirement - ~20 containers per hour
- Basic requirements
  - Cargo size → Higher energy sources and signatures
  - Throughput → Decision in <180s
  - Dose Limits

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Passport Scanner Technologies

Beam

9 MeV Bremstrahlung
CW Photons

Measured Particle

Photons: Effective-Z (EZ-3D™)
Nuclear Resonance Fluorescence (NRF)
Neutrons: Photofission (prompt)

Scan	Algorithm	Input	Functionality / Output
Initial	EZ-3D™ Reconstruction	Medium-resolution energy spectrum	3-D density and Effective-Z map Anomaly identification/3D location
Initial	Transmission X-ray	Medium/High spatial resolution transmission image	Anomaly 2D location & density Shape/edge recognition
Initial	Portal Networked Detection System	Medium-resolution passive spectrum	Identification and localization of radioactive sources
Initial & Prolonged	Photofission	Digitized pulses from liquid organic scintillator	Identifies presence of fissionable material
Prolonged	NRF 3D	High-resolution energy spectrum	Complete isotopic composition in the region-of-interest
	Anomaly Classification	Output of NRF 3D, PNPF, EZ-3D™ and transmission algorithms	Performs data fusion, classifies anomaly as threat or innocuous, predicts detect/clear time

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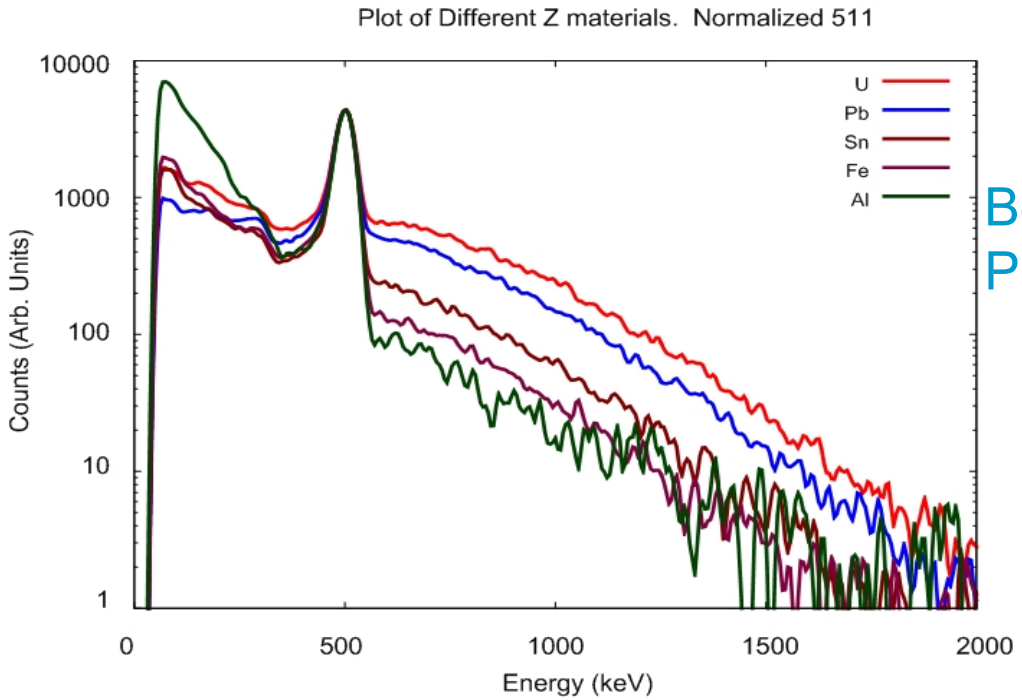
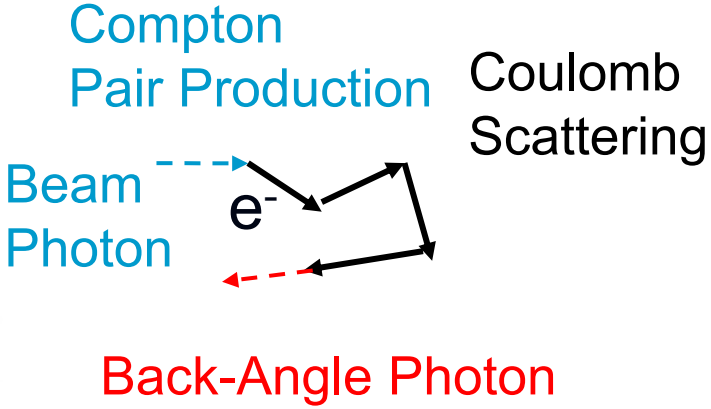
EZ-3D™ Technology Summary





- EZ-3D™ effect ~ Zα
- Detection is automated
- Rapidly identifies high-Z anomalies

Single Compton Scatter with Ebeam = 5 MeV
- E_{photon} (120°) = 320 keV
- E_{photon} (180°) = 240 keV

Pair Production → e+e- annihilation (~Z^2)
- E_{photon} = 511 keV

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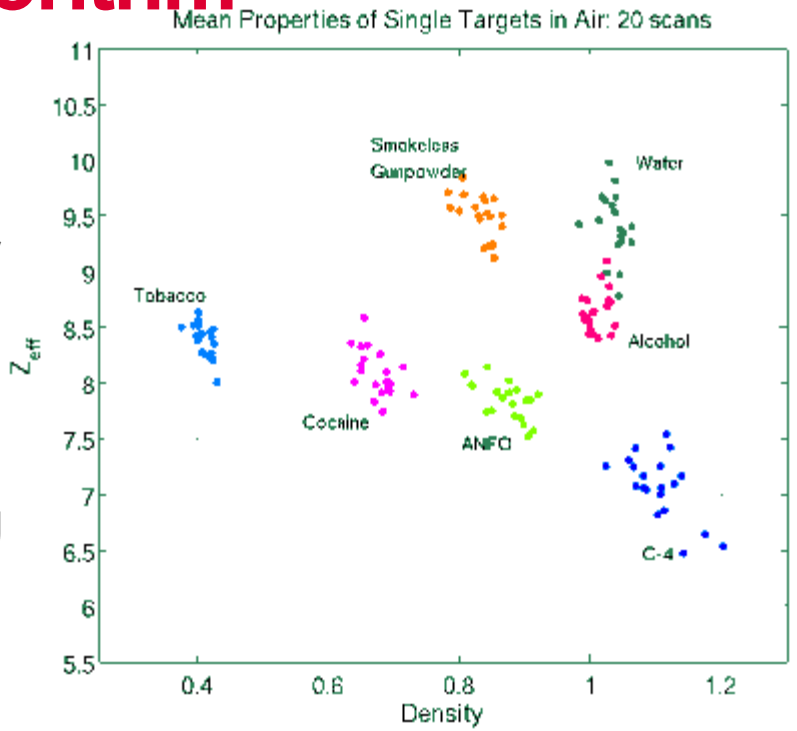
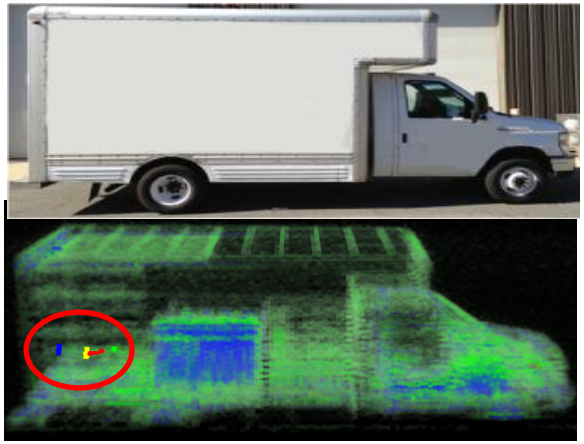
EZ-3D™ Detection Algorithm

- Utilize Z_{eff} and density image produced by Reconstruction
- Detection: use simple axis aligned upper and lower thresholds on Z_{eff} and density
- Thresholds determined by using reconstructed image voxels from training scans





Threat Object	Type	Color
Calcium Hypochlorite	Oxidizer	Blue
Butane	Flammable Gas	Yellow
Gasoline	Flammable Liquid	Red
Hydrogen Cyanide	Toxic	Green

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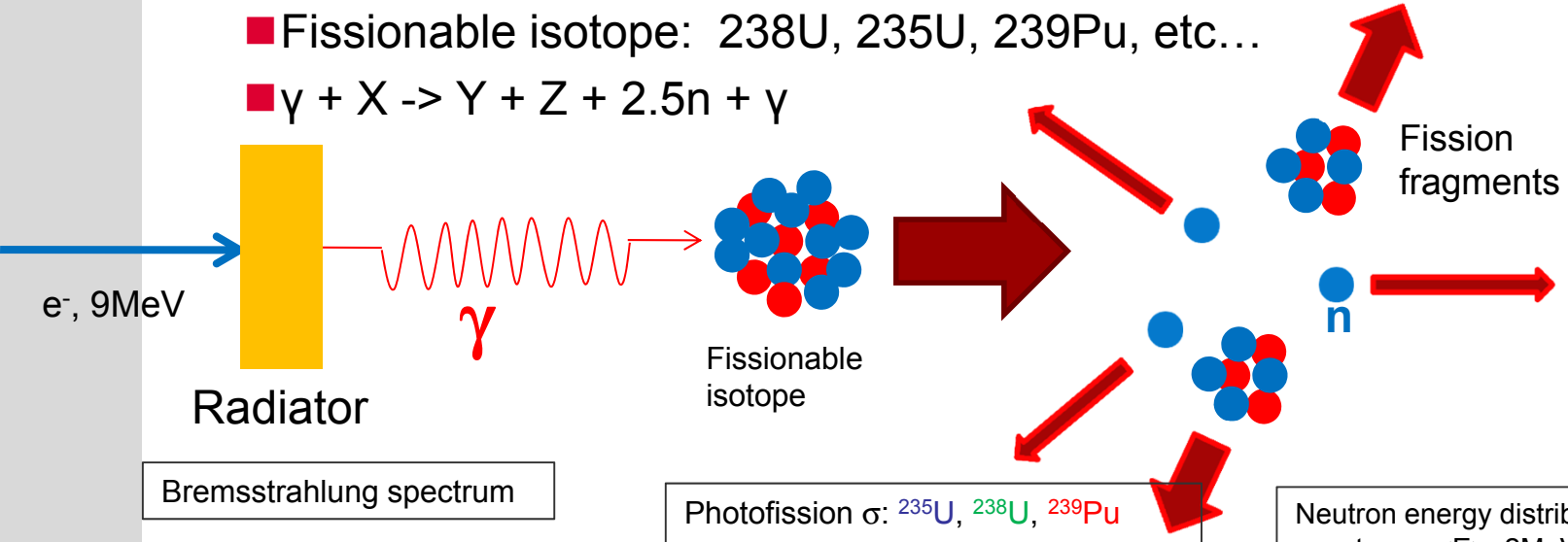
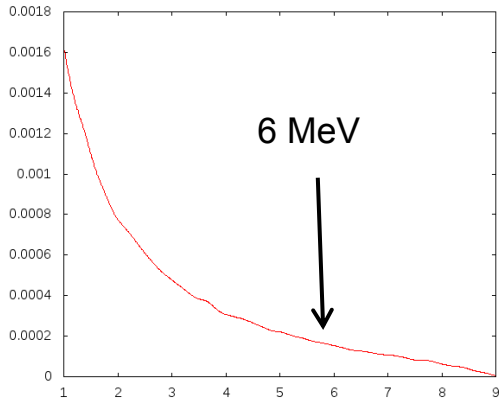
Prompt Neutrons from Photofission

- Photofission
  - >6MeV photon
  - Fissionable isotope: 238U, 235U, 239Pu, etc…
  - γ + X -> Y + Z + 2.5n + γ

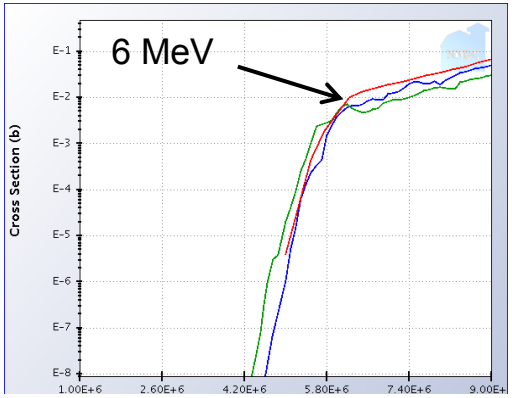


Bremsstrahlung spectrum



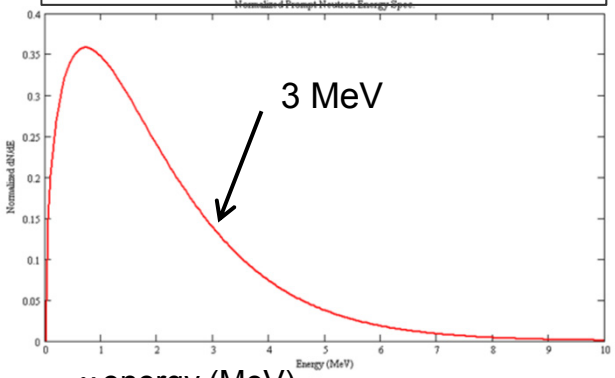
Incident γ energy (MeV)

Photofission σ: ^{235}U, ^{238}U, ^{239}Pu



Incident γ energy (eV)

Neutron energy distribution, Watt spectrum, <E>~2MeV



γ energy (MeV)

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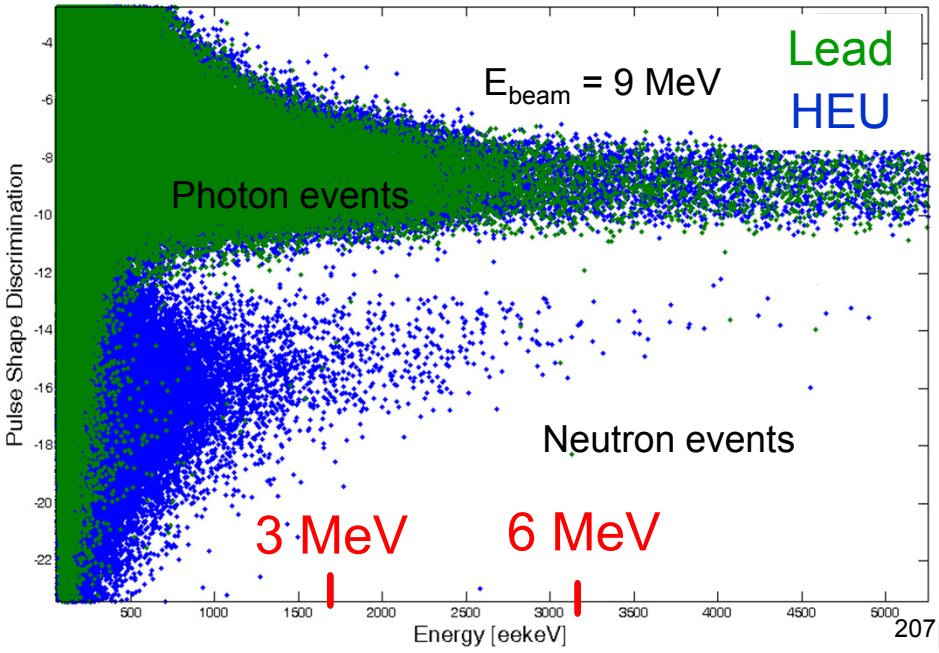
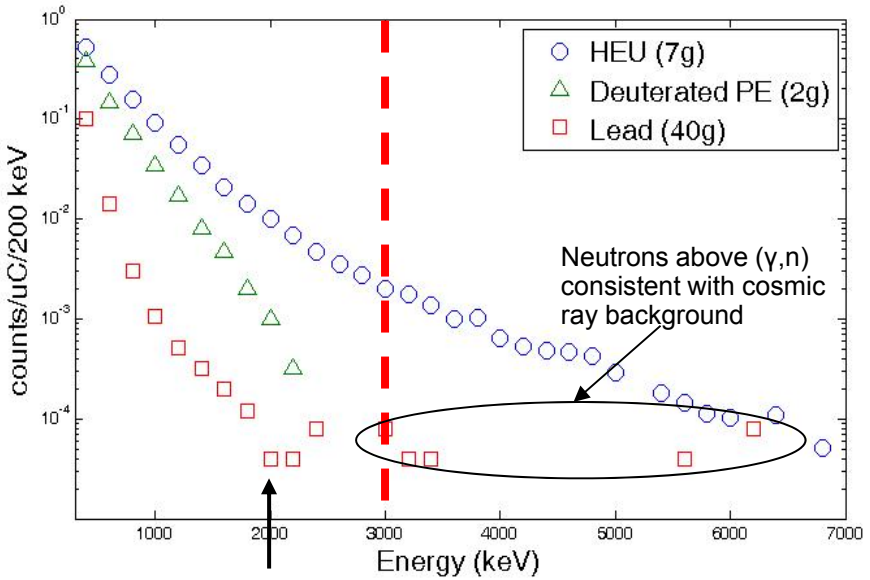
Photofission Signatures

- Neutrons
  - Prompt high energy neutrons provide unique signal for fissionable material
  - Neutron energy distribution independent of incident photon energy
  - Significant neutron yield for E_n > 3 MeV → highly transmissive
  - Minimal background contamination above threshold
- Requires > 5 MeV photons

Pulse Shape Discrimination



Neutron Energy Deposition Spectra



^{207}Pb(γ,n) maximum neutron energy

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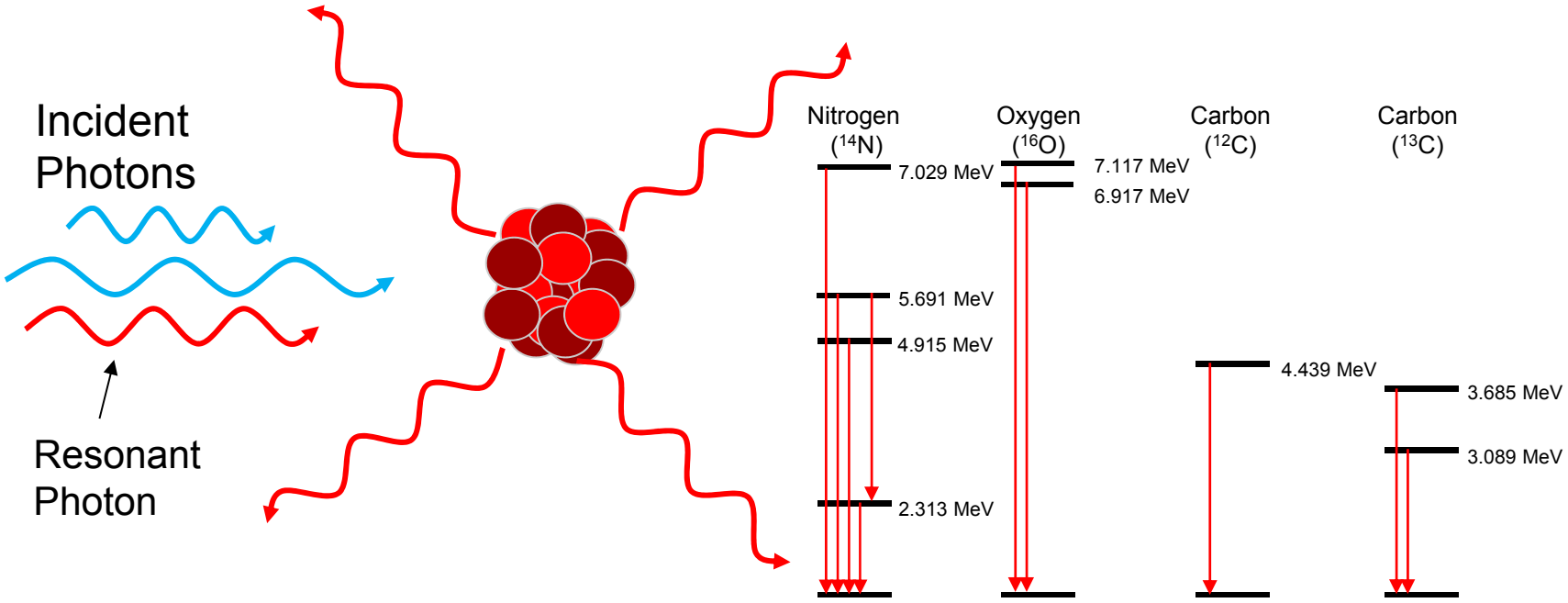
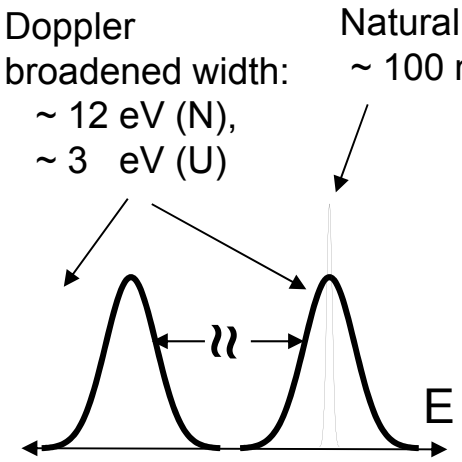
Nuclear Resonance Fluorescence





- Unambiguously distinguishes isotopes
  - Identifies material composition
  - Detection and clearing with confidence level quantification
- NRF states for most elements with Z > 2. Large cross sections
- Energy Range (1.5-8 MeV) - maximum transmission
- Nearly Isotropic - Optimum Angle (110o – 130o)
- Downshifted (Doppler recoil) ~ 1keV - No self absorption

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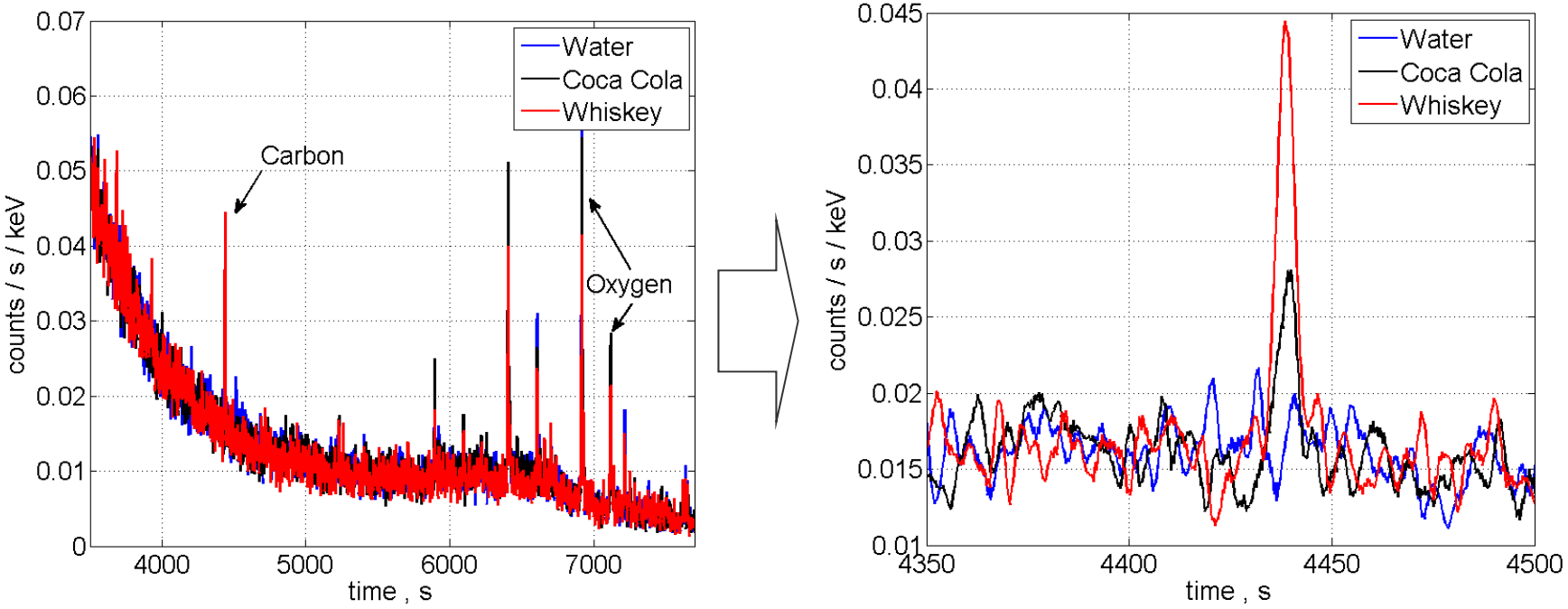
NRF on Materials



- Materials consist of Isotopes in specific ratios
- Probability that the ratios observed correspond to each material is computed

Material	Carbon counts/s	Oxygen counts/s	C/O Ratio
Water	0	0.73	-
Coca Cola	0.14	0.75	0.2 ± 0.014
Whiskey	0.27	0.53	0.5 ± 0.013

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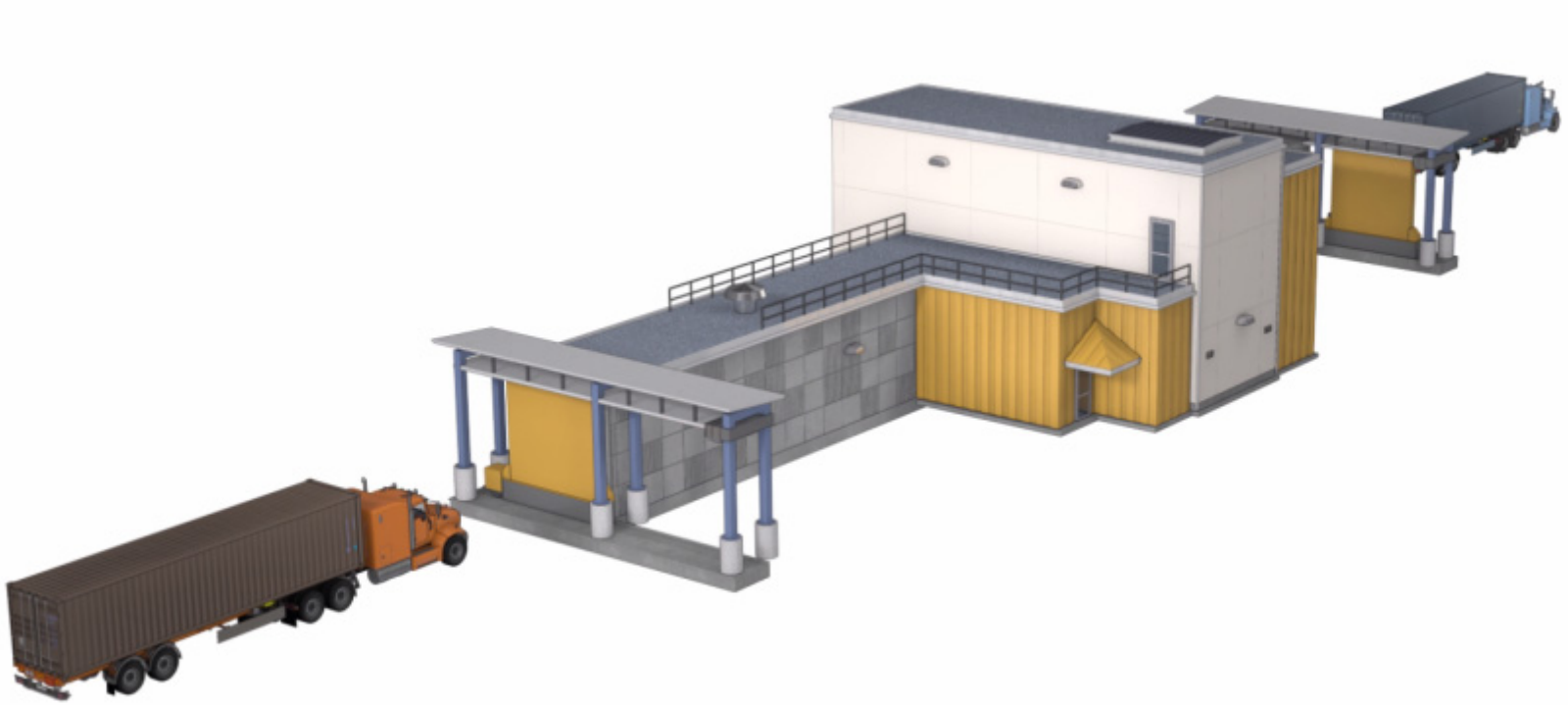
SmartScan 3D™
Automated Cargo Inspection System



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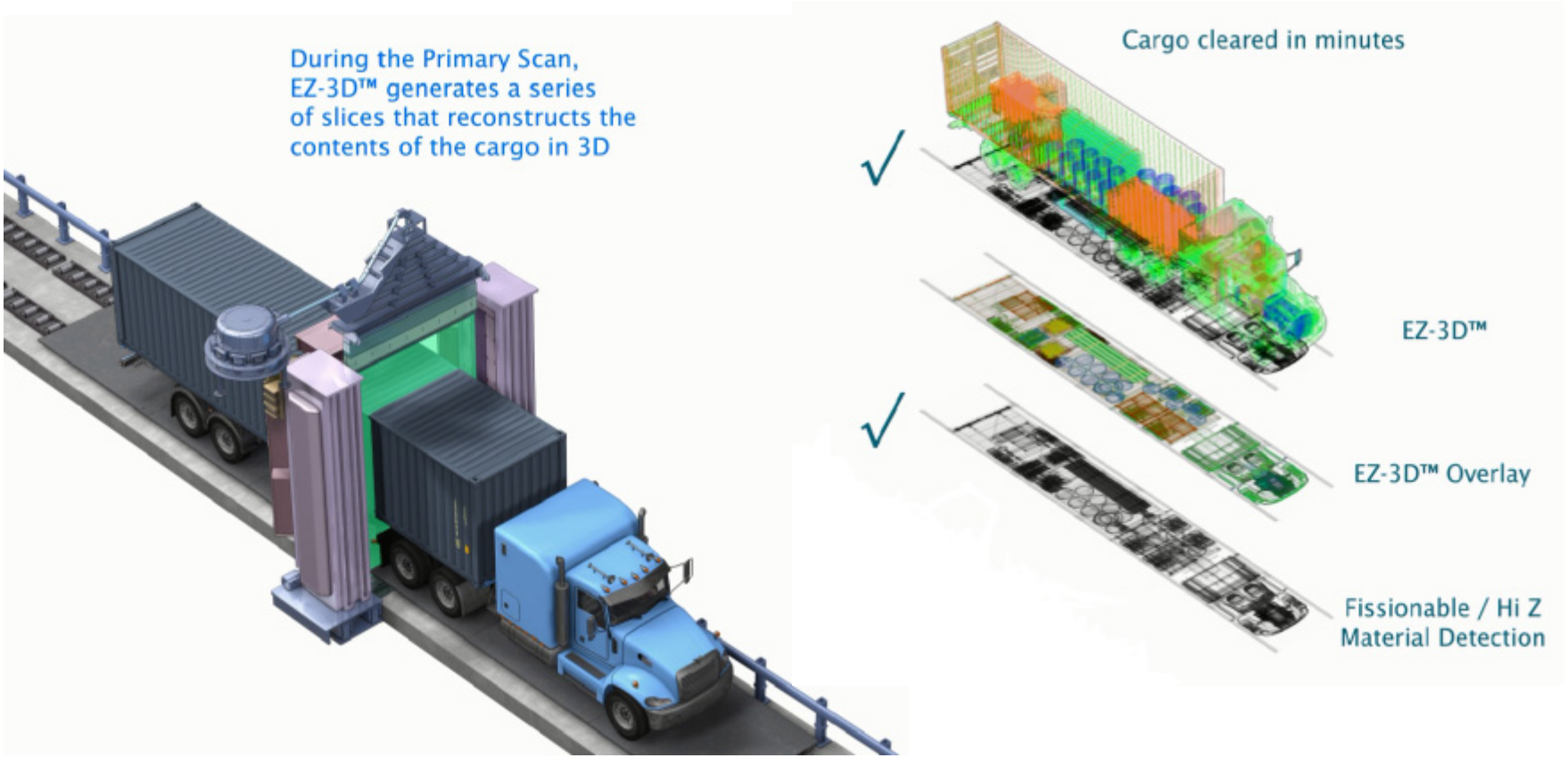
Full Capability Scanner



This full configuration identifies anomalies and resolves potential threats

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Scanner Core Technologies

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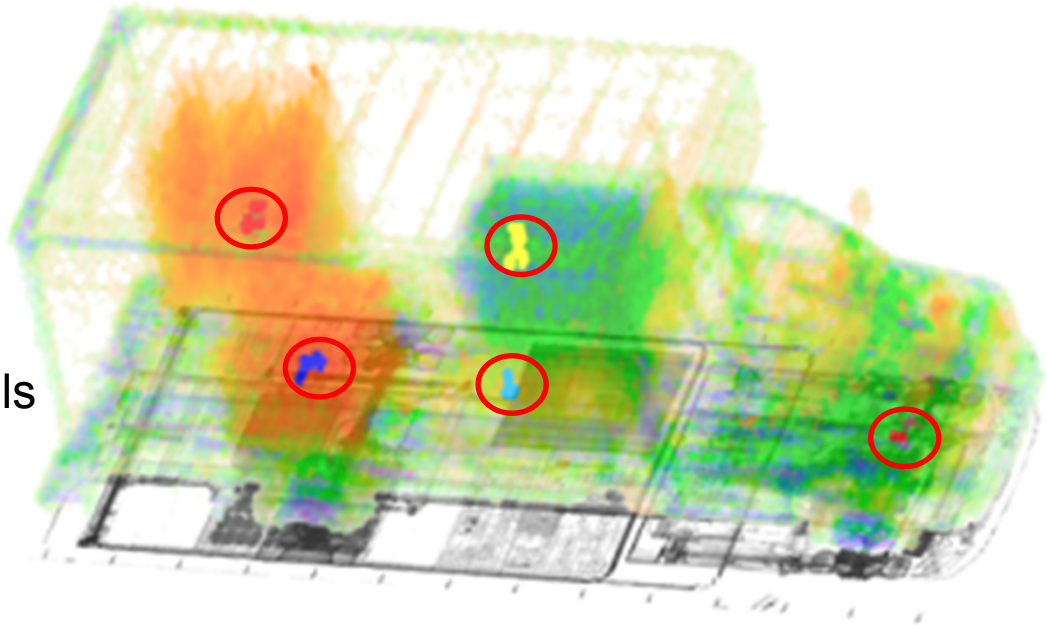
EZ-3D Volumetric Data of Density and Effective Z

Color Scale = Zeff Range

Transparency = Density

Cargos

- Organic
- Inorganic
- Metals
- Dense Metals



Targets

- Tobacco
- C4 Explosive
- Cocaine
- High - Z

- Cargo is scanned slice-by-slice and reconstructed in 3D
- The voxels are aggregated into regions-of-interest
- These ROI's are analyzed for targeted materials

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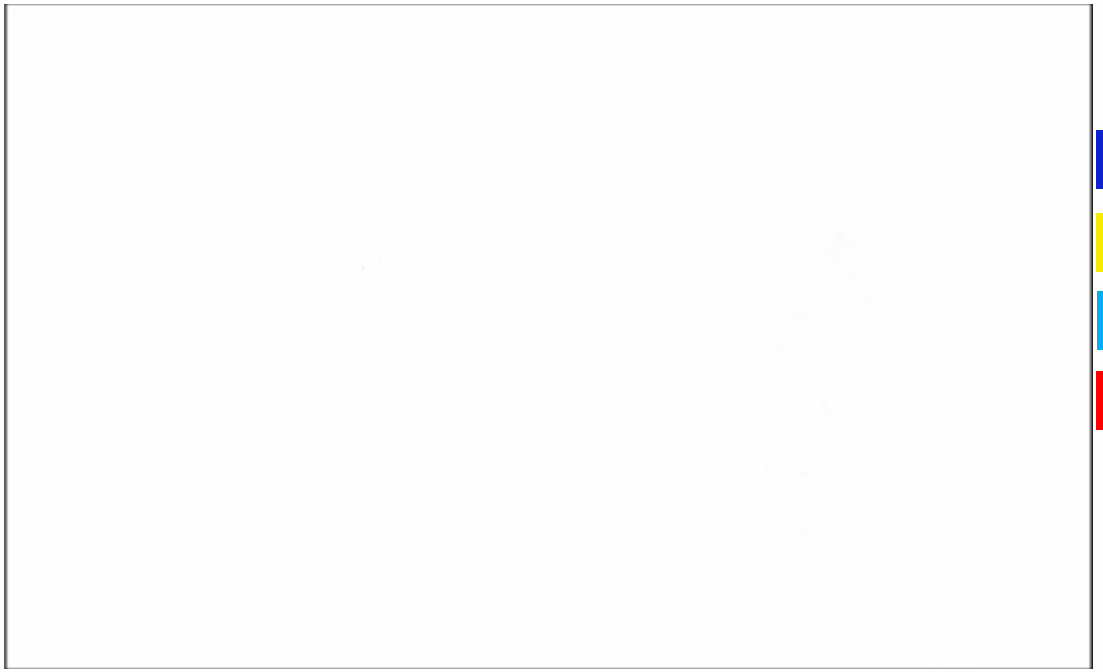

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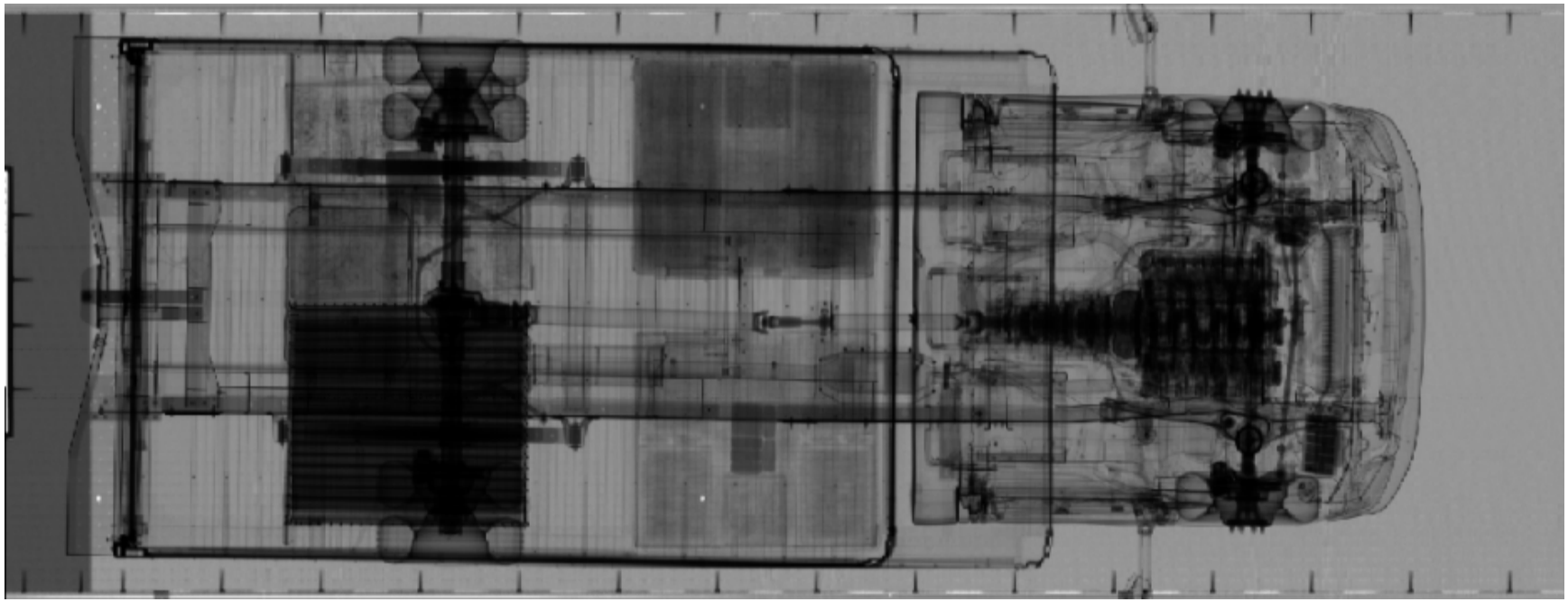
Transmission Image



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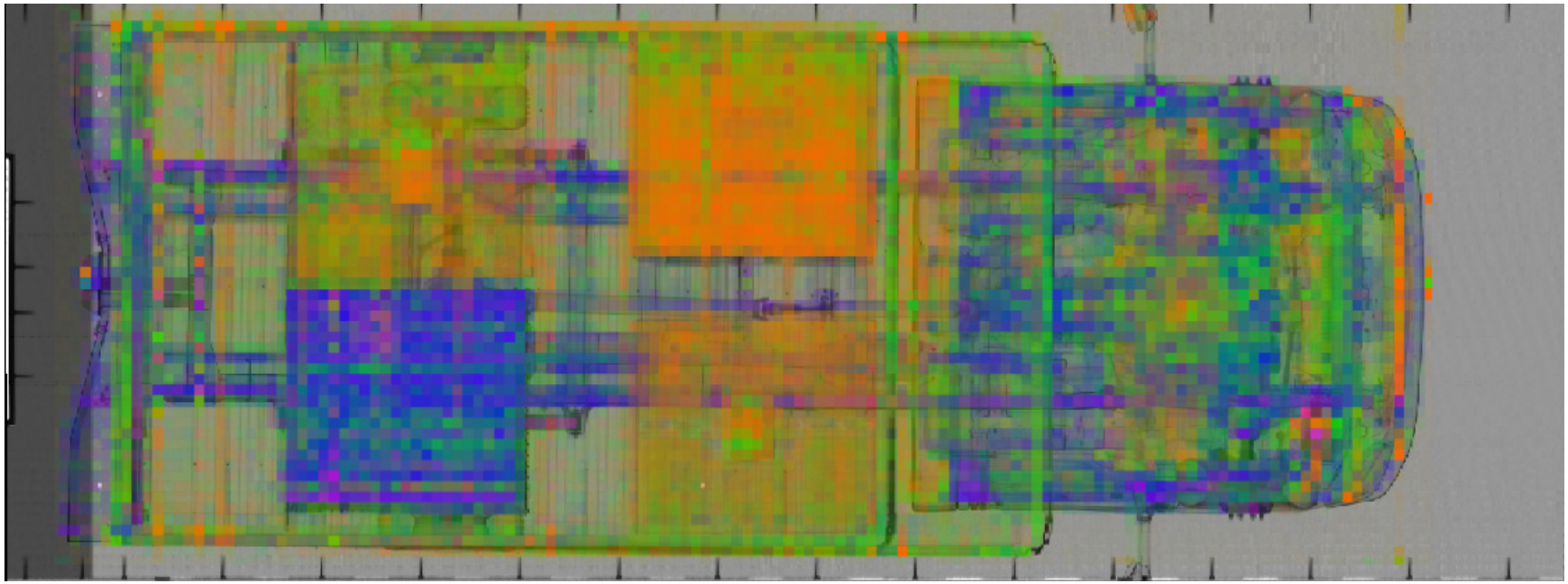
Transmission with EZ-3D™ Overlay



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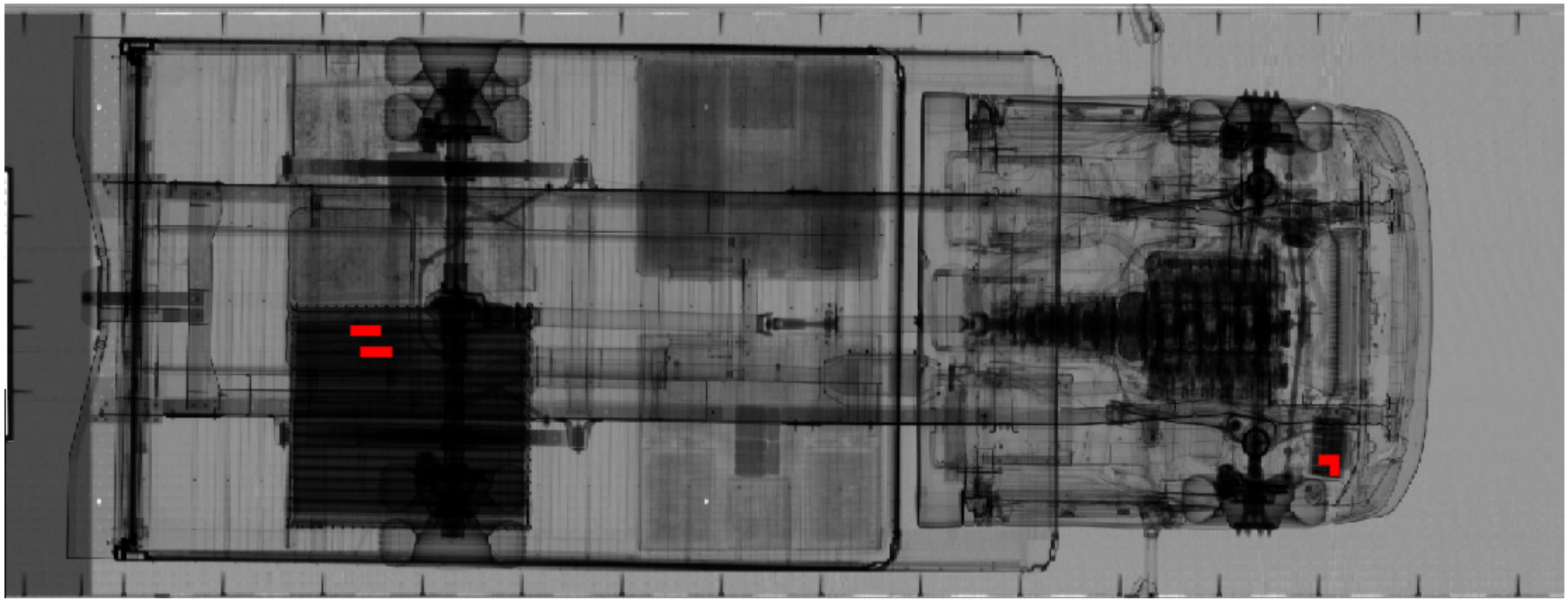
Transmission with Automated High-Z Alarms



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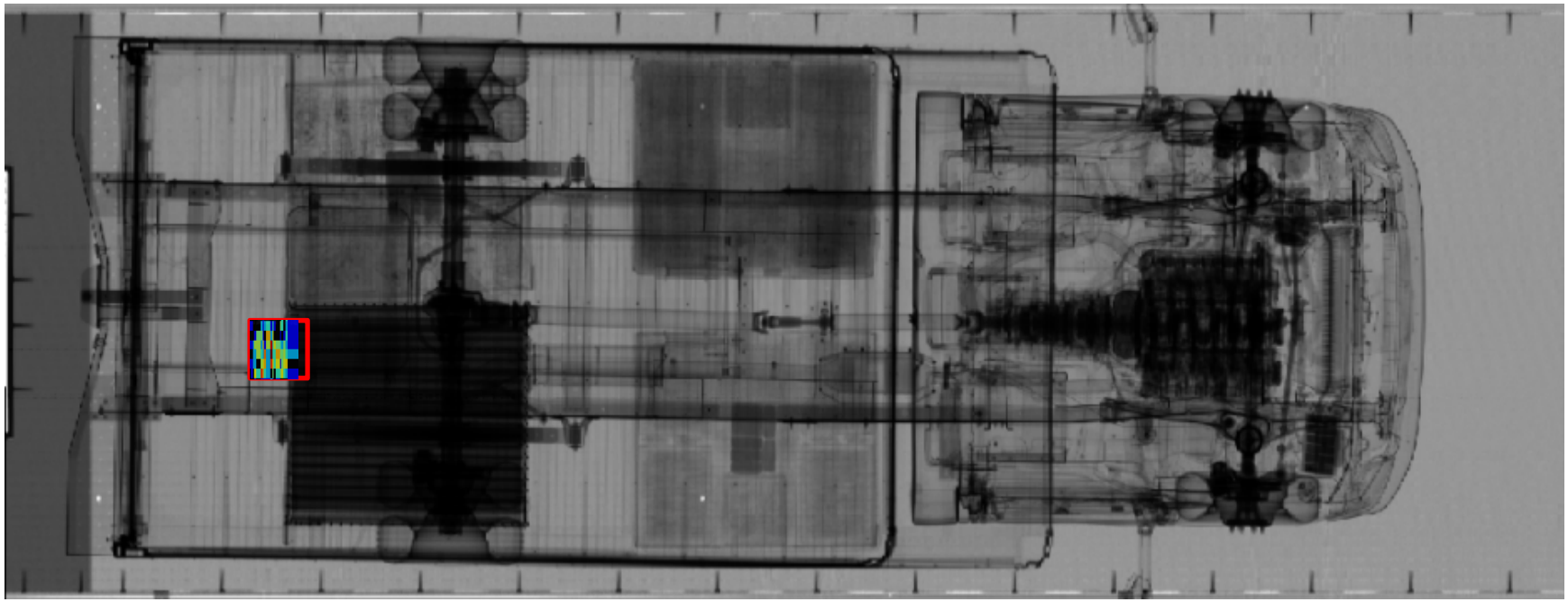
Transmission with Fission Alarms



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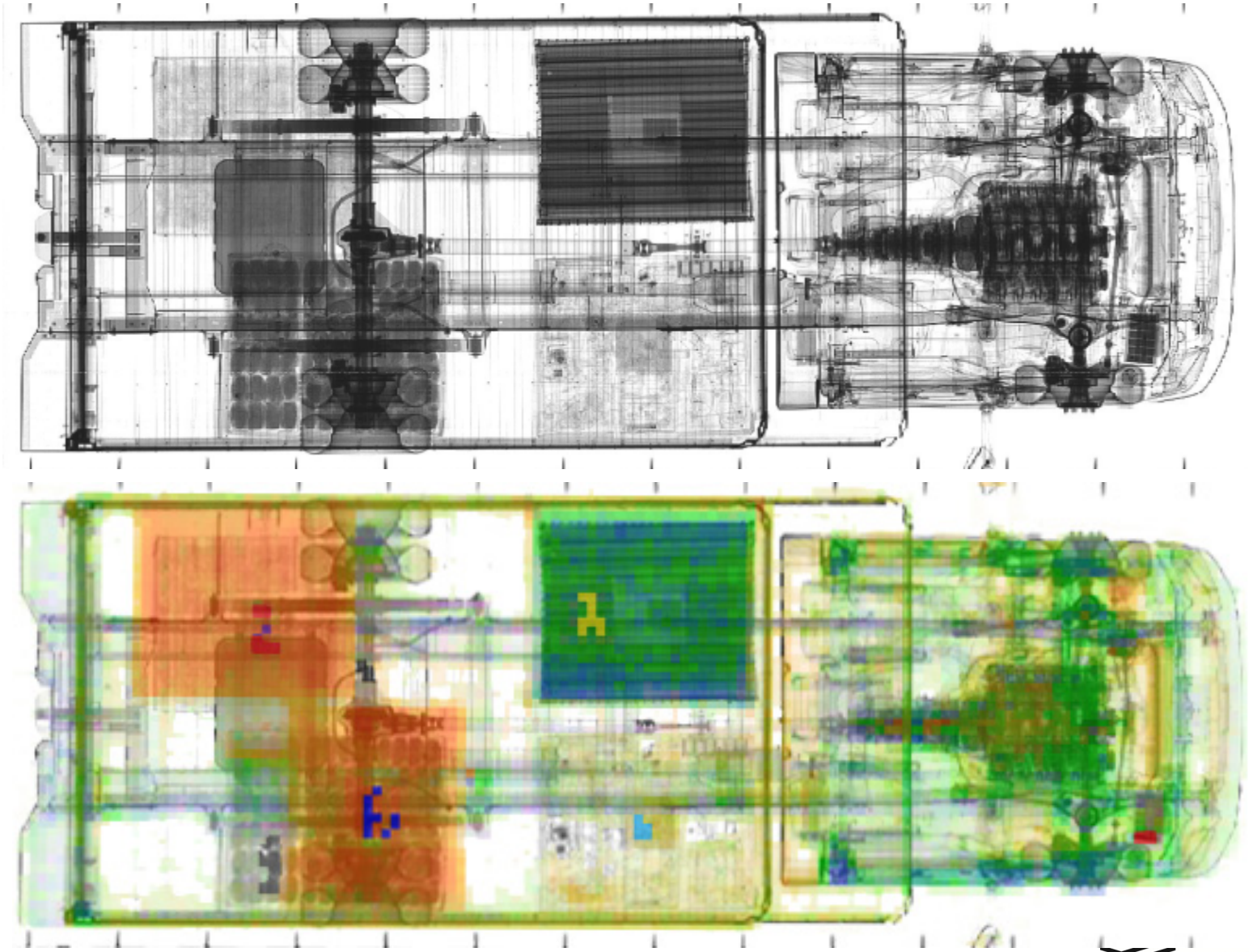
HR Transmission with EZ-3D™ Overlay



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SmartScan 3D™ System Operation

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Conley Container Terminal – Artist Rendition

Conley Container Terminal – August 2016

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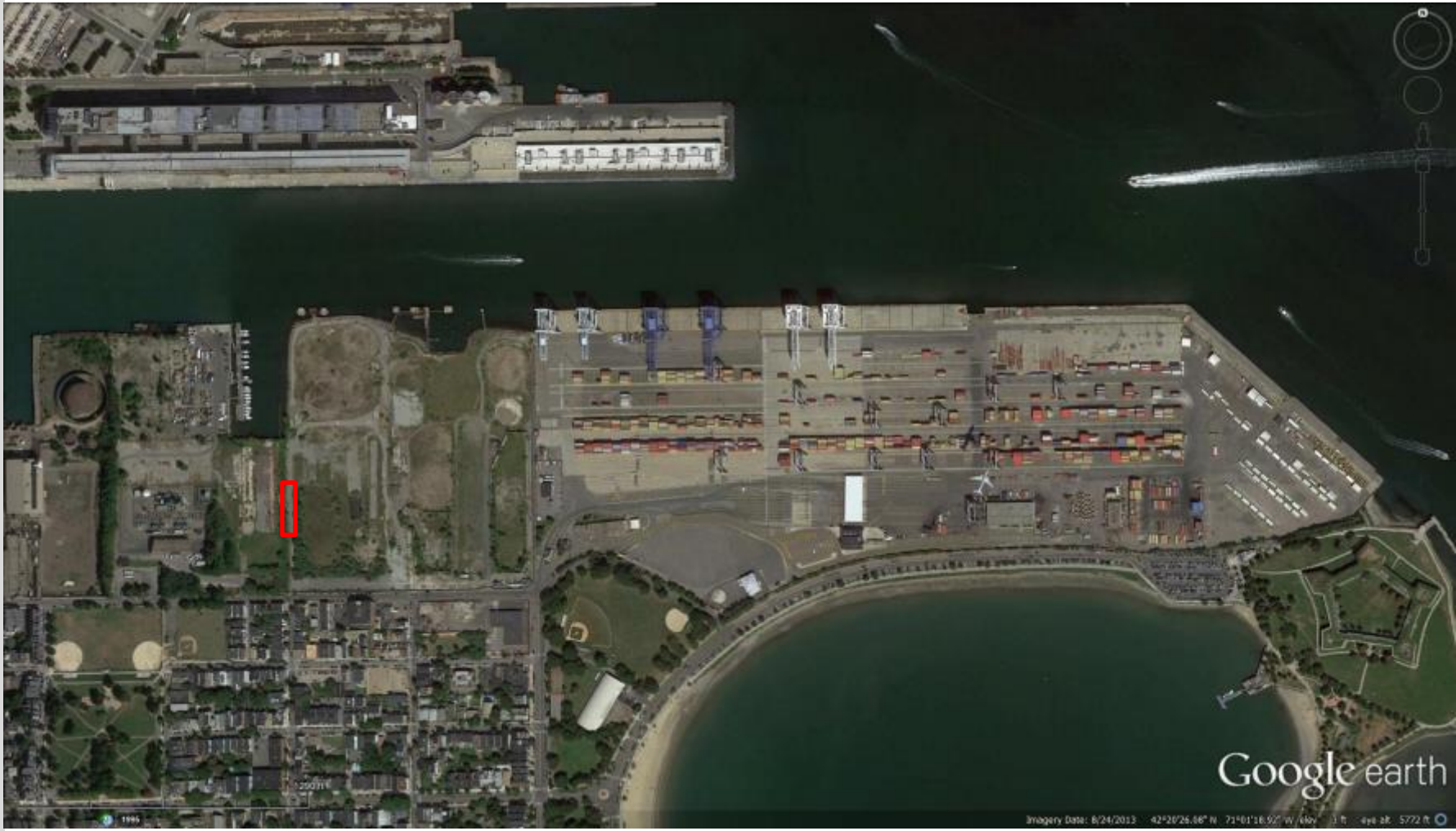
Port of Boston



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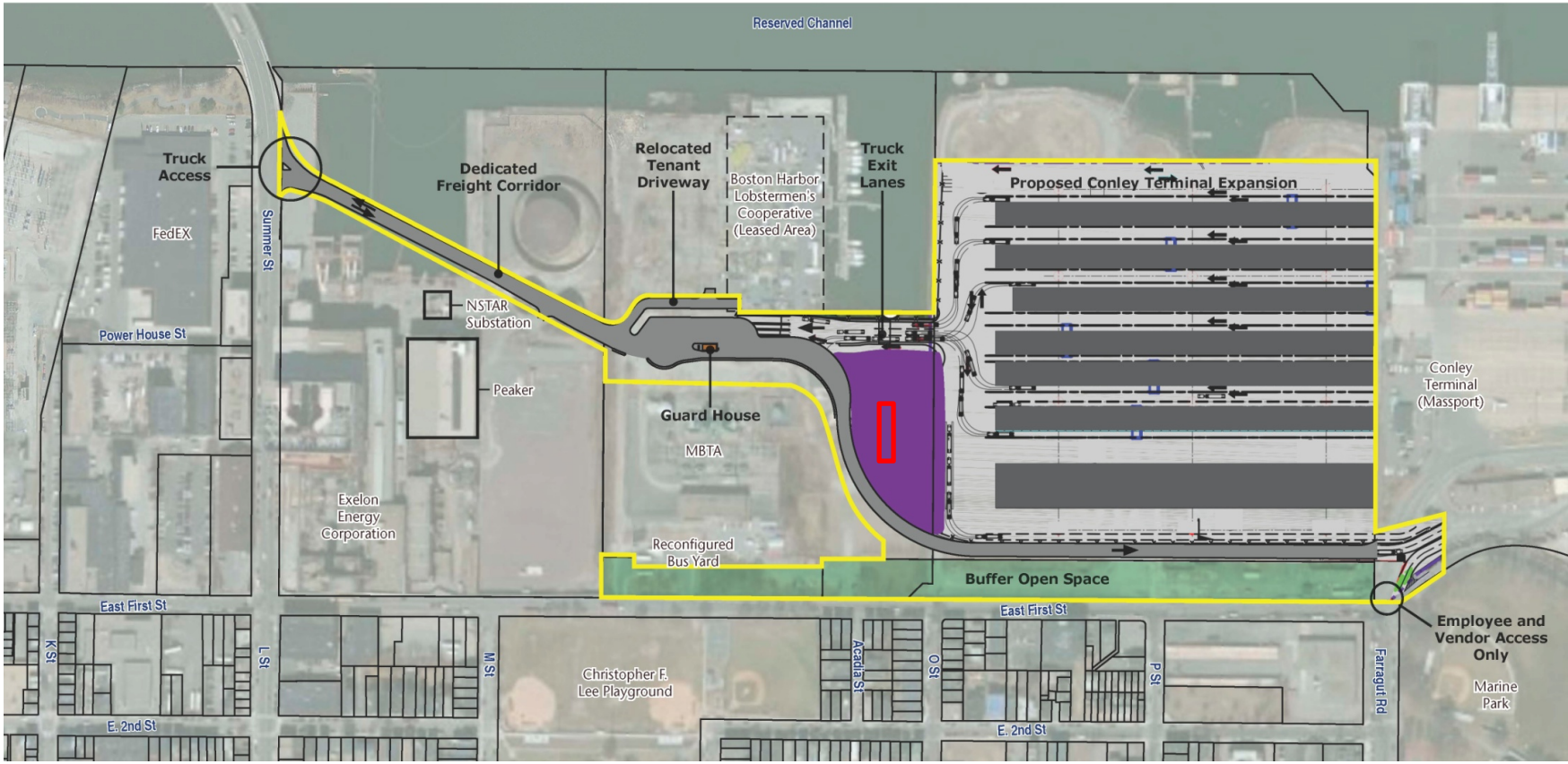
Conley Terminal Expansion



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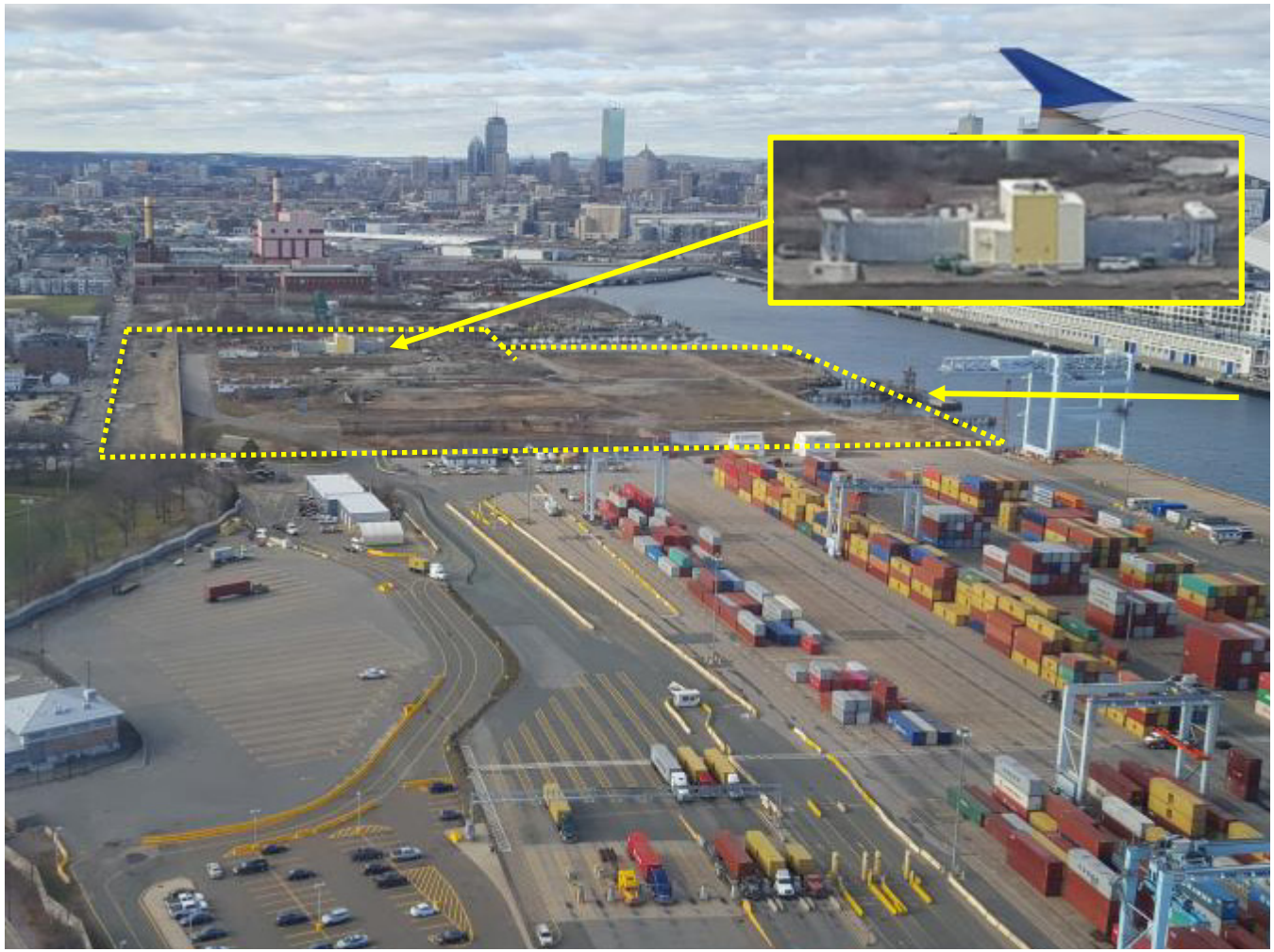
Conley Port Expansion



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Existing Sources

- IBA Rhodotron

- 9 MeV
- 100% CW (~ 230 MHz)
- 0.005 – 3 mA
  - Rapidly adjustable < 100 µs
- Emittance: < 10 π mm-mrad
- Beam Position Stability ~ 0.5 mm
- Energy:
  - > 99% within an energy interval of 1%
  - Stability: ± 0.5 %

Rhodotron

3 -> 10 MeV

0 -> 245 kW

Electron beam

Main application

Medical device sterilization

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New Sources

- Near Term:

Cost	Footprint	Power Efficiency	Energy Stability	Beam Position Stability
< ~ 1M$	< 8 m^2 to support mobile systems	> 50% wall plug	~ 0.01%	~ 0.1mm

- Next Generation:
  - Quasi-monochromatic CW sources, ~5MeV, 9MeV
    - Reduce dose per scan
    - Increase the signal/dose ratio in radiographic applications
    - 8-10 MeV source for photofission applications
  - Tunable, monochromatic sources

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Thank You

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