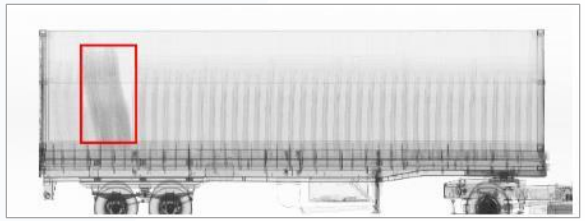




The Why, What and How of Particle Accelerators for Security

Mike Jenkins

May 2023

Rapiscan systems | AS&E

CARGO SCANNING & SOLUTIONS

RAPISCAN SYSTEMS | AS&E — PART OF THE OSI SYSTEMS FAMILY OF SECURITY COMPANIES

Contents

Background

Why we use particle accelerators for security

What particle accelerators are used

How can you improve the particle accelerators used for security

Please ask feel free to ask questions during the talk

About Me

8 Years at Daresbury

PhD at Lancaster University on Undulator-based positron sources for linear colliders

Post Doc position in High Power RF at Lancaster University

- Focus on normal conducting linacs
- Main area of responsibility was design and testing of linacs for industry

High Power RF Engineer in ASTEC

6 Years in Industry

Cyclotron Engineer for Alliance Medical

Radiation Physicist at Rapiscan Systems Ltd

OSI Systems' Family of Security Companies

Comprehensive Security Solutions

Rapiscan systems | AS&E

- Vehicle Screening
- Cargo Inspection
- Air Cargo Screening
- Rail Cargo Scanning
- Radiation Detection

GATEKEEPER Intelligent Security

- Intelligent Optical Inspection for Vehicles and Occupants

S2 GLOBAL

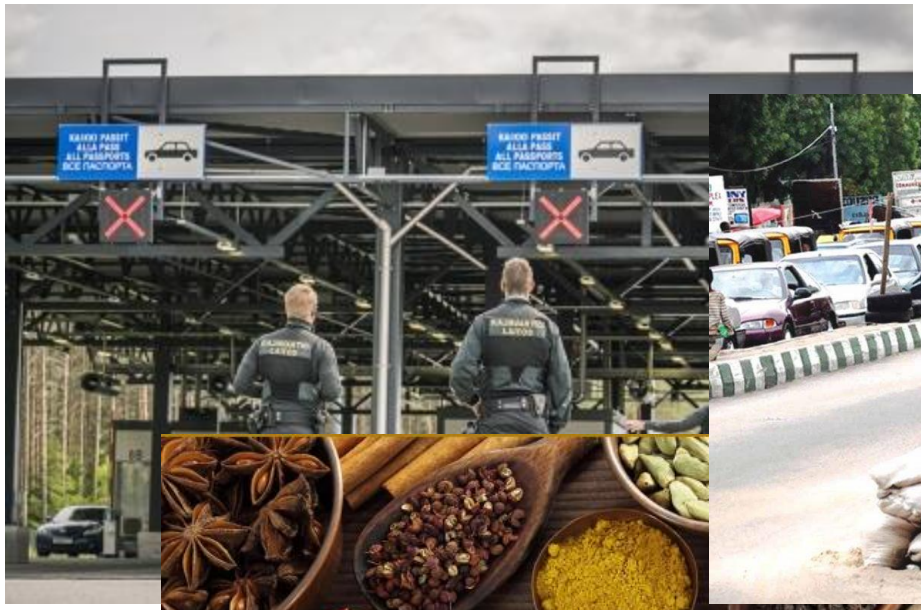
- Fully Managed Services
- Operational Efficiency Solutions
- Security Platform Integration
- Advanced Training Programs
- Event Security Services

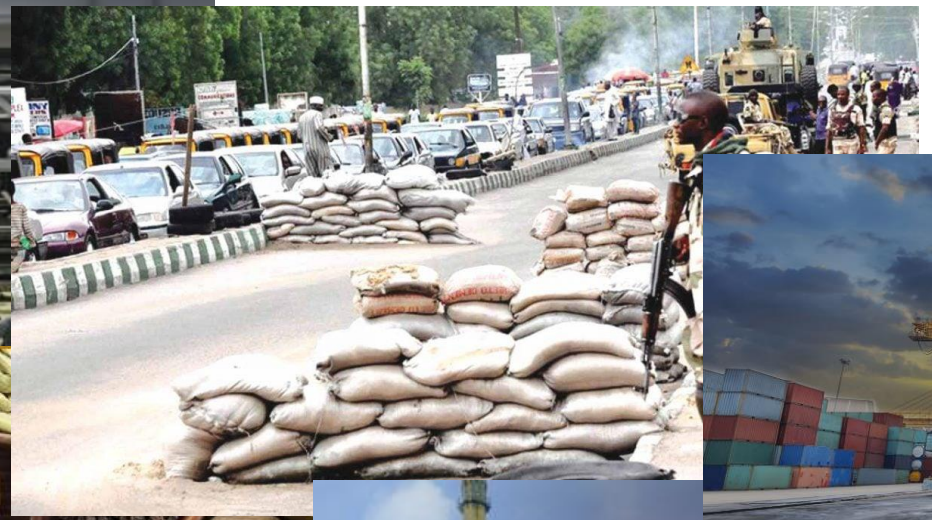
Rapiscan systems

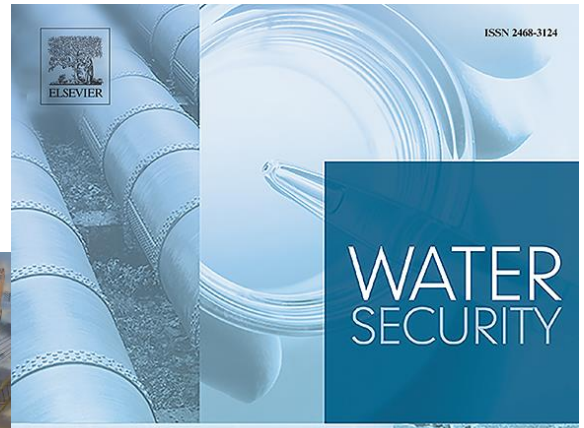
- Aviation Checkpoint Screening
- Checked Baggage
- People Screening
- Material-Specific Detection

CARGO SCANNING & SOLUTIONS

Types of Security







Food Security

Types of Security

Inspection

- Imaging and Evaluation of people/objects
  - Borders
  - Infrastructure
  - Hardware
  - Cargo
- Typically x-ray or THz

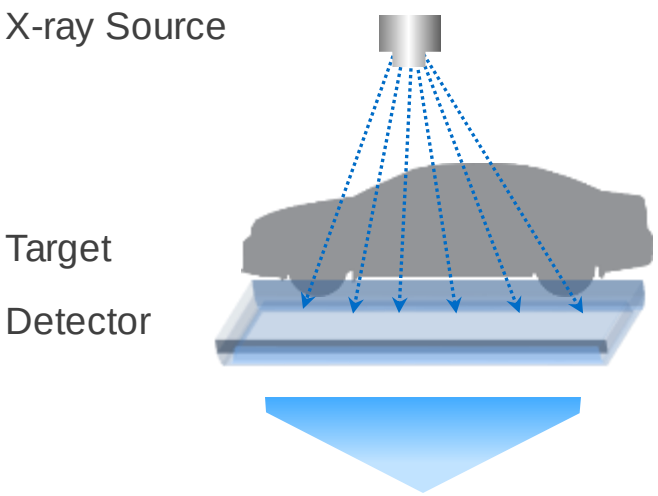
Processing

- Improve, Treat or Protect materials
  - Wastewater
  - Soil
  - Food
- Typically x-ray or electron beams

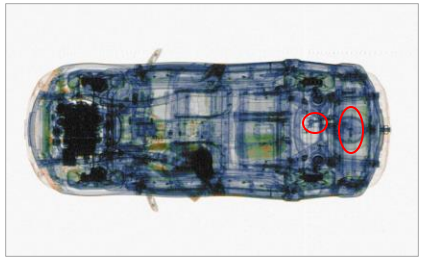
Inspection Technology:
Transmission X-rays and Z Backscatter X-rays

Transmission

X-rays detect by passing an X-ray beam through a target to a detector on the far side.

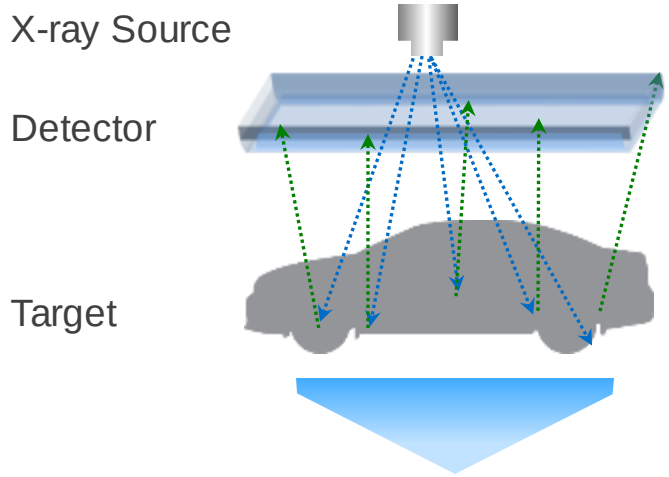


The transmission image reveals two weapons in the rear of the vehicle

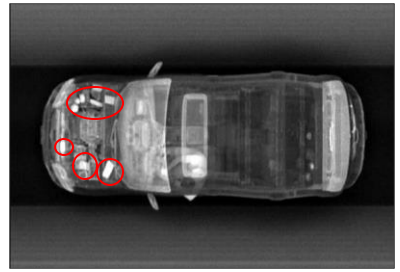


Z Backscatter

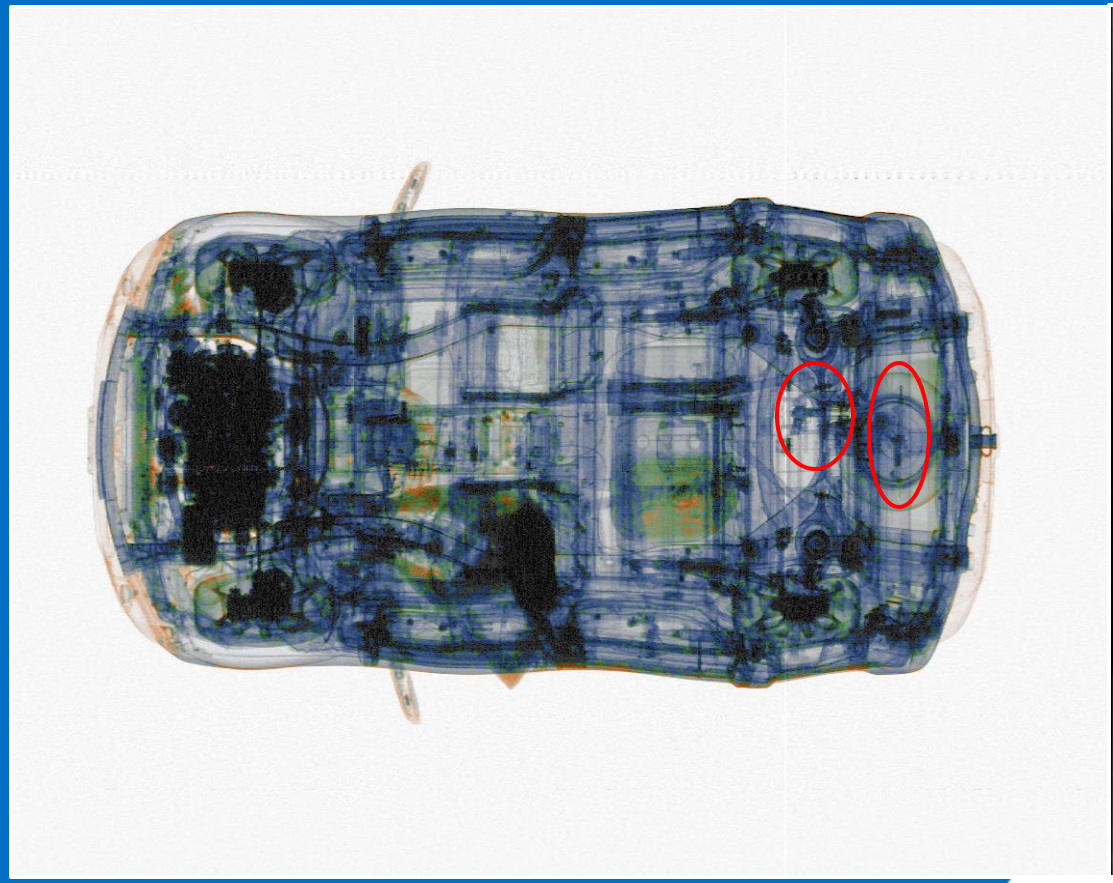
X-rays detect by reflecting an X-ray beam from a target to a detector on the near side, creating a photo-like image that is easy to interpret.

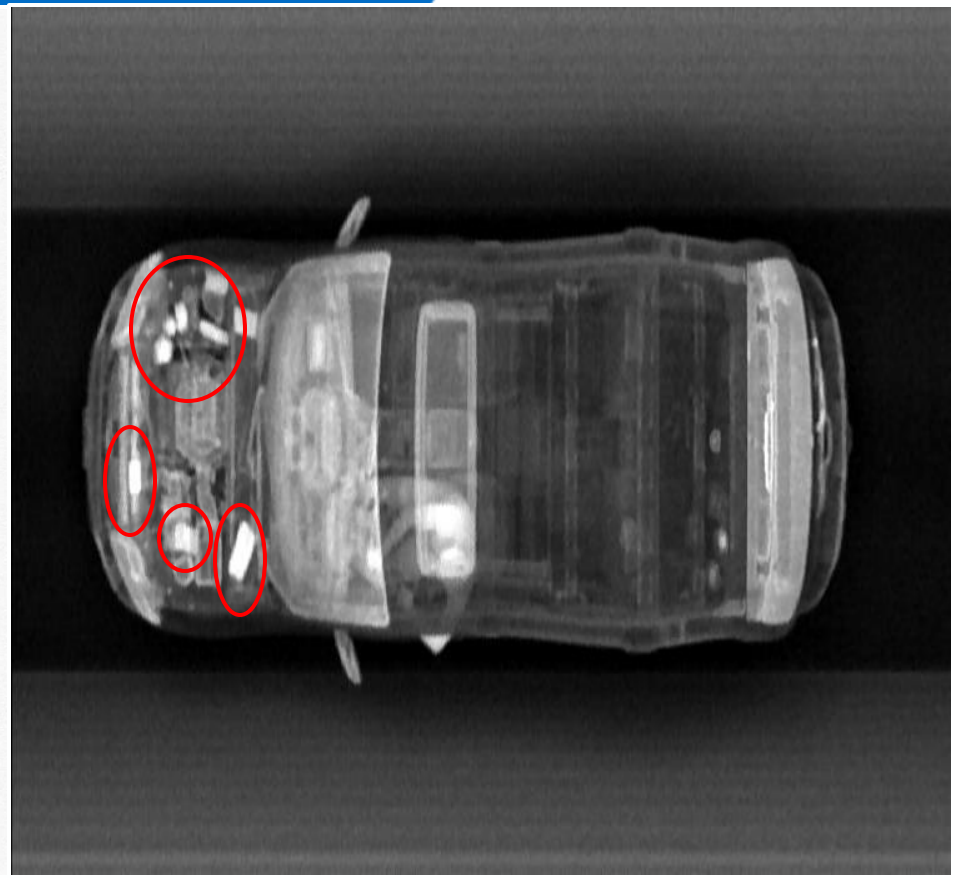


The Z Backscatter image of the same vehicle reveals hidden drugs and currency



Inspection Images – Tube Based System





Why we need particle accelerators for security

For Inspection Systems:

- Need high energy x-rays to image denser objects
- THz imaging of people

For Processing Systems:

- Direct electron beam irradiation
- High energy x-rays

What Particle Accelerators are used?

What needs to be considered?

- Robustness
- Reliability
- Simplicity of manufacture
- Flexibility
- Ease of use
- Size

Robustness

Reliability

- Particle accelerator needs to work reliably
  - Operation can be 24/7
- Downtime causes a variety of problems
  - Delays
  - Increased security risks
  - Revenue loss
  - Potential health risks
  - Loss of life

End users need to have confidence that when they turn the accelerator on it will work

Simplicity of Manufacture

- Links back to robustness and reliability
  - Need to minimise complexity
  - Less components mean less things to go wrong
- Particle accelerators for security applications are not one offs
  - Most security systems tend to be low margin
  - This means high volume needed
  - Need to use manufacturing techniques which are viable at large volume

Flexibility

- Manufacturers of security systems typically have broad product ranges
- End users have diverse requirements
- Aim is to be able to address as many different requirements with one particle accelerator design as possible

Flexibility

Portal


Eagle P60


Eagle P60 ZBx


Z Portal for Trucks


Z Portal for Cars


Sentry Portal


Eagle P25


CarView


CarView InLane

Gantry


Eagle G60


OmniView Gantry


OmniView ZBx


Eagle C25

Mobile


Eagle M60


Eagle M60 ZBx


ZBV Line

Trailer


Eagle T60


Eagle T60 ZBx


Eagle T25

Rail


Eagle R60


Eagle R90

Air Cargo


Eagle A25

Handheld


MINI Z

Flexibility

- Manufacturers of security systems typically have broad product ranges
- End users have diverse requirements
- Aim is to be able to address as many different requirements with one particle accelerator design as possible
- Rapiscan AS&E currently have 16 product lines which use particle accelerators
  - We use 3 different particle accelerators designs
  - Would not be feasible to use a bespoke particle accelerator for each product line

Ease of Use

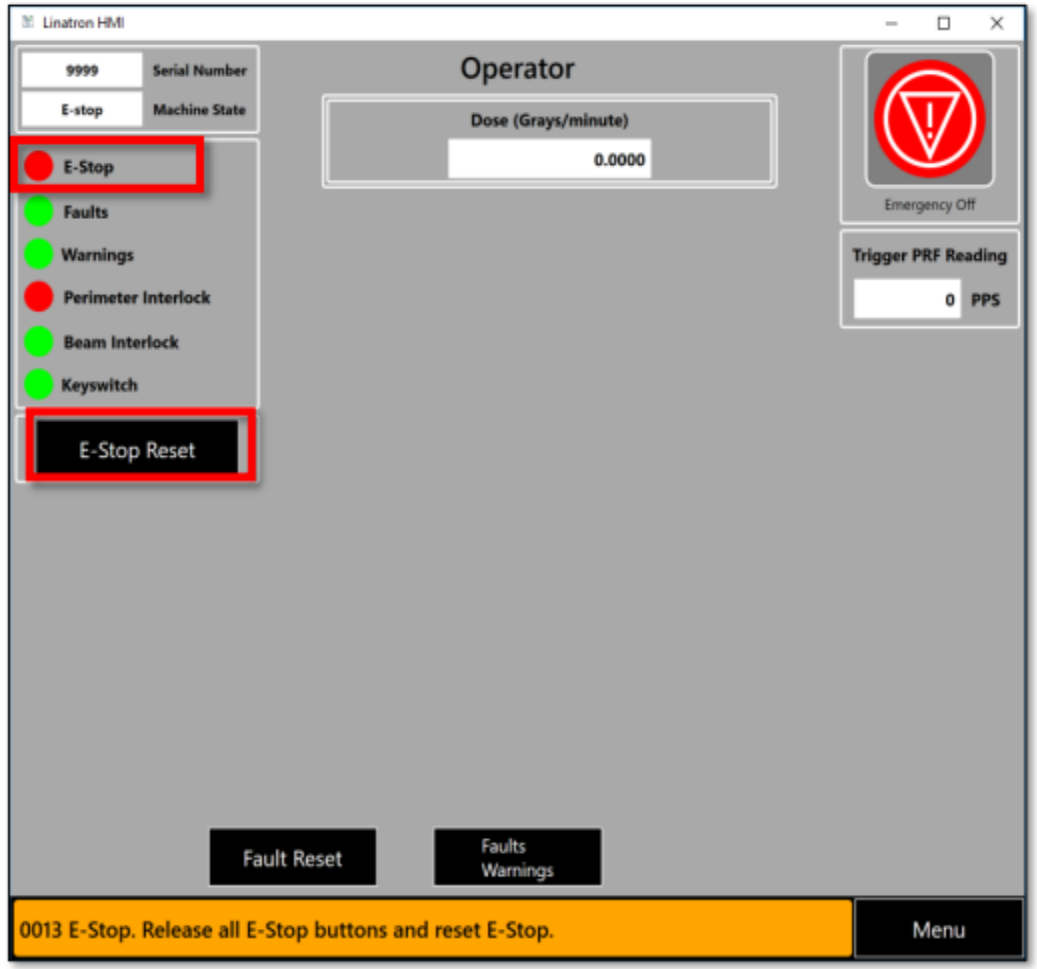


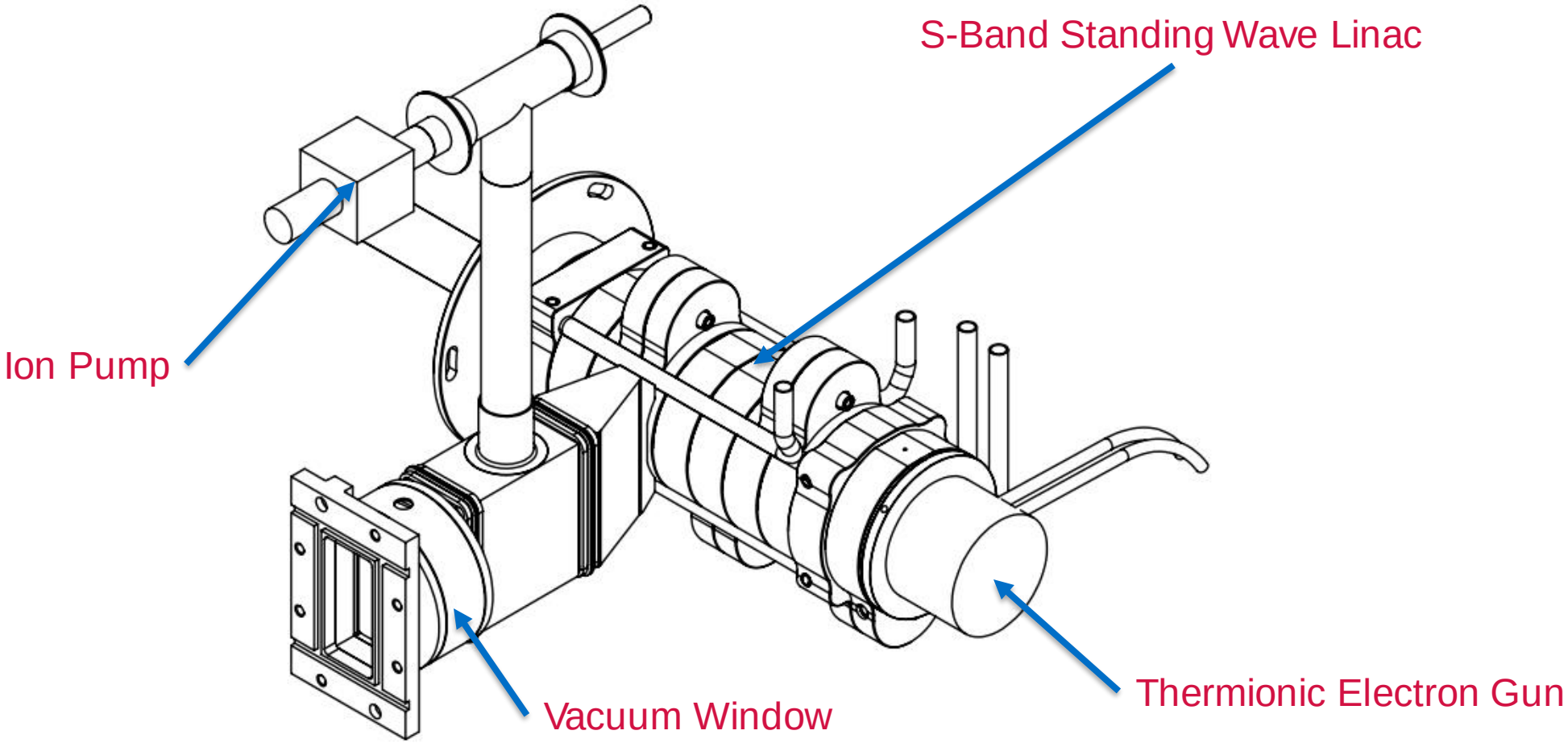
Figure: 3.9 Operator screen red E-stop indicator highlighted

- End users are unlikely to be particle accelerator physicists or engineers
- Need to simplify the operation as much as possible for the end users
- Automate as many functions as possible

Size

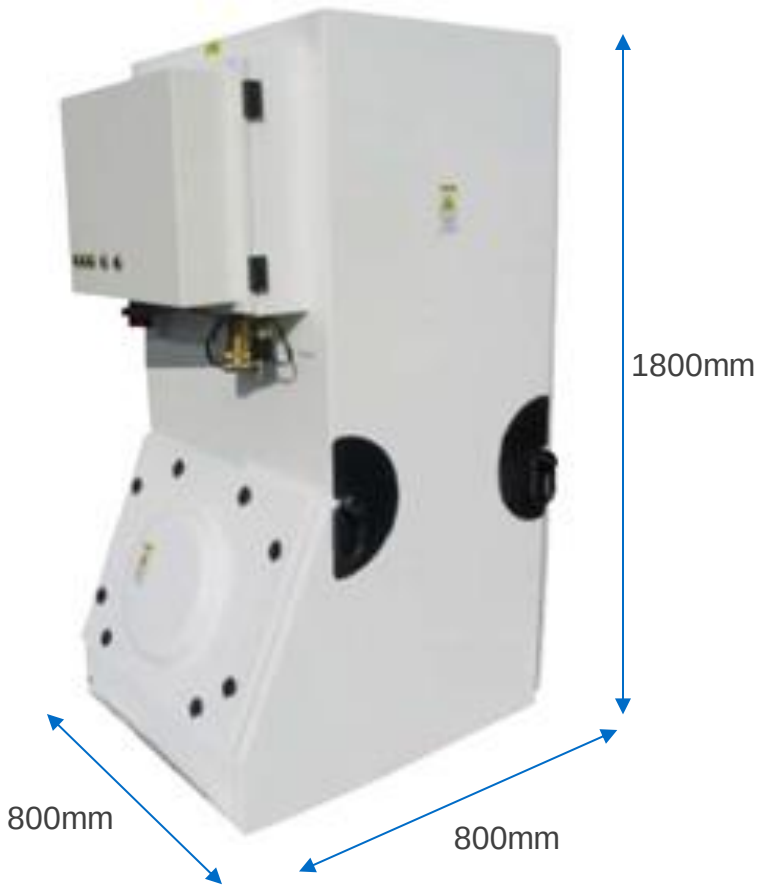
- Size and weight of particle accelerator is important
- Applications for particle accelerators are varied
  - Mobile systems
  - Systems in warehouses
  - Retrofit of an accelerator based security system into existing facilities
- Shielding considerations
  - Smaller the accelerator the less shielding needed
  - Big impact on weight

Typical Particle Accelerator for Security



Ancillary Systems

- RF Source
- Modulator
- Electron Gun Power Supply
- Waveguide
- Control system
- Cooling system
- AC Distribution
- Shielding



Linac Sub-Assemblies

Beamline

- The beam sub-assembly consists of a cavity, electron gun, RF window, target and ion pump.

Electron Gun Modulator

RF Power Supply

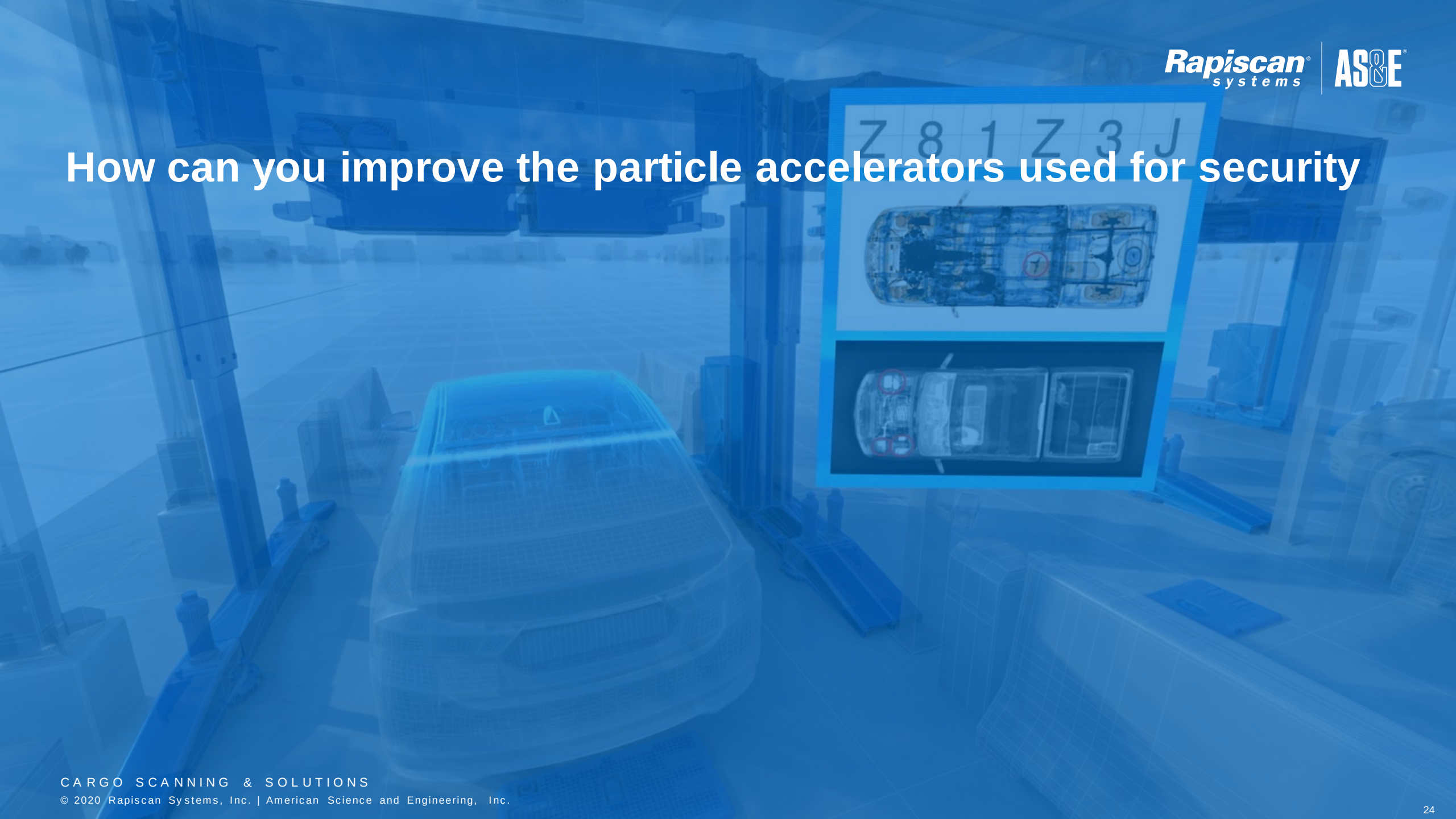
RF Source and Distribution

- Typically use an e2v magnetron and electromagnet for the RF source
- The RF distribution is made up of components from AFT microwave and other suppliers

Typical Particle Accelerator for Security

- Normal conducting electron linac
- Beam energy ranges from 1 to 9 MeV
  - Typical energies are 1MeV, 3MeV and 6MeV
  - Activation of materials is a concern
- Beam currents up to 200mA
- Beam spot size of <2mm
- Repetition rates of up to 800Hz
  - Typically closer to 400Hz

How can you improve the particle accelerators used for security



Development of Particle Accelerators

- There has been little development of the particle accelerators used in security
- Accelerator design is mature and due to risk adverse market no fundamental design changes have happened
- Two biggest recent changes in particle accelerators for Cargo and Vehicle Inspection are:
  - Mono block system – circa 2015
  - Solid state modulator technology – circa 2018

How can you help develop particle accelerators for security?

Engage Industry

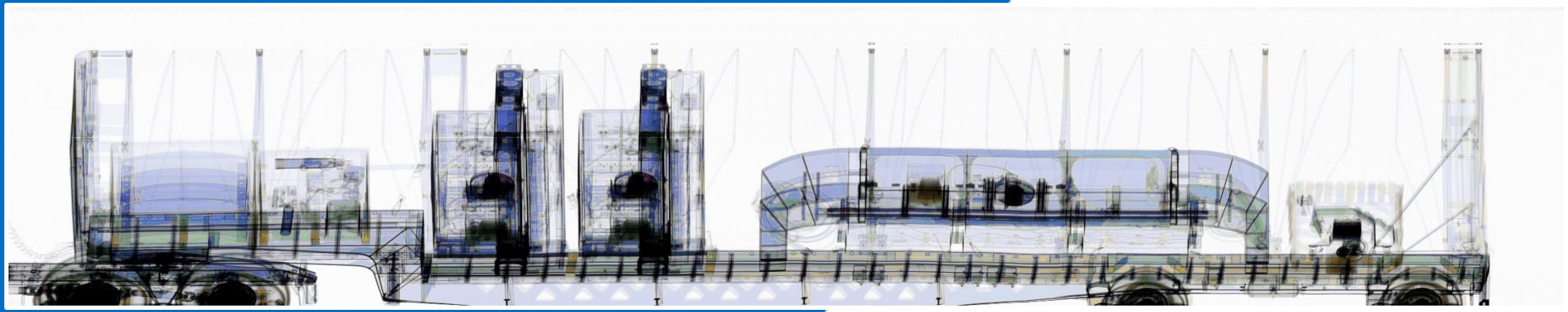
- To develop the particle accelerators used in security the first step is to ignore the accelerator
- Need to understand the application you want to target
  - Different applications will have different needs
  - There maybe a common problem across applications
- Engage industry
  - Most companies in the security field are willing to engage with researchers
  - Industry can tell you what they need
    - It is very likely to be different to what you would expect

For the rest of this seminar we will look at products that Rapiscan Systems make and see what are the areas of development

Drive-Through Cargo Inspection
Eagle® P60

- High penetration and resolution with material discrimination to assist operators in the inspection of dense cargo
- High-throughput scanning of up to 100 trucks per hour
- Large field of view for scanning vehicles up to 5 m tall
- Small system footprint with optional surface mount to reduce civil works
- CabScan® technology for the safe inspection of the cab of the truck

Eagle P60 Image



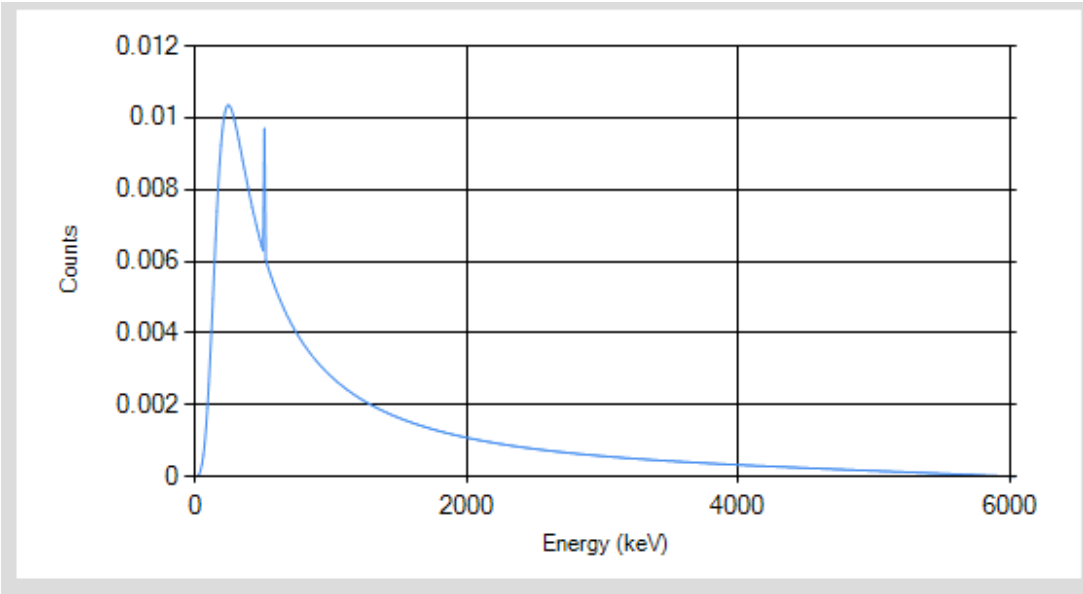
Eagle P60

- Uses 6/4 MeV electron linac to produce x-rays via conversion target
- Generates x-ray image by pulsing the linac and producing a fan beam of x-rays
- L-shaped detector
- Each x-ray pulse fo
- The width of that li
- Line width and maximum rep rate of the linac determine the drive through speed on the system

1. X-ray spectrum
2. X-ray output
3. Throughput of system

X-Ray Spectrum

- The x-ray output from industrial linacs is very broad
- Majority of x-rays are at low energy which are not useful
- Can this spectrum be changed?
- Can we get a flat spectrum?
  - Target development
  - Electron beam changes



X-ray Output

- Stability of x-ray output is critical to performance
- How can we improve the stability?
  - Thermal optimisation
  - RF source
    - Magnetron developments
    - Magnetron replacement
  - Control system
    - Dose feedback system
  - Diagnostics
    - Real time energy measurements

Image Performance Metrics

Pulse to Pulse Stability:

$$\varphi = 100 \times \frac{\sigma_x}{\bar{x}}$$

Drift:

$$\delta = 100 \times \frac{|\bar{x}_1 - \bar{x}_2|}{\bar{x}_1}$$

Scan to Scan Stability:

$$StS = 100 \times \frac{|\bar{x}_{1A} - \bar{x}_{1B}|}{\bar{x}_{1A}}$$

$$EtS = 100 \times \frac{|\bar{x}_{2A} - \bar{x}_{1B}|}{\bar{x}_{2A}}$$

Throughput of the System

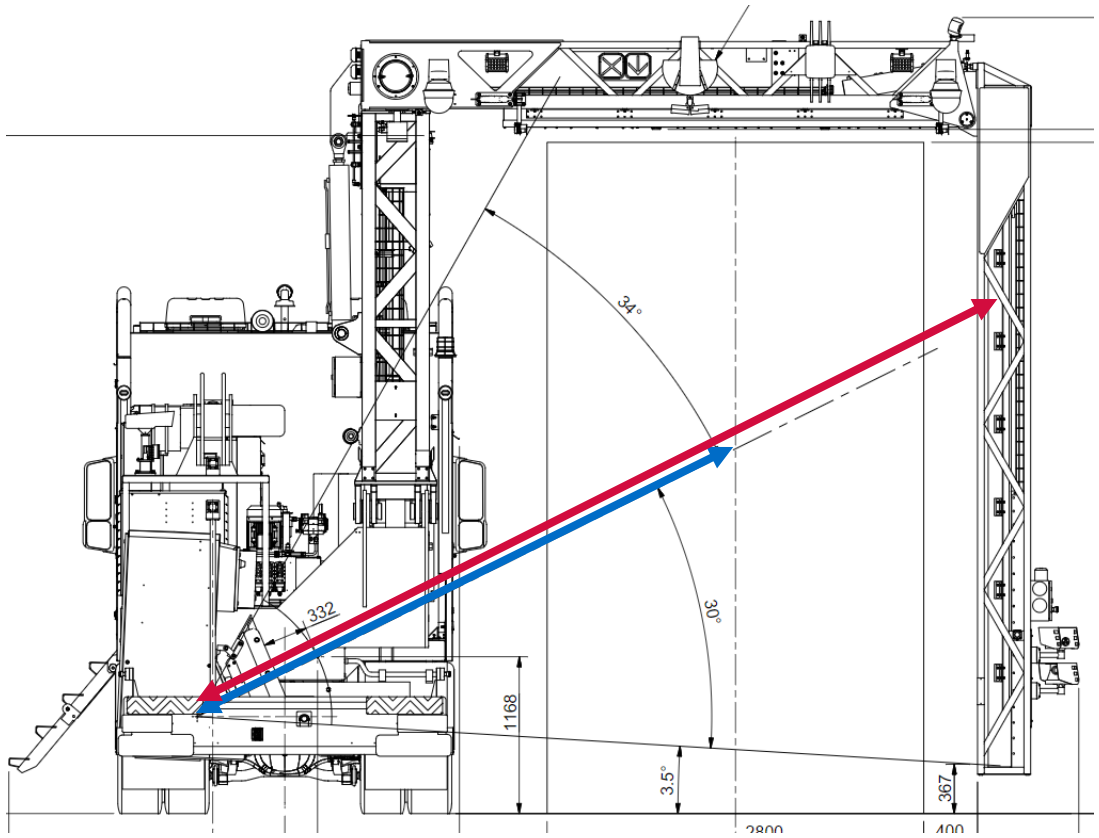
- The throughput of a system is a measure of how many conveyances a system can image in an hour
  - Current systems have a throughput of up to 120 vehicles an hour
- Throughput is driven by how fast a conveyance can travel through the system
  - Speed is limited by:
    - Linewidth
    - Repetition Rate
    - Material Separation Requirements

Line Width

- Line Width is determined by the size of the detector and the magnification factor of the system
- Magnification is given by:

$$M = \frac{S_{DET}}{S_{MID}}$$

- Therefore to increase maximum speed need to increase repetition rate or detector size
- Typical values:
  - M = 1.5
  - Line Width 3.5mm



Conveyance Speed

Line Width (mm)	3.5
Max Rep Rate (Hz)	400
Dual Energy	Yes
Number of Columns	2
Maximum Speed (mm/s)	1400
Scan Duration (s)	12

- How can we speed up the conveyance without under sampling?
  - More detector area
    - Reduces resolution of the system
    - Adds cost
  - Pulse faster
  - Do material separation a different way
    - Single energy output + stacked crystals
    - 2 energies in one RF pulse

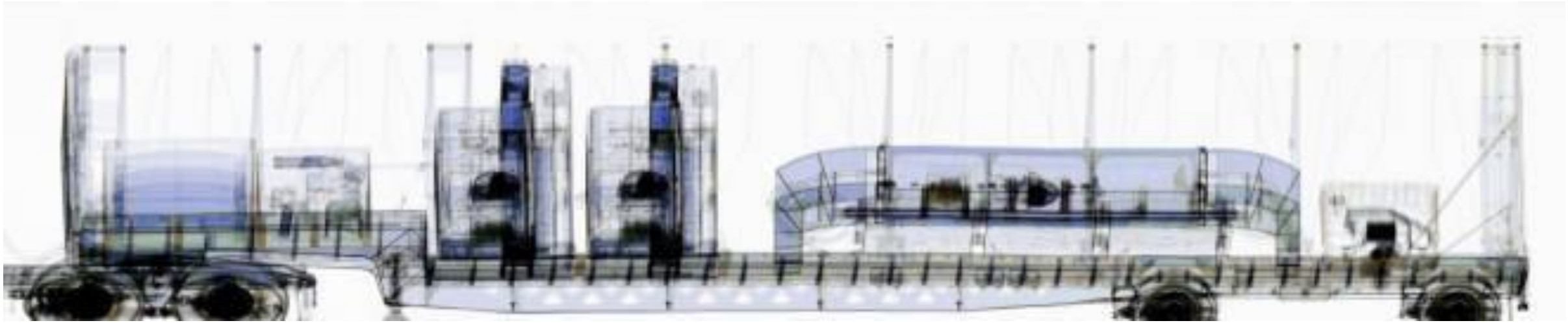
Material Separation

This is an industry standard requirement where different materials need to be identified within an image

To do this dual energy linacs are used which interleave high and low energy pulses

Typically the high and low energy pulses have different RF peak power and different gun currents

If we can have two energy pulses in one RF pulse we double the effective repetition



Intra-Pulse Dual Energy Systems

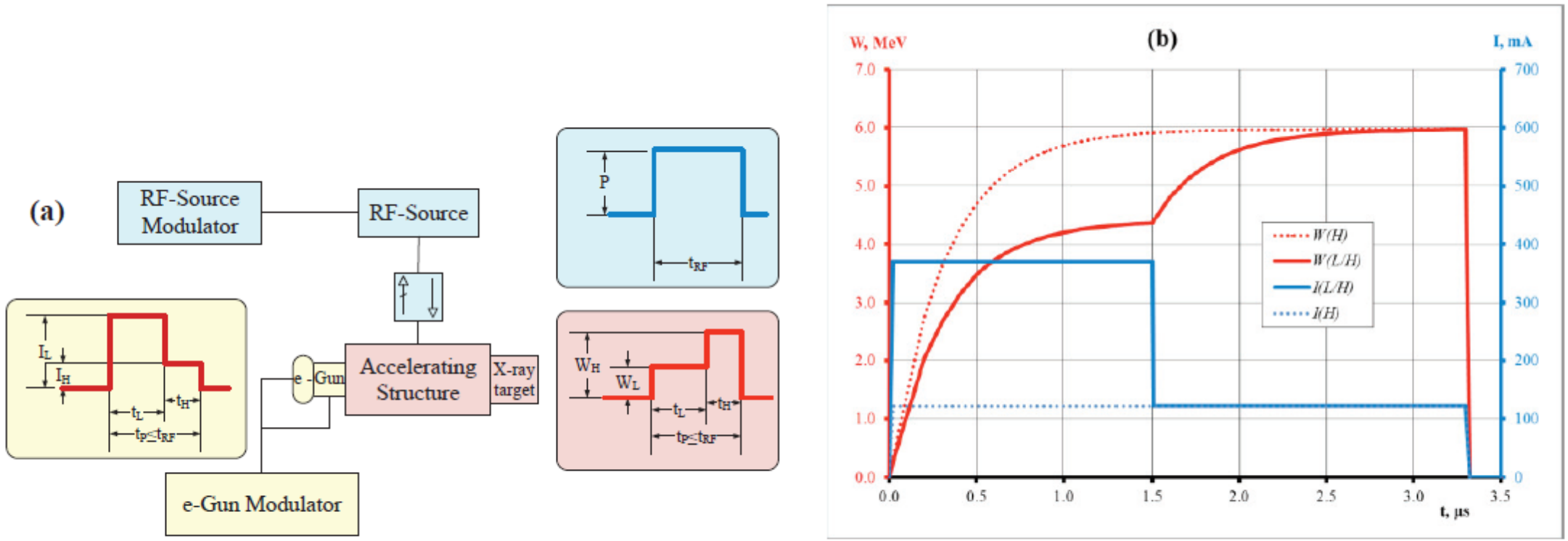


Fig. 1. (a) Block-diagram of intra-pulse dual-energy linac; (b) Electron beam energy and current for intra-pulse dual-energy operation (solid lined) and high energy pulse (dotted line) for interlaced operation.

Intra-Pulse Dual Energy Systems

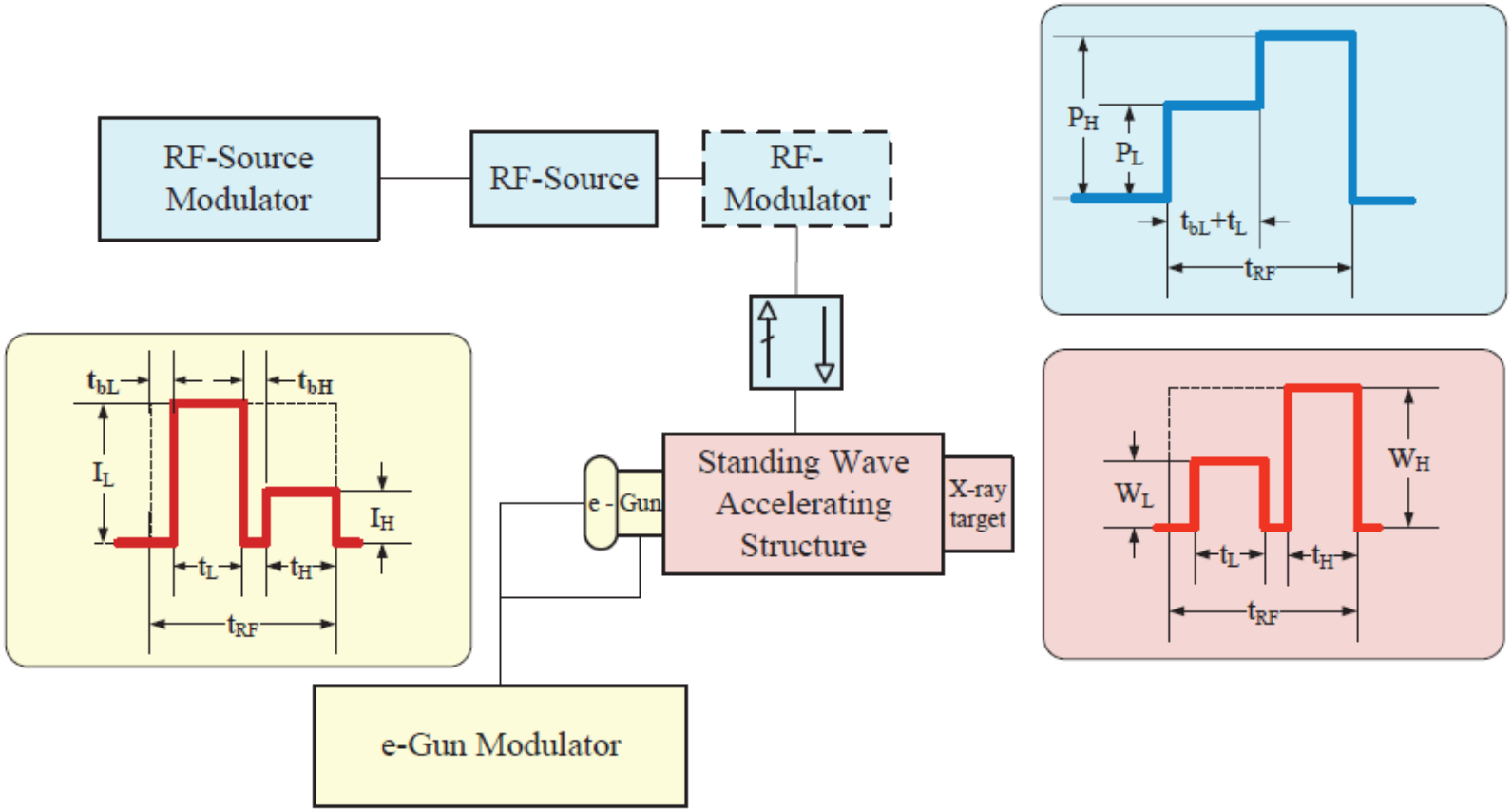


Fig. 2. Block-diagram of intra-pulse dual-energy linac with delayed application of electron beam currents corresponding to high and low energy levels.

How can we do Intra-Pulse?

It needs to be:

- Robust
- Reliable
- Simple to manufacture
- Flexible
- Easy to use
- Compact

These are the same considerations that apply to any industrial linac development

Summary

Why do we use particle accelerators for security?

- Need a variety of particle beams for different applications

What particle accelerators are used for security?

- Most a normal conducting electron linacs, also use betatrons and cyclotrons depending on the application

How can we develop particle accelerators for security and industry in general?

- Talk to industry first
- Remember developments need to work in a variety of settings with a variety of end users

If you want to know more

- Plan to host a series of visits for researchers at Rapiscan Stoke
- Tour of the site and overview of research areas where you can help
- If interested please get in touch

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