# Dual energy modulation: Precision driven material discrimination

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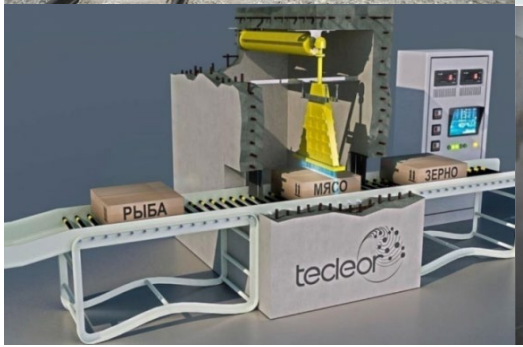
Introduction to ScanTechnology

# Linear electron accelerators for different applications

x-ray inspection systems


medical (radiotherapy)

sterilization (antibacterial treatment of food, seeds, etc.)




non-destructive testing

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# Linear electron accelerators for different applications

x-ray inspection systems

klystrons

linear accelerators

modulators

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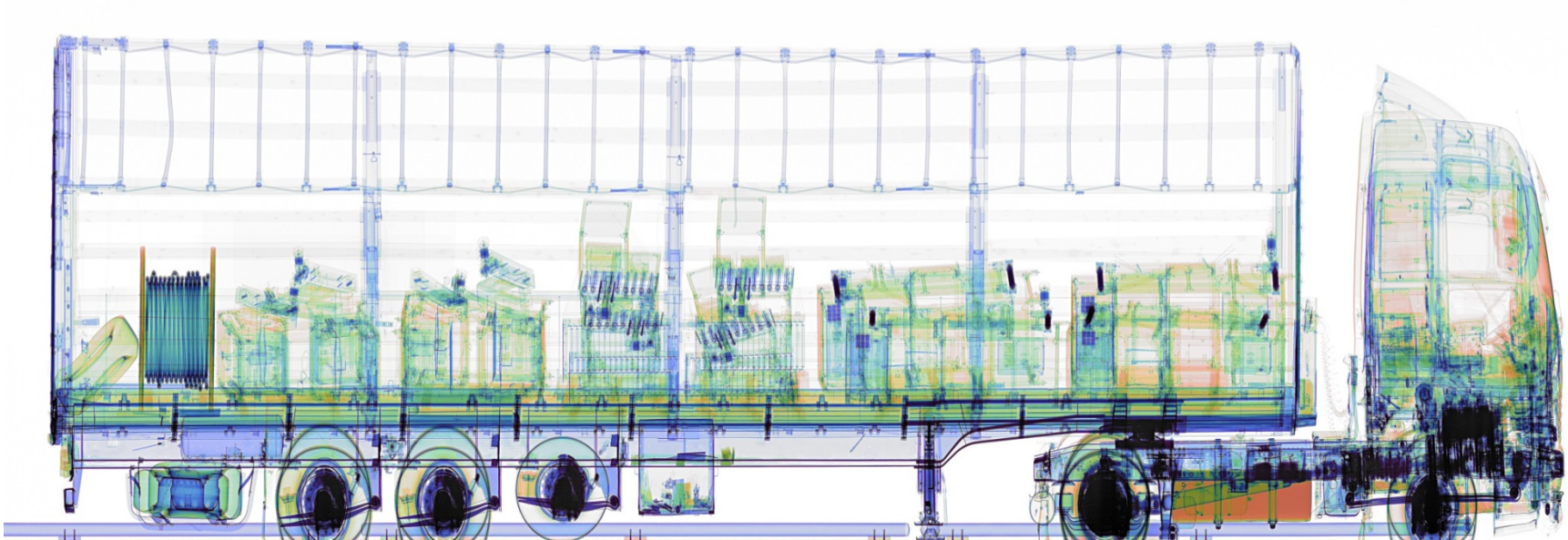
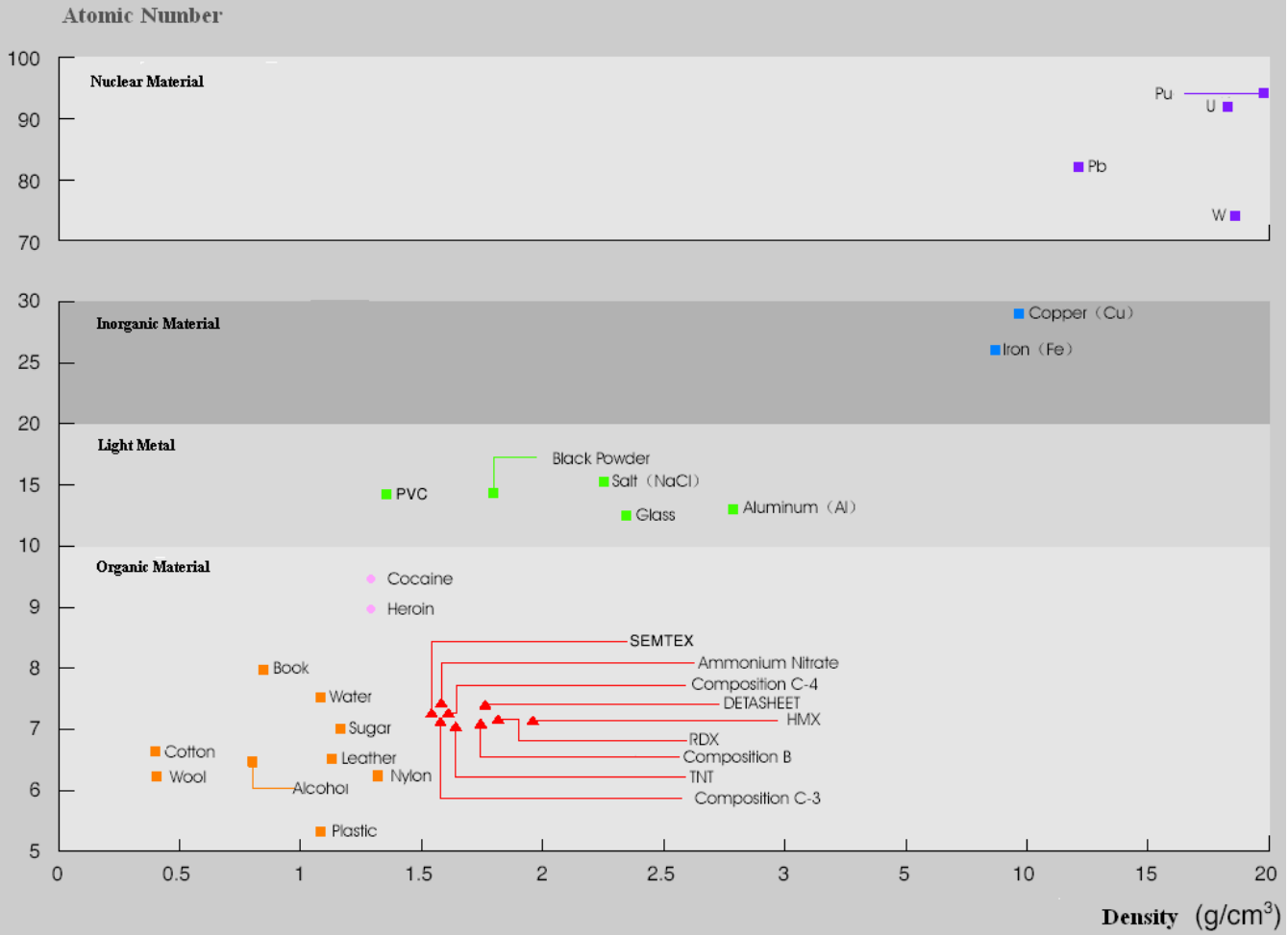
# why solid state modulators + klystron linacs are the best choice?

# X-ray inspection systems: material differentiation

Differentiation is possible because materials have diverse degrees of attenuation for high and low energy x-rays, which allows to identify at least organic (low atomic number Z) and inorganic materials (high atomic number Z).

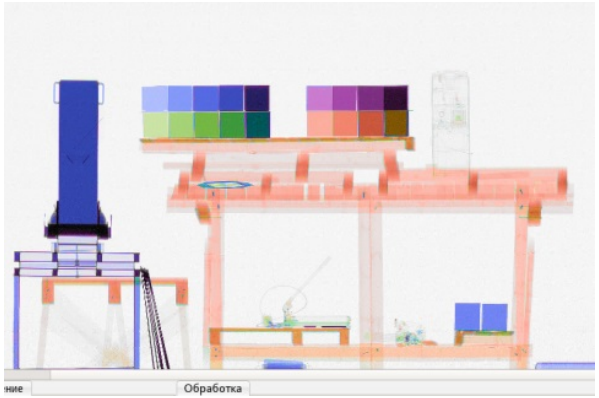


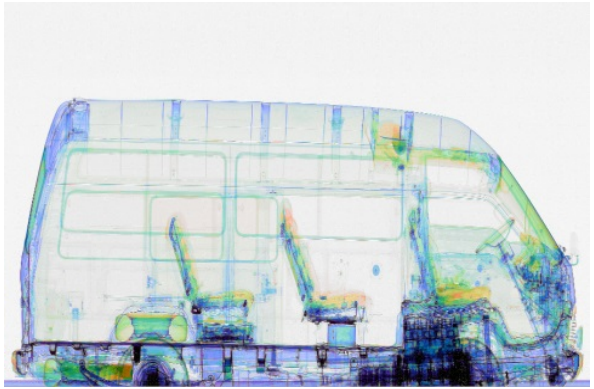



# How to differentiate materials with same atomic number

Explosives can be localized in the compact cluster on criteria $Z_{eff}$ – density or in single projection X-ray image: $Z_{eff}$ – mass thickness – mass.

# Material differentiation of up to 4 groups



red - organic materials with low atomic numbers (1<Z<10): sugar, water, polyethylene, textile, etc.

green - materials with medium atomic numbers (10<Z<20): salt, minerals, aluminium, etc.

blue - metals with medium to high atomic numbers (20<Z<50): steel, copper, nickel, etc.

lilac - heavy metals with high atomic numbers (Z>50): gold, lead, tungsten, etc.

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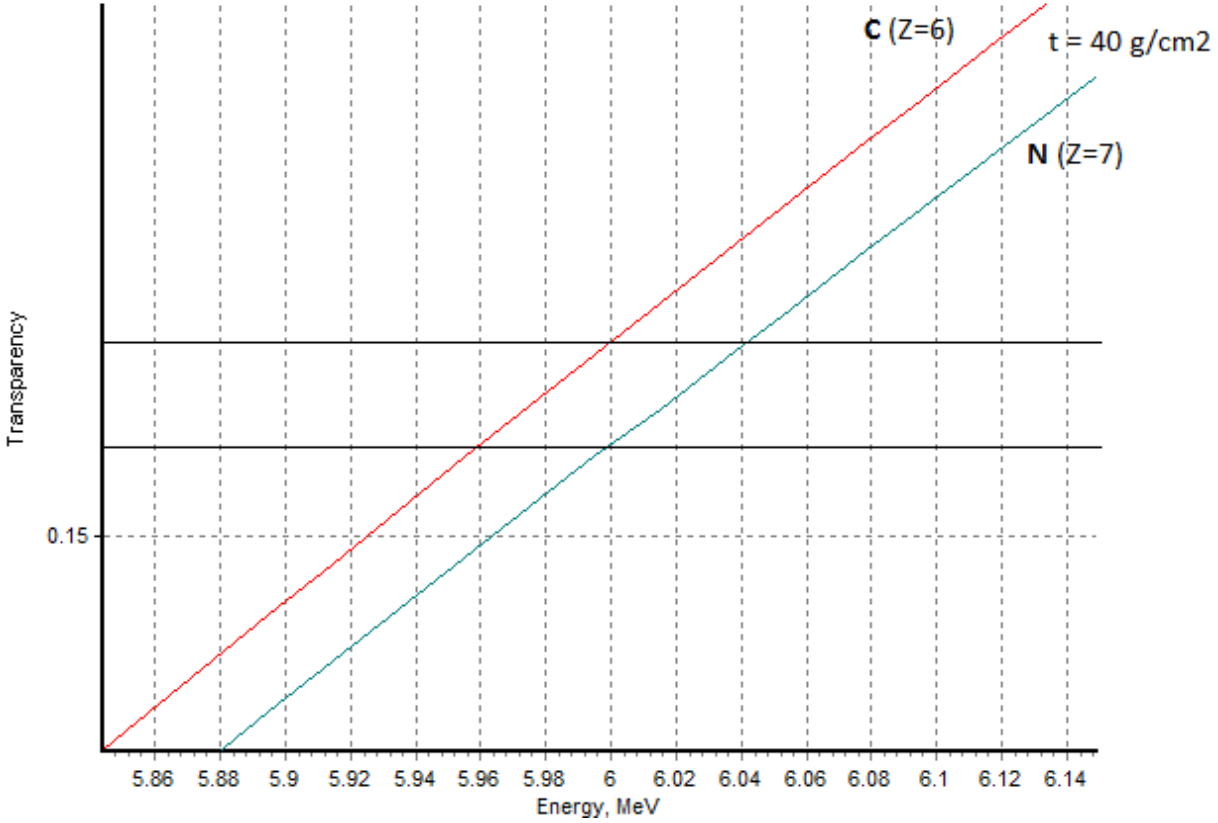
# Requirements to x-ray beam stability (high energy)




Effective boundary of high and low energy to provide the accuracy of materials discrimination of ±1 for the group of materials of interest to detect explosives (carbon and nitrogen with atomic numbers of 6 and 7 respectively and mass thickness 40 g/cm$^2$)

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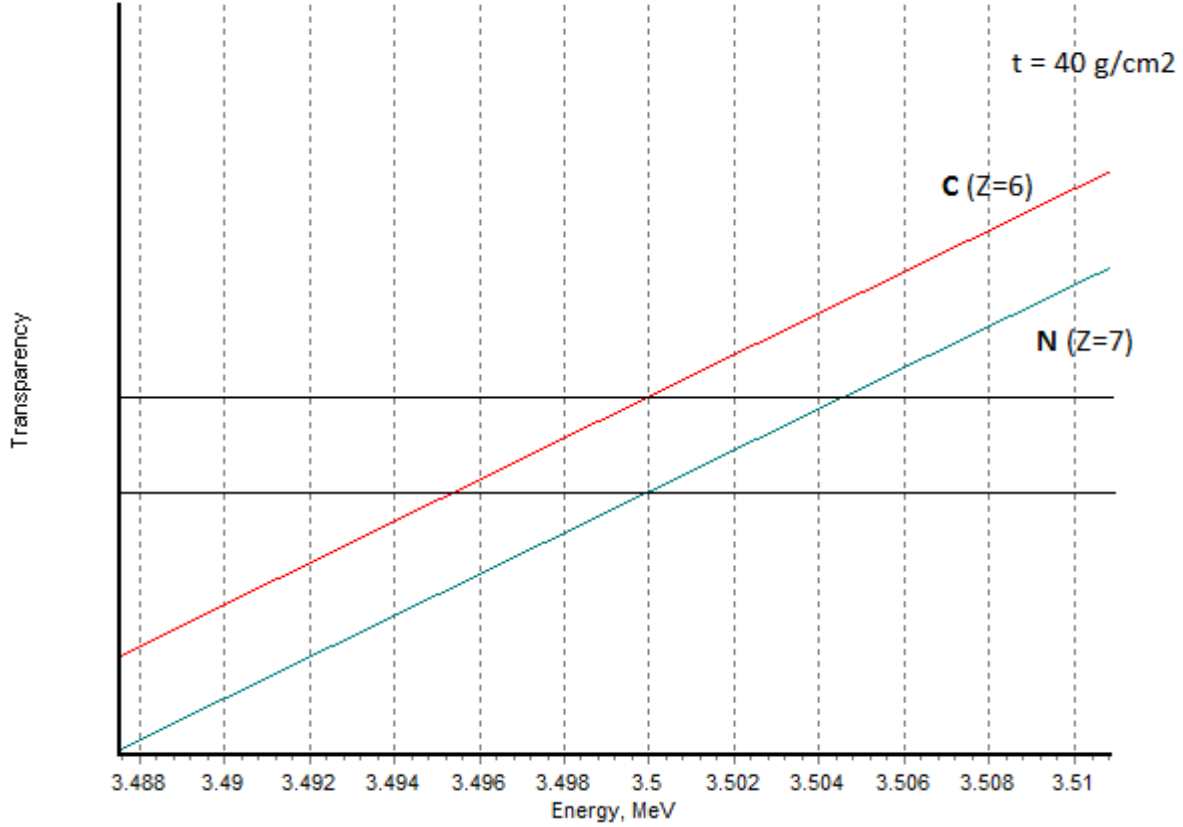
# Requirements to x-ray beam stability (low energy)




The accuracy of material discrimination of ±1 impose high requirements to the stability and quality of generated x-ray beam, which can be obtained using klystron linear accelerators together with an advanced frequency control.

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# Ensuring beam stability: a) linear accelerator

| Parameter | Value |
|---|---|
| Operating frequency | 2856 MHz or 5712 MHz |
| Electron beam high energy | 6 MeV |
| Electron beam low energy | 3.5 MeV |
| Dose rate at 1 m at high energy | 0.05 … 3 Gy/min |
| Dose rate at 1 m at low energy | 0.05 … 3 Gy/min at 1 m |
| Dose rate at dual energy | 0.1 … 6 Gy/min at 1 m |
| Repetition rate in dual energy mode | 2x200…2x1000 Hz |
| Pulse length | 1…3 μs |
| High energy stability | 0.2% |
| Low energy stability | 0.2% |
| X-ray start-up time | < 1 s |
| X-ray cut-off time | < 10 ms |
| Focal spot size | < 1 mm |
| Radiation leakage | 10-6 |

Klystron linear accelerators which ensure precise energy modulation together with accurate pulse stability are coupled to multi-beam S- or C-band klystrons and have high characteristics of accelerated beam stability, which is particularly important to ensure the accuracy of $Z_{eff}$ estimation up to ±1.

All of the above is provided with the help of a very important component – the solid state pulse modulators.

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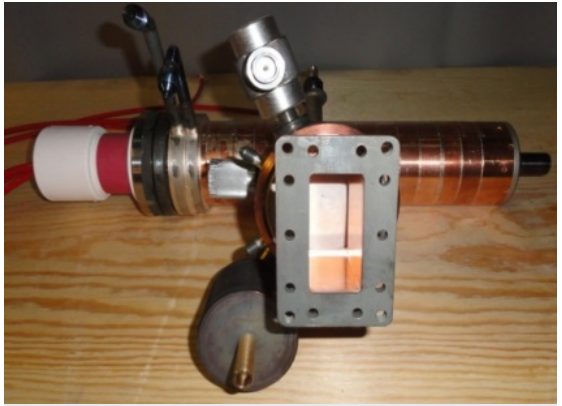
# Ensuring beam stability: b) solid state modulator



For fast and precise non-instrusive x-ray inspection of railway freight the combination of ScandiNova PG200 modulator running at up to 2000 Hz with the klystron KIU-168 is used to provide high quality scanning at train speeds of up to 70 km/h

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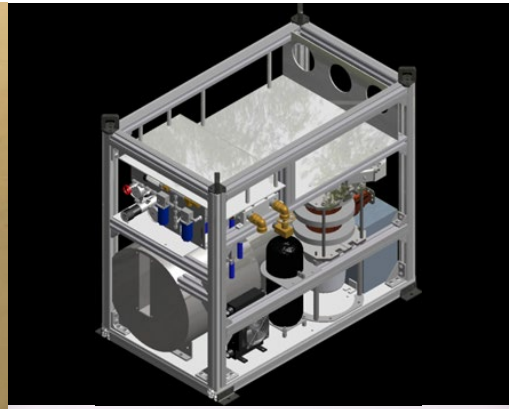
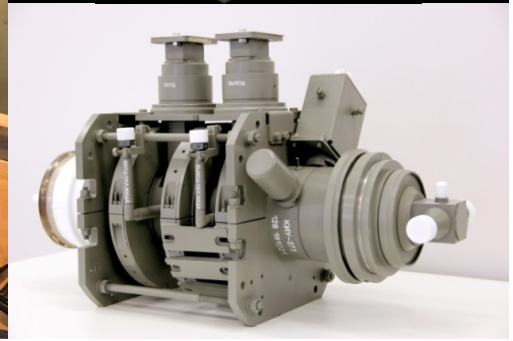
# klystron linear electron accelerator + solid state modulator (M200D)

For the mobile inspection systems where size and weight matter yet the performance is the key - the combination of ScandiNova M200D modulator with the C-band klystron KIU-273 is used to provide precise material discrimination and meet the highest safety standards.





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# klystrons tested: operating specifications

| Operating Specifications | KIU-268 | KIU-168 | | KIU-273 |
|---|---|---|---|---|
| | | mode 1 | mode 2 | |
| Operating frequency, MHz | 2856 ± 2 | 2856 ± 5 | | 5712 ± 4 |
| Max. output pulse power at any phase of load, MW, not less than | 6.0 | 4.0 | 6.0 | 3.0 |
| Min. output pulse power at any phase of load, MW, not more than | 3.0 | 1.5 | 2.0 | 1.0 |
| Average output pulse power, kW, not less than | 25.0 | 6.0 | 6.0 | 6.0 |
| Supplied pulse power, MW, not more than | 15 | 10 | 15 | 7.7 |
| Supplied average power, kW, not more than | 62.5 | 15 | 15 | 15 |
| Efficiency in saturation mode, %, not less than | 42 | 45 | 45 | 45 |
| Filament power, W, not more than | 650 | 700 | | 420 |
| Modulating pulse length, μs | 7.0 – 16.0 | 2.5 – 7.0 | | 3.0 – 7.0 |
| Duty cycle, approx. | 0,42% | 0,15% | 0,10% | 0,20% |
| Cathode pulse voltage, kV, not more than | 55 | 46 | 53 | 45 |
| Filament voltage, V, not more than | 24 | 26 | | 16 |
| Ion pump voltage, kV | 4.0 ± 0.5 | 4.0 ± 0.5 | | 4.0 ± 0.5 |
| Beam pulse current, A, not more than | 300 | 230 | 300 | 160 |
| Filament current, A, not more than | 30 | 35 | | 30 |

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# Tack så mycket!
# Thank you!


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