Multilayer Material Discrimination Methods with Dual-energy X-ray

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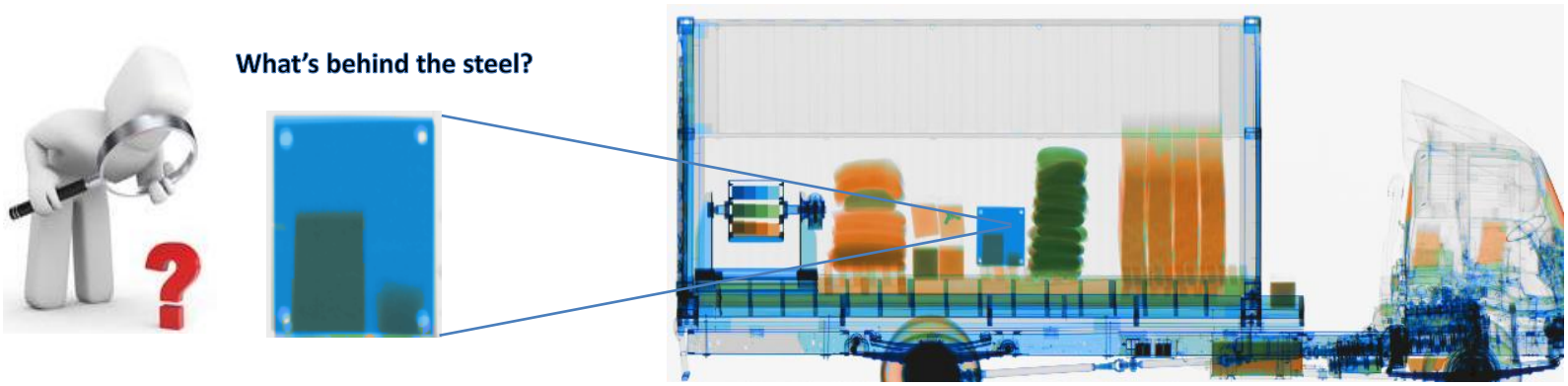
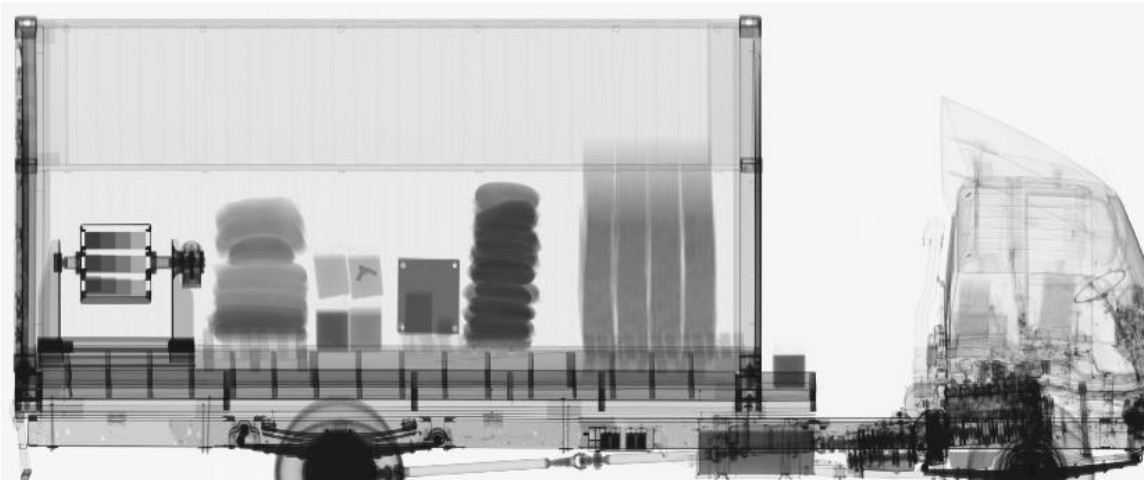
5 Nov 2014

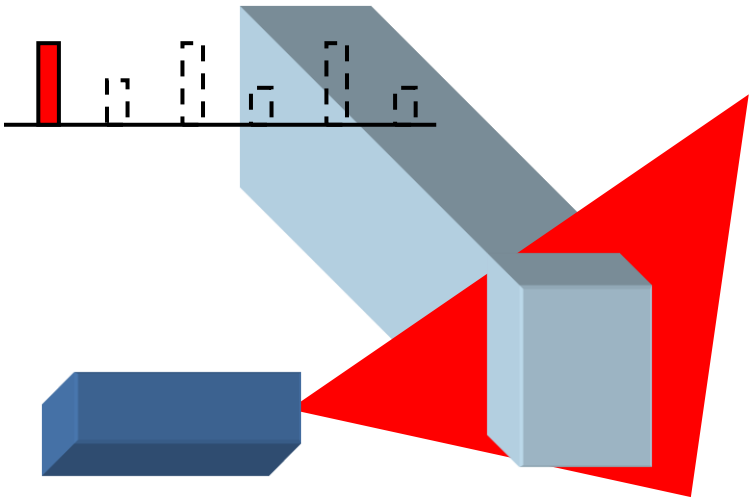
The problem

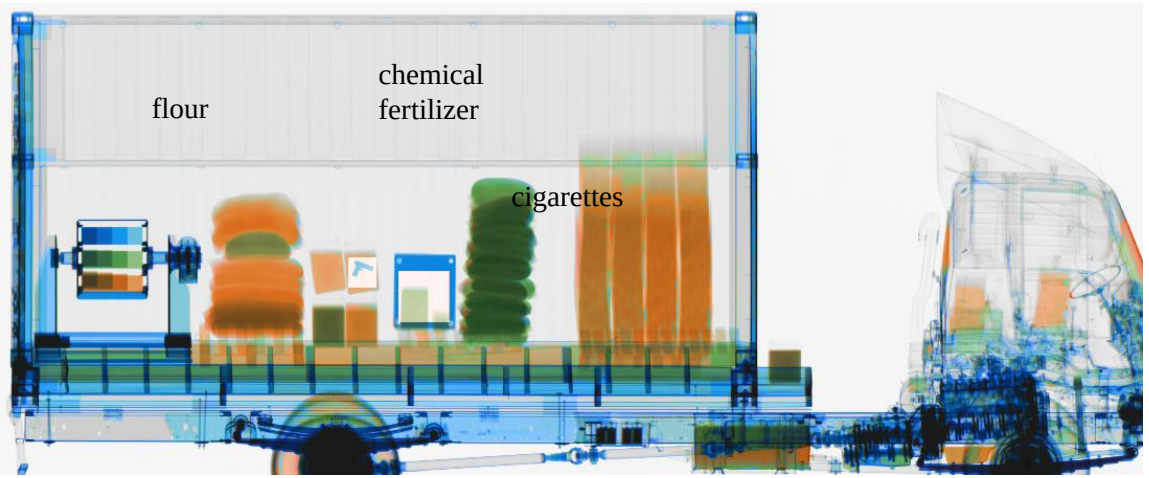


- A solution for the problem of overlapping materials on ray-pathes in X-ray imaging.

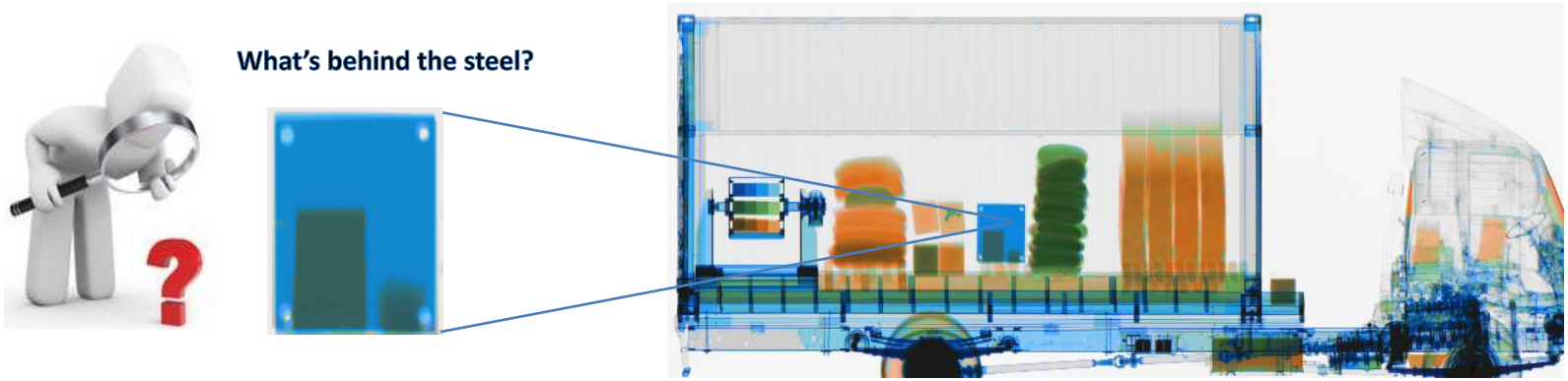
Large Container Scanner





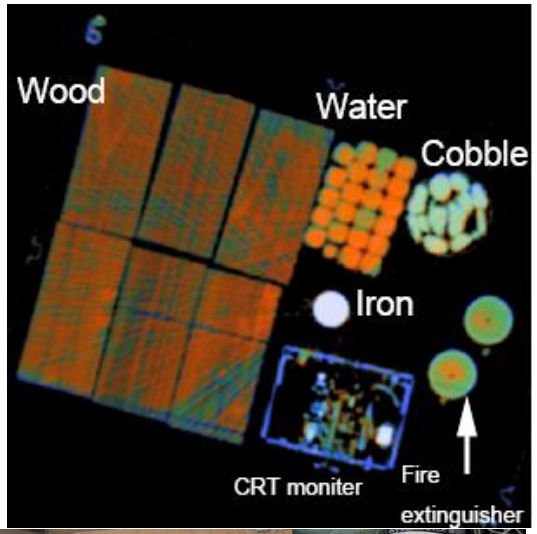


The Problem



- Dual-energy X-ray systems can obtain the effective atomic number of the distributed objects in the beam direction, visualizing a colored image.
- How about multilayer conditions? Contrabands, explosives are usually multilayered with other goods.
- Multilayer material discrimination problem shall be studied.

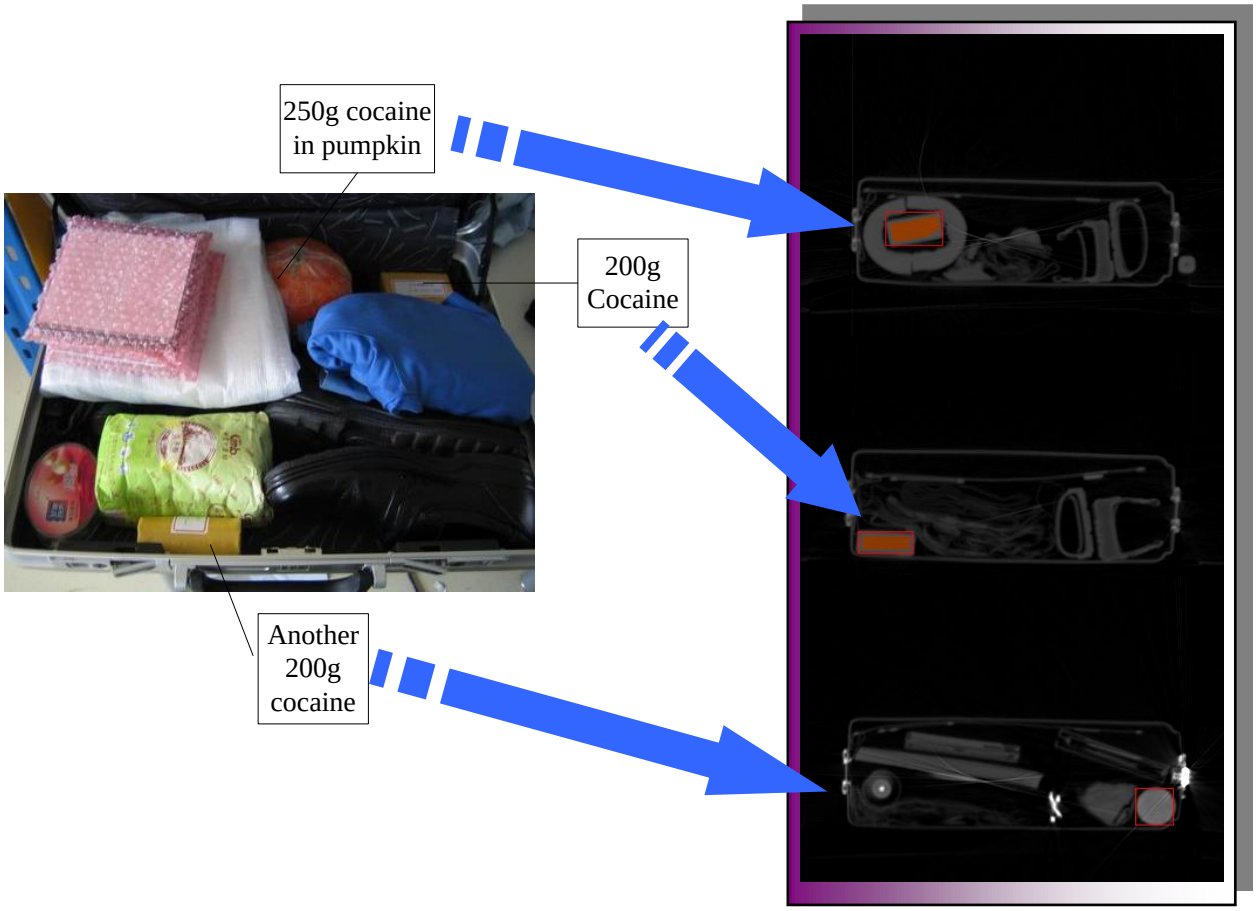
Dual Energy CT (MeV)



Dominate effects: Pair production & Compton

--A reconstruction method for dual high-energy CT with MeV X-Rays, IEEE TNS, VOL. 58, NO. 2, 2011.

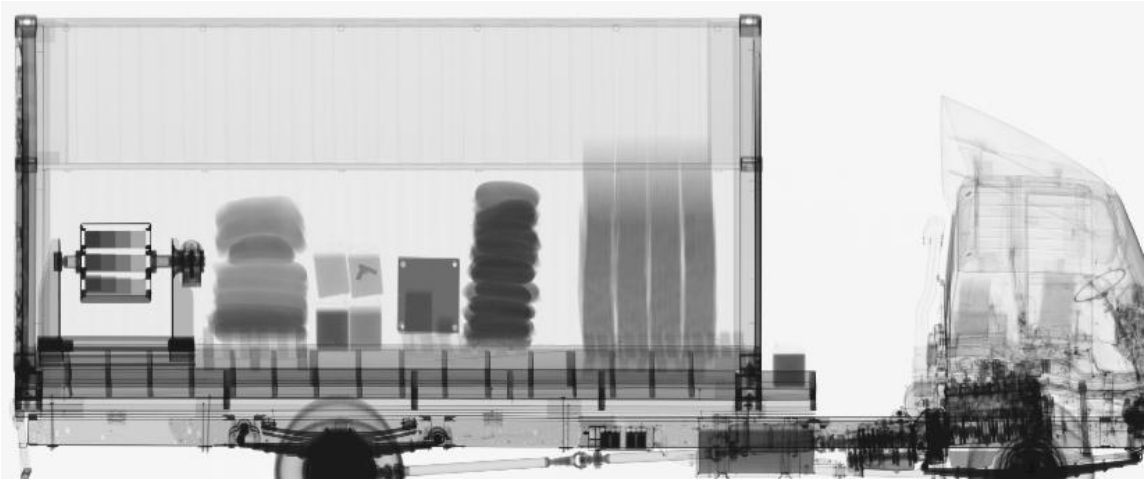
Dual Energy CT (KeV)

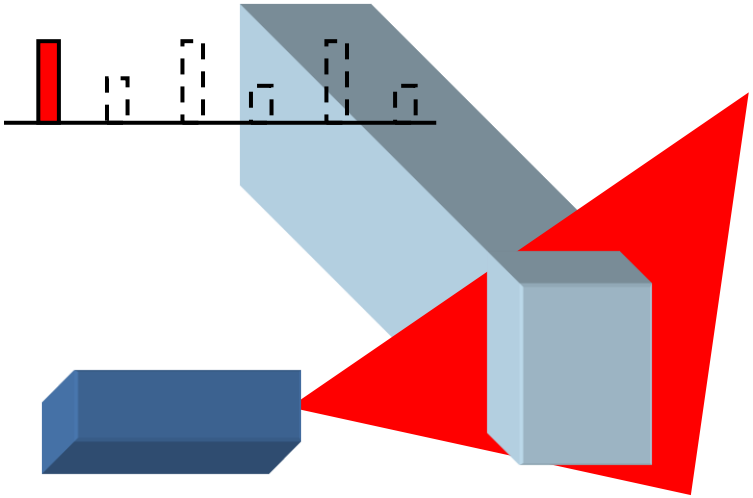


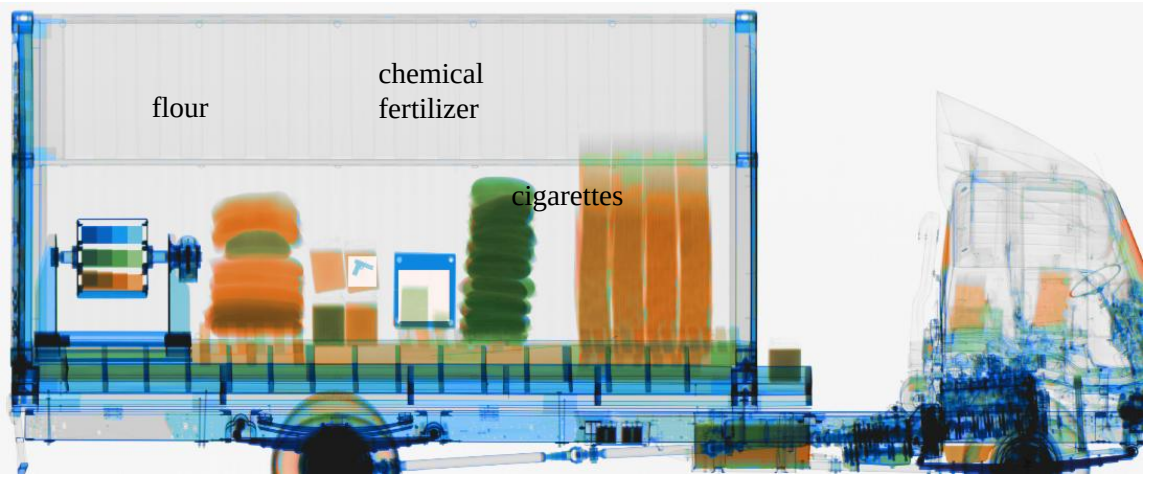
Dominate effects: Photo-electric & Compton

- *A practical reconstruction method for dual energy computed tomography, J. X-ray Sci & Tech. 16(2), 2008.*
- *Dual energy CT reconstruction method with incomplete data, IEEE NSS-MIC record, 2013, N25-2*

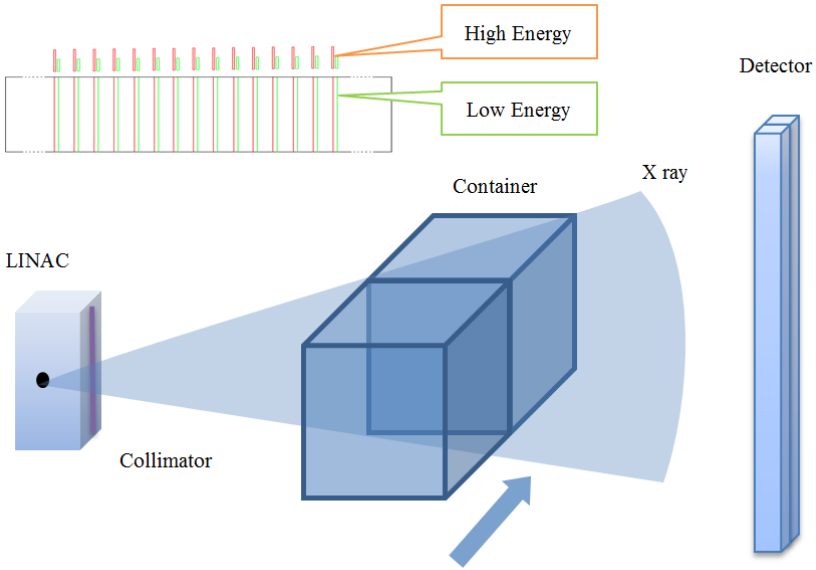
Large Container Scanner

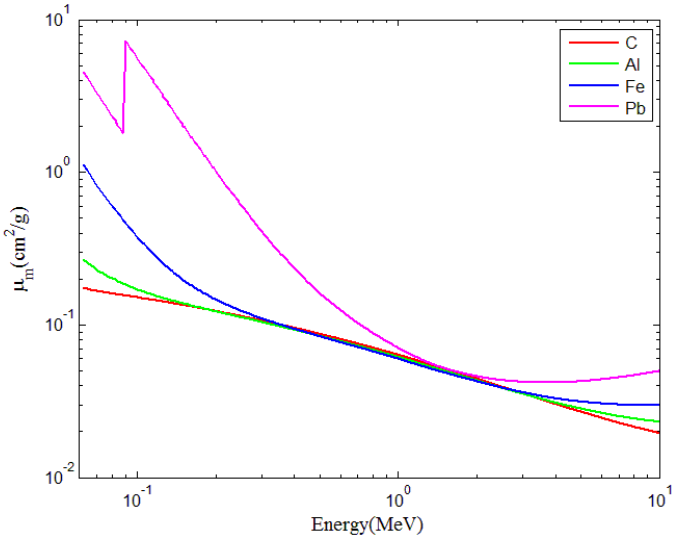






Dual-energy X-ray Radiography

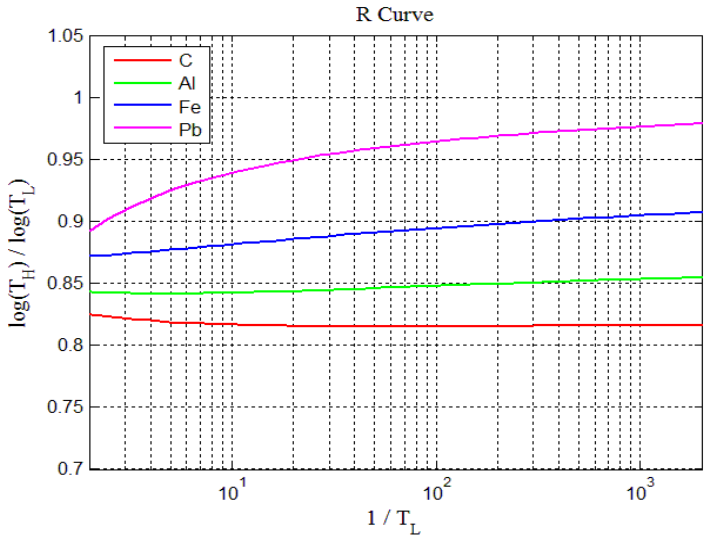




transparency $T = I/I_0 = \exp(-\mu_m t_m)$

$$\begin{cases} T(E_H, t_m, Z) = \dfrac{I_H}{I_{0H}} = \dfrac{\int_0^{E_H} p(E_H)\exp(-\mu_m t_m)\,\varepsilon\, E_H dE_H}{\int_0^{E_H} p(E_H)\varepsilon\, E_H dE_H} \\ T(E_L, t_m, Z) = \dfrac{I_L}{I_{0L}} = \dfrac{\int_0^{E_L} p(E_L)\exp(-\mu_m t_m)\,\varepsilon\, E_L dE_L}{\int_0^{E_L} p(E_L)\varepsilon\, E_L dE_L} \end{cases}$$

$$\mathrm{R}(E_H, E_L, t_m, Z) = \frac{ln(T(E_H, t_m, Z))}{ln(T(E_L, t_m, Z))} = \frac{\overline{\mu_m}(E_H, t_m, Z)}{\overline{\mu_m}(E_L, t_m, Z)}$$



Dual-energy X-ray Radiography

High Energy Transparency

Low Energy Transparency

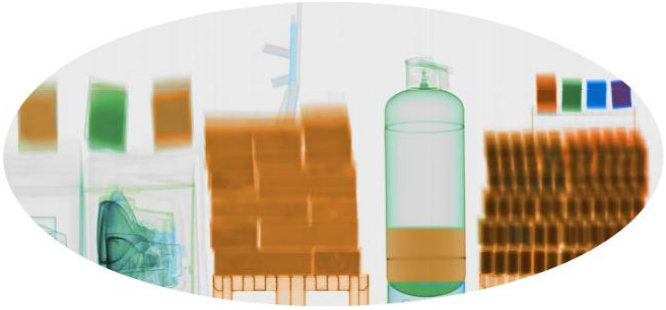
Synthesized Transparency

Material Information

Dual-energy X-ray Radiography

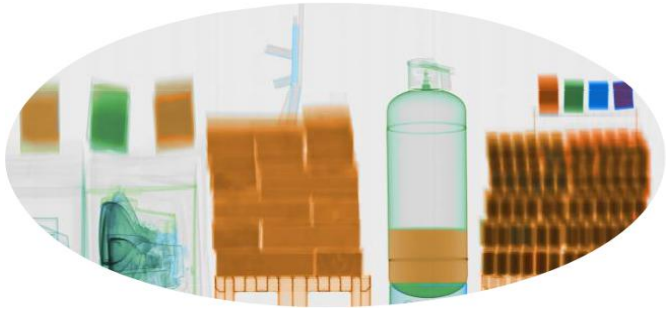
Synthesized Transparency

Material Information



- Colorization of the dual-energy X-ray image implies the material information of the objects been imaged.

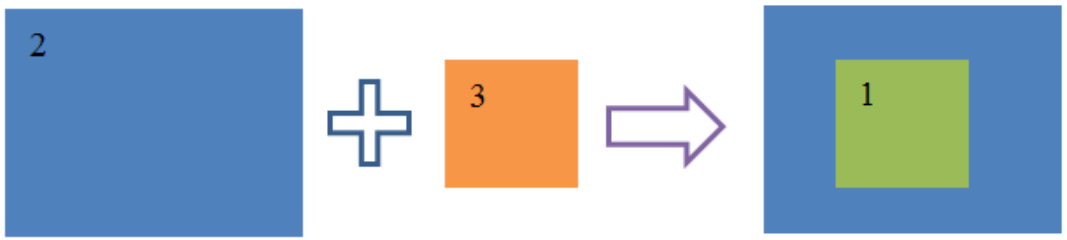
Dual-energy X-ray Radiography

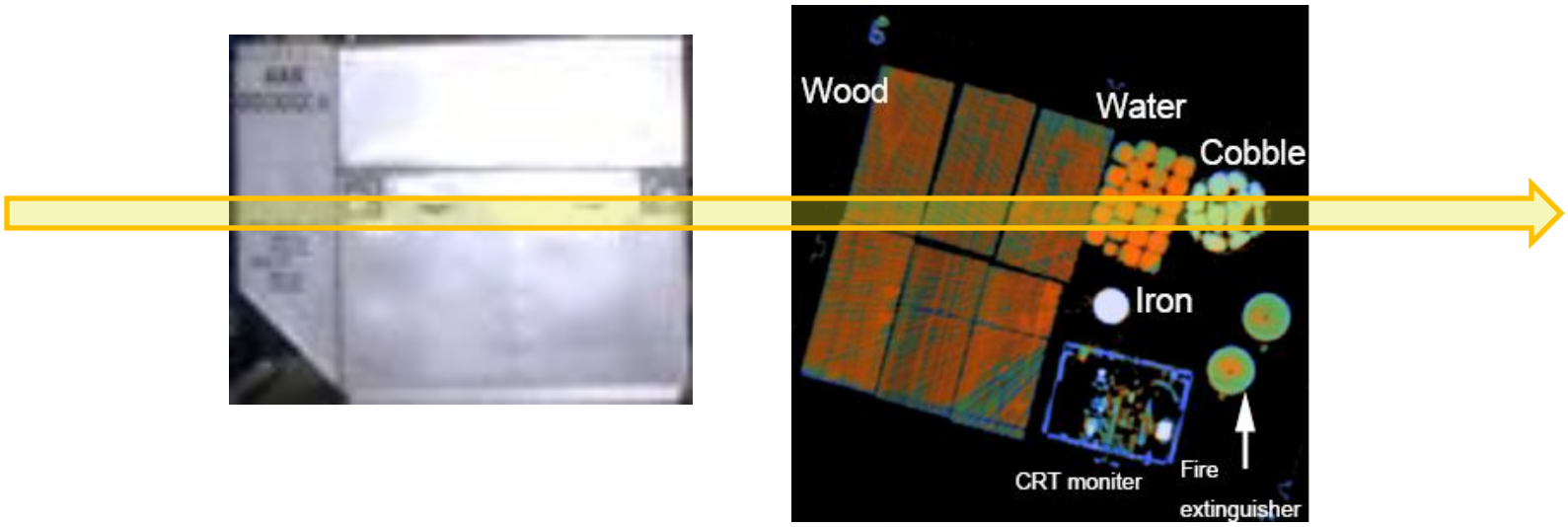


Materials	Equivalent atomic number range	Typical Material	Color
Organic	$1 \leq Z \leq 10$	Graphite	
Compound	$10 < Z < 18$	Aluminum	
Inorganic	$18 \leq Z < 57$	Iron	
Heavy metal	$Z \geq 57$	Lead	

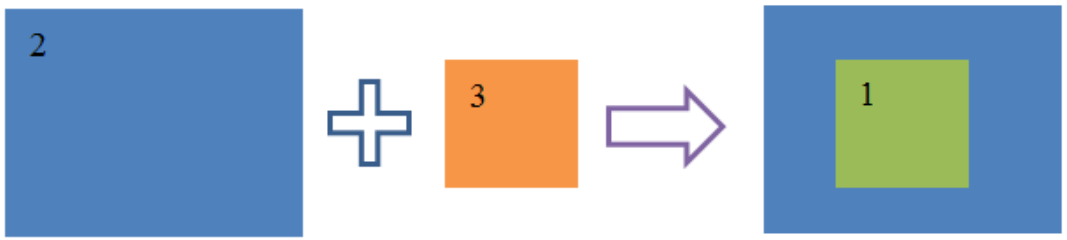
- Colorization of the dual-energy X-ray image implies the material information of the objects been imaged.

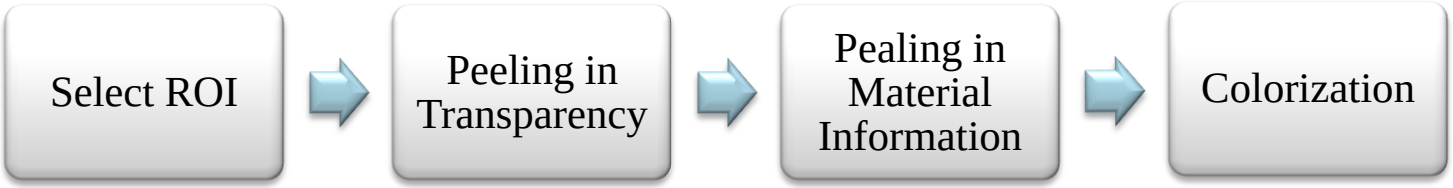
Multilayer Material Discrimination





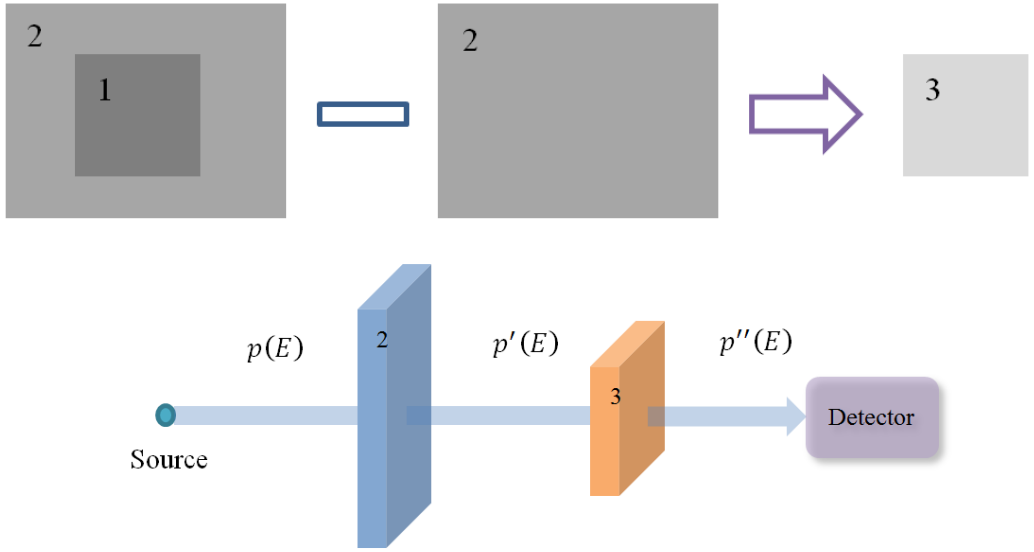
Multilayer Material Discrimination





- The procedure of multilayer material discrimination, within an area of uniform distribution.

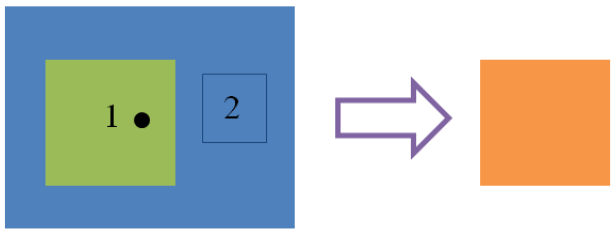
Peeling in Transparency

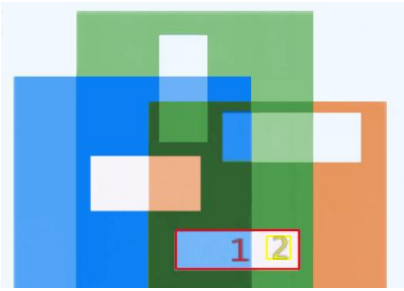


- The overall transparency from one ray path is equivalent to the cascade of transparencies from multi-layer materials.
- Number of layers can be determined by automatic local segmentation, or can be manually selected.

Peeling in Material Information

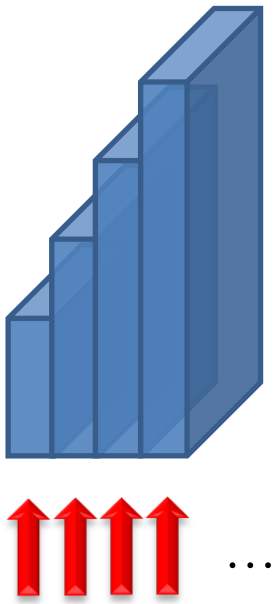
- **Slope Curve Method**
- **Beam Hardening Correction Method**





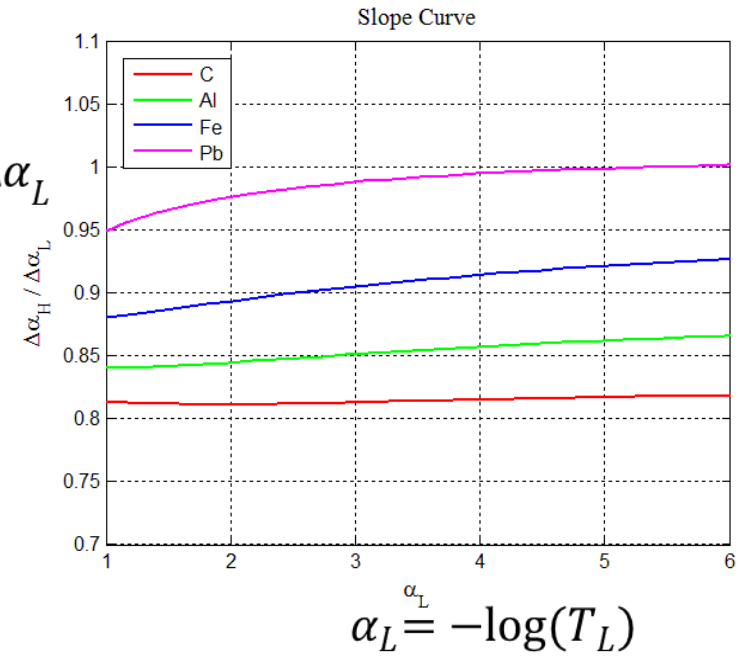
Peeling in Material Information

Slope Curve Method



…

$$k = \Delta\alpha_H / \Delta\alpha_L$$

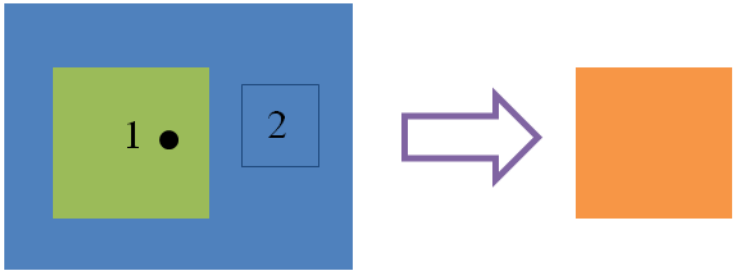


$$\alpha_L = -\log(T_L)$$

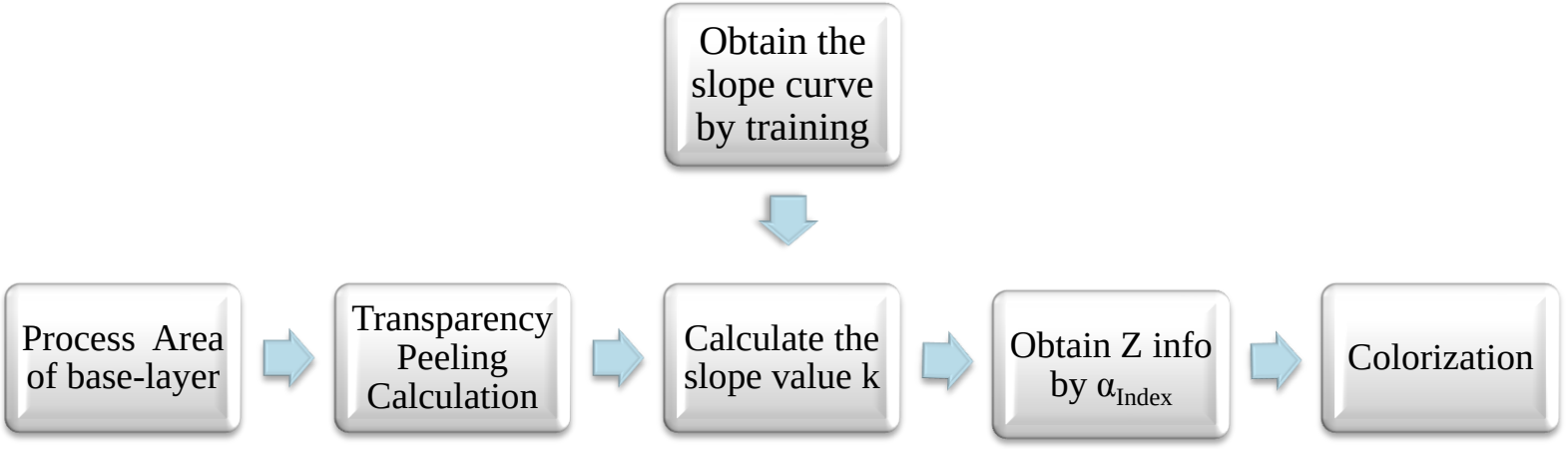
- The classification curve (R curve, etc.) can reflect the beam hardening effects.
- We obtain the slope curve by measuring the step-wedges of known thickness made of standard materials and calculating the slope value.

Peeling in Material Information

Slope Curve Method

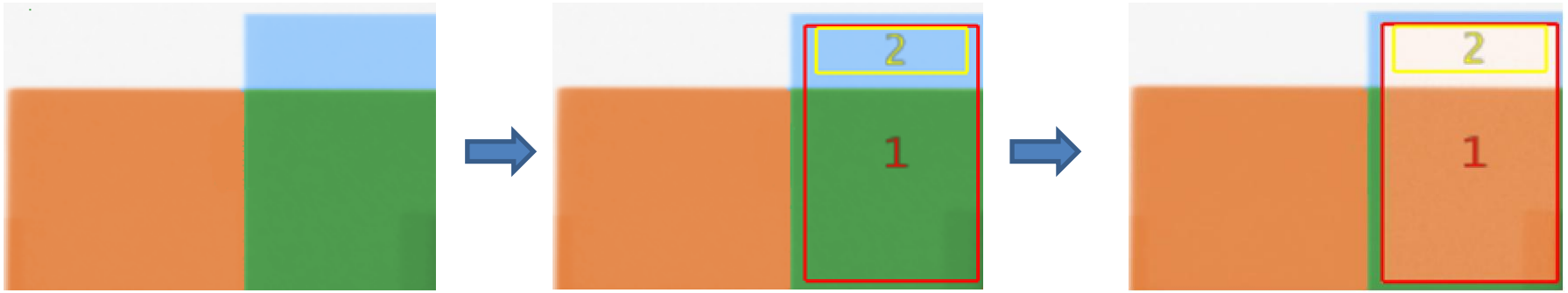


- Slop is from baseline of the material in base-layer
- Weighted combination of transparency



Peeling in Material Information

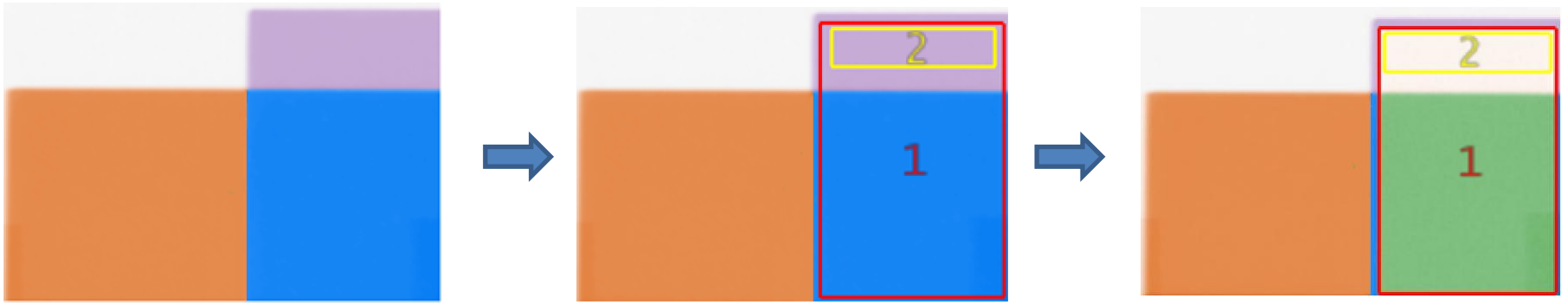
Slope Curve Method



- The experiment by placing the steel plate behind the graphite plate shows nice result using slope curve method.
- The look up index α_{Index} is calculated by using a weight factor, which is usually 0.2~0.4 by experience.

Peeling in Material Information

Slope Curve Method

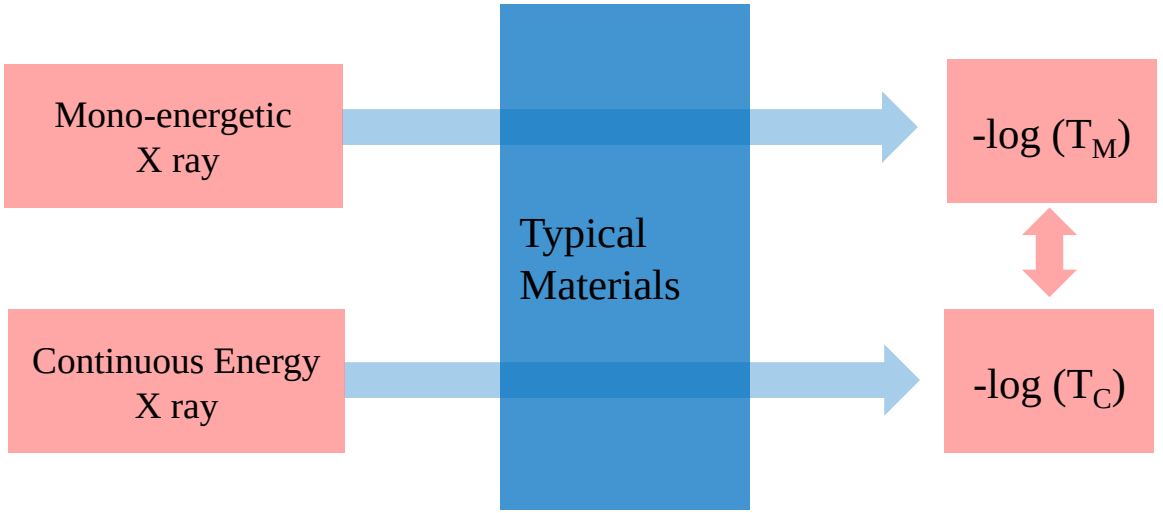


Partially peeled

- Experiment by placing the lead plate behind the graphite plate, the peeling result turns green.

Peeling in Material Information

Beam Hardening Correction Method

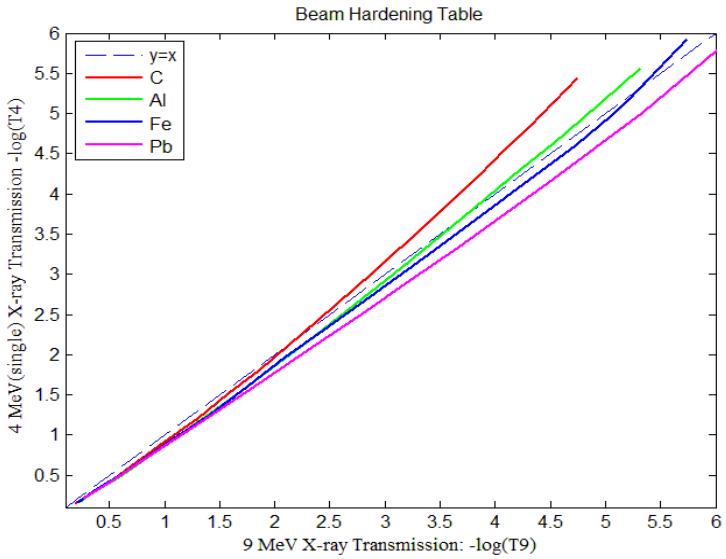


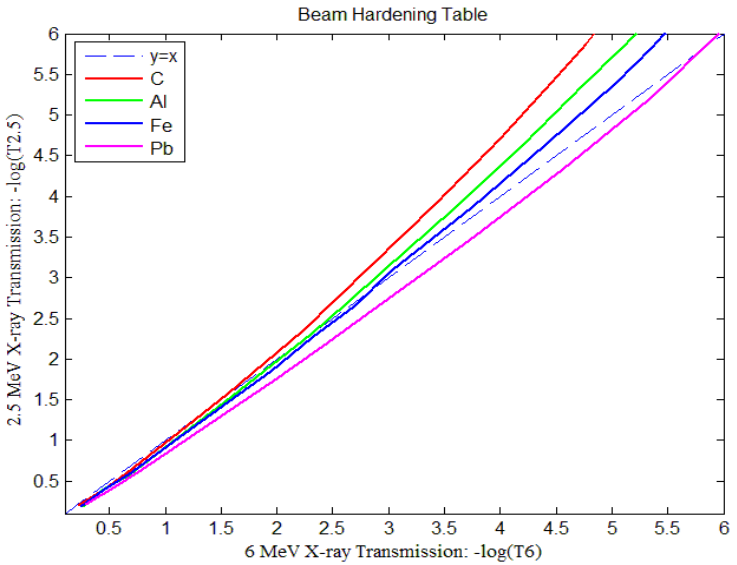
The Beam Hardening Table (BHT)

- With the continuous energy spectrum X-ray and chosen mono-energetic X-ray associated by mapping their transparencies, the beam hardening effect will be corrected.

Peeling in Material Information

Beam Hardening Correction Method

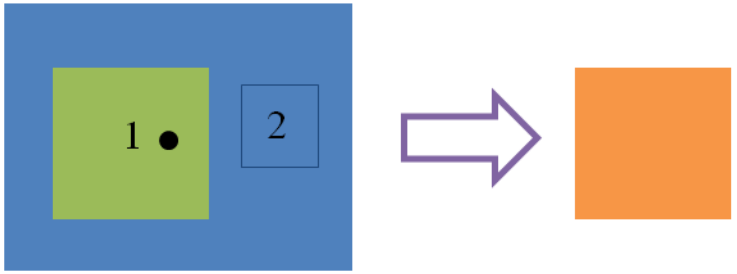


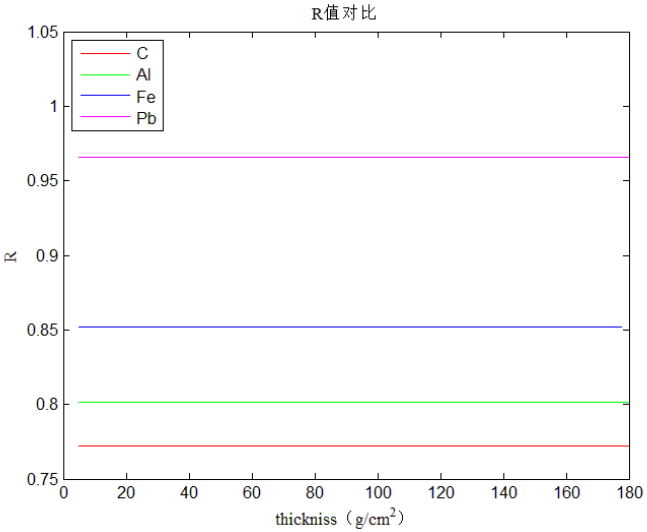


- Each material has its own beam hardening table, use certain table according to the dual-energy material discrimination results.
- Select a corresponding mono-energy X-ray for the mapping. Here we use mono-energetic 4/2.5MeV system to map the continuous energy 9/6MeV system.
- The R value after beam hardening correction will be independent from mass thickness.

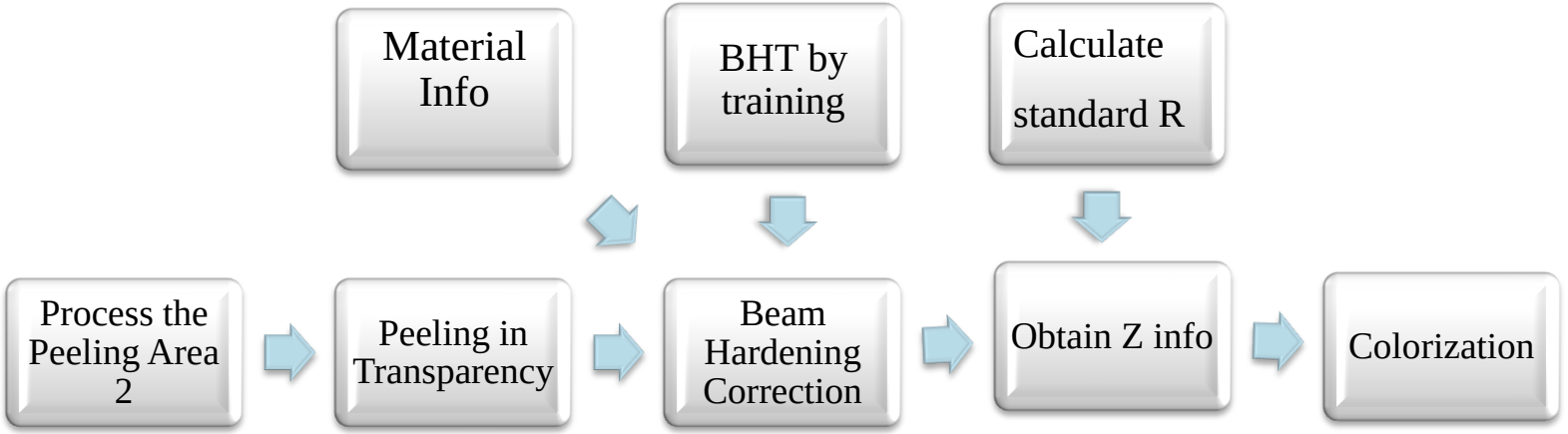
Peeling in Material Information

Beam Hardening Correction Method



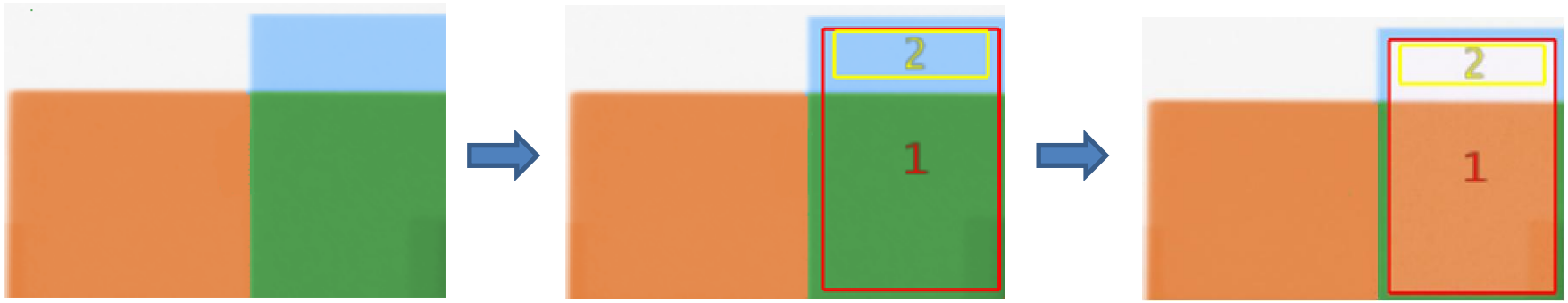


- Slop index from baseline of material 2



Peeling in Material Information

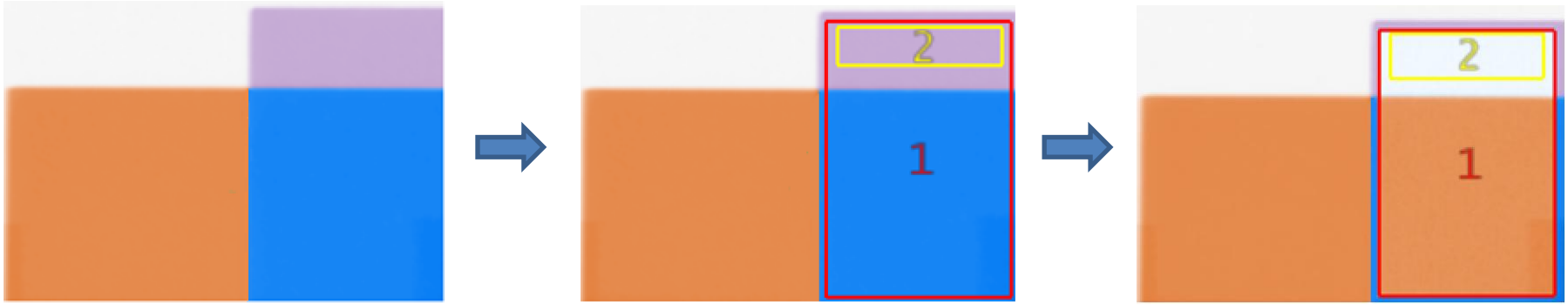
Beam Hardening Correction Method



- The experiment by placing the steel plate behind the graphite plate shows nice result using beam hardening correction method.

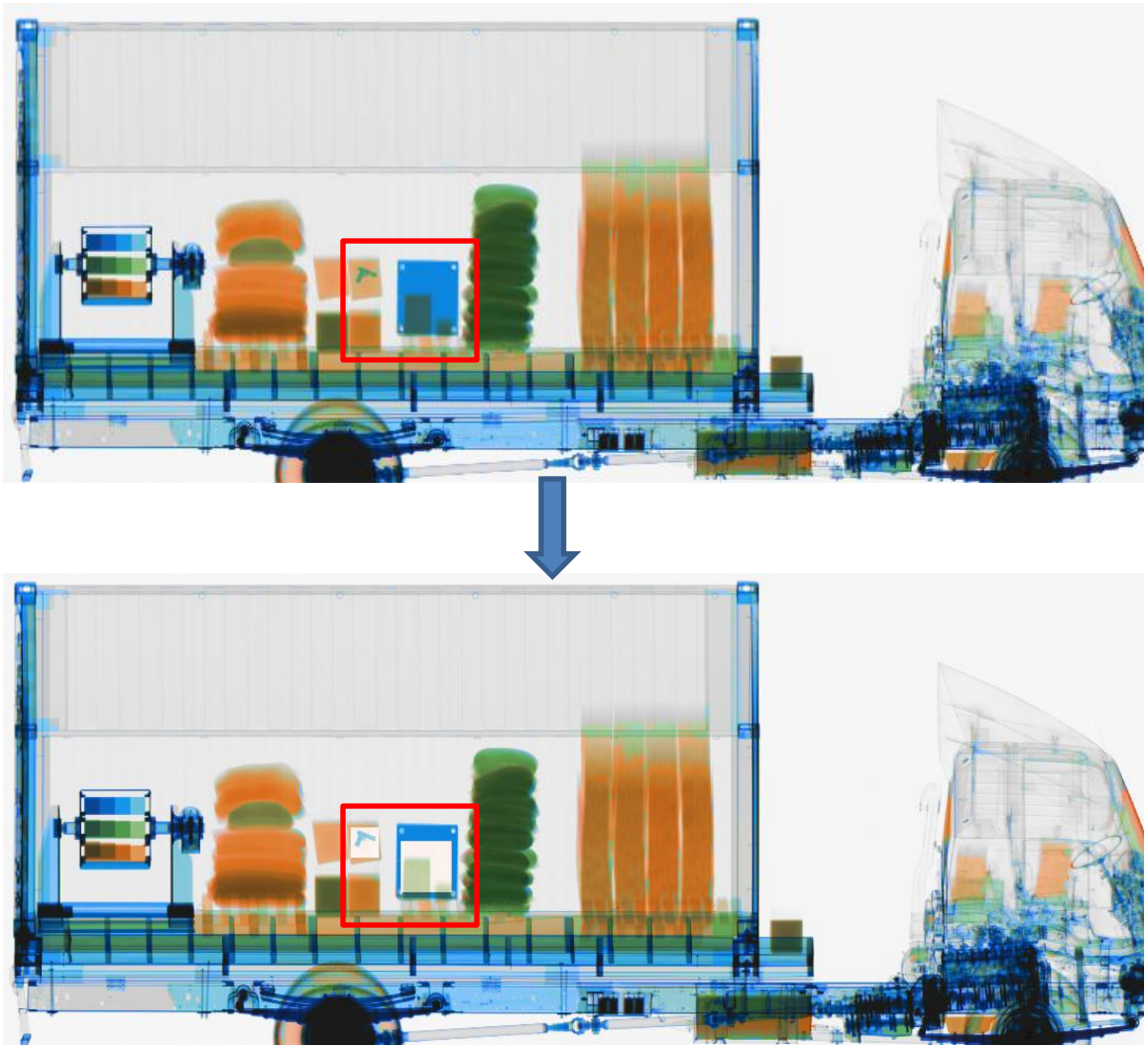
Peeling in Material Information

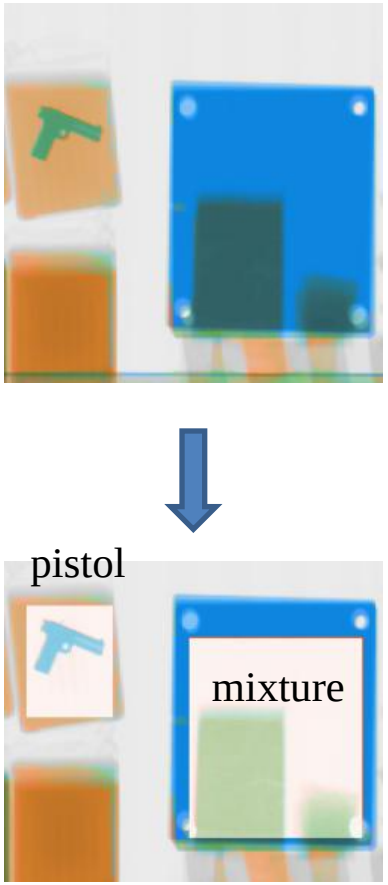
Beam Hardening Correction Method



- The experiment by placing the lead plate behind the graphite plate also shows nice result using beam hardening correction method.

Multilayer Material Discrimination

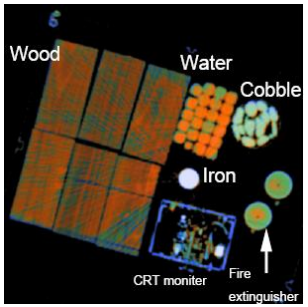


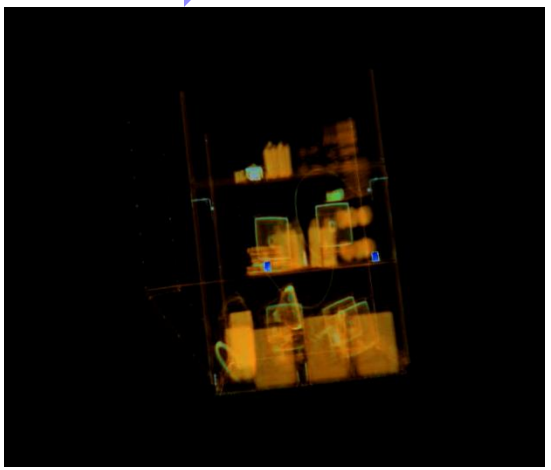


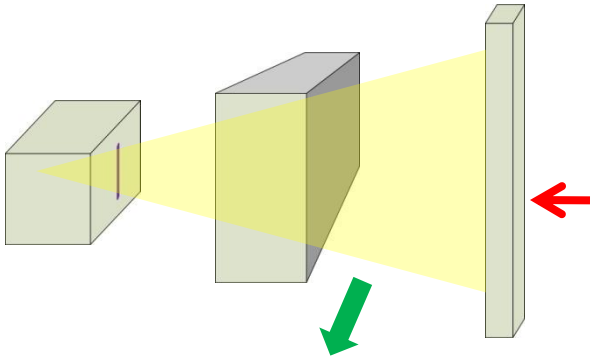
Multilayer processing in ROI

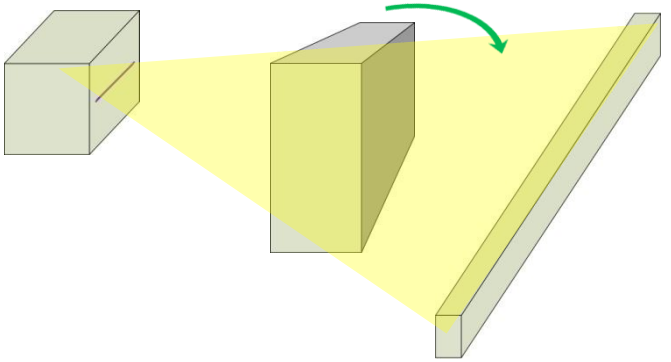
A Comprehensive Solution

Increasing accuracy





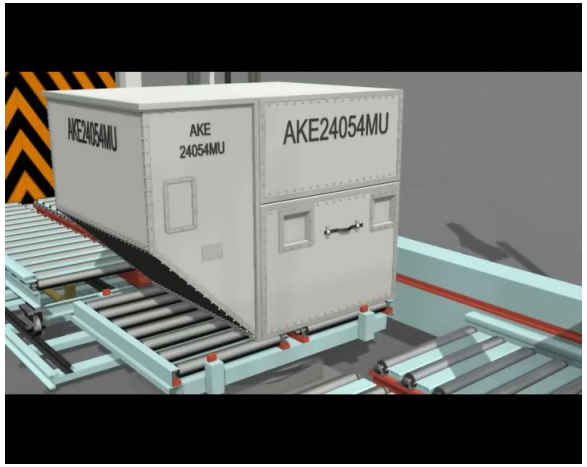


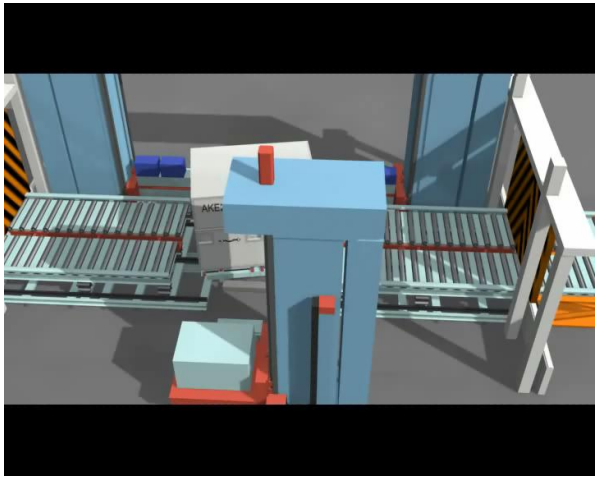


Dual Energy Scanning → ROI: Multilayer Discrimination → Dual-Energy CT

Discussion

- Dual-energy information provides us material discrimination capability.
- Radiographic images are of limited accuracy in the inspections. Overlapping of multiple objects are common situations. Multilayer material “peeling” can check materials layer by layer within a region of interest.
- A comprehensive solution for performance optimization would be dual energy Radiography (Speed) + conditional CT (accuracy).





Thank you !

- This work is supported by NUCTECH. com
- All data are provided by NUCTECH.com