François Vander Stappen (IBA)

Monte Carlo simulations
applied to food irradiation

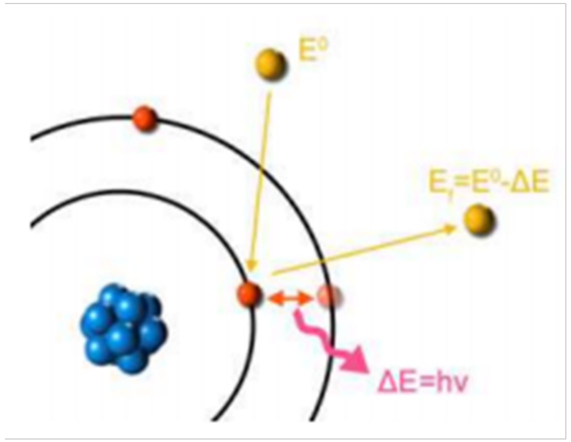
Outline

- Why do we need Monte Carlo ?
  ➔ a bit of physics
- How does it work & available tools
- Practical example: apple pallet
- Results

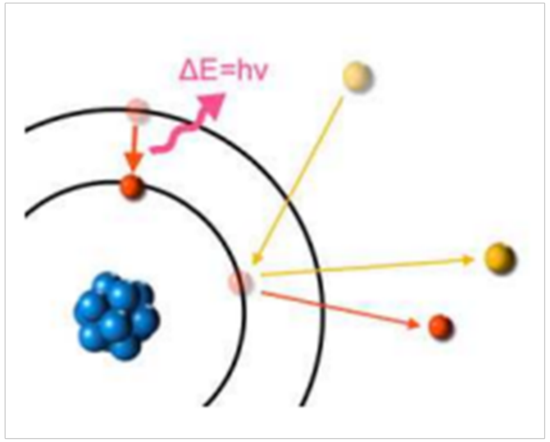
Particle–matter interactions: electrons

Collisions

Excitation

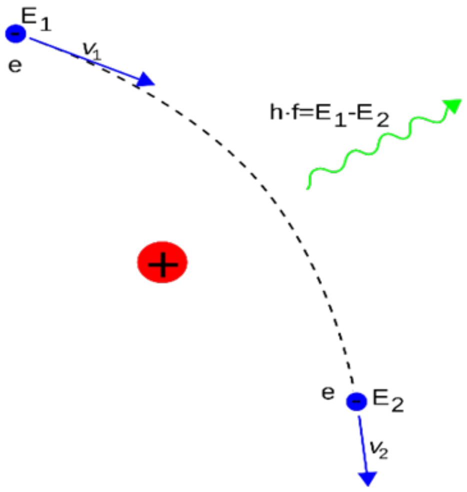


Ionisation



Secondary electron emission

Bremsstrahlung

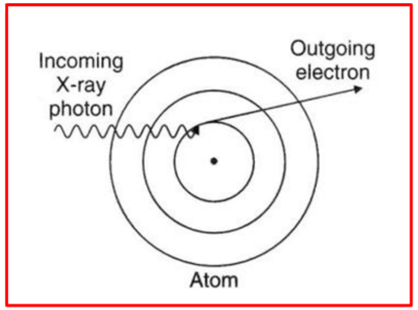


➔ Energy (dose) deposition

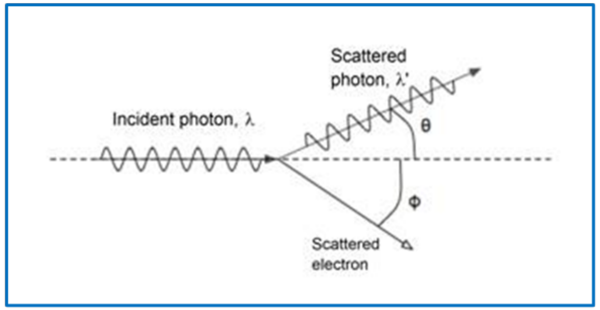
➔ X-ray production

Particle–matter interactions: photons

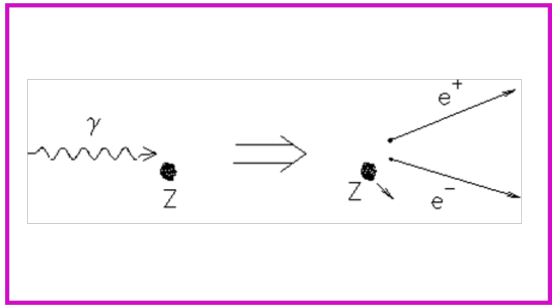
Photoelectric effect



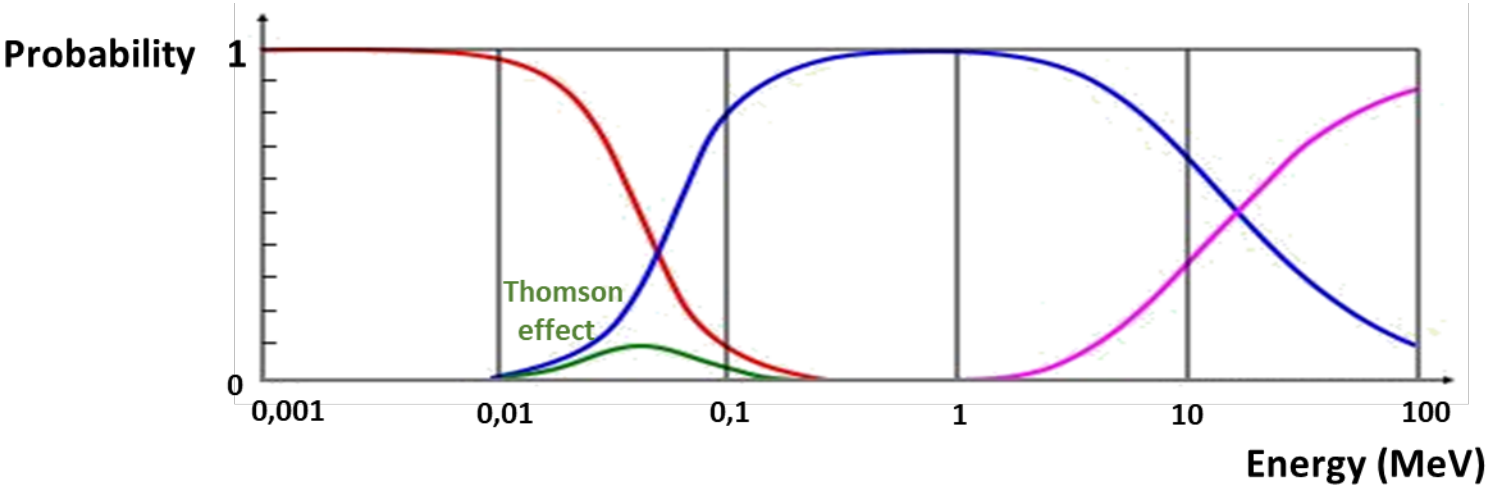
Compton effect

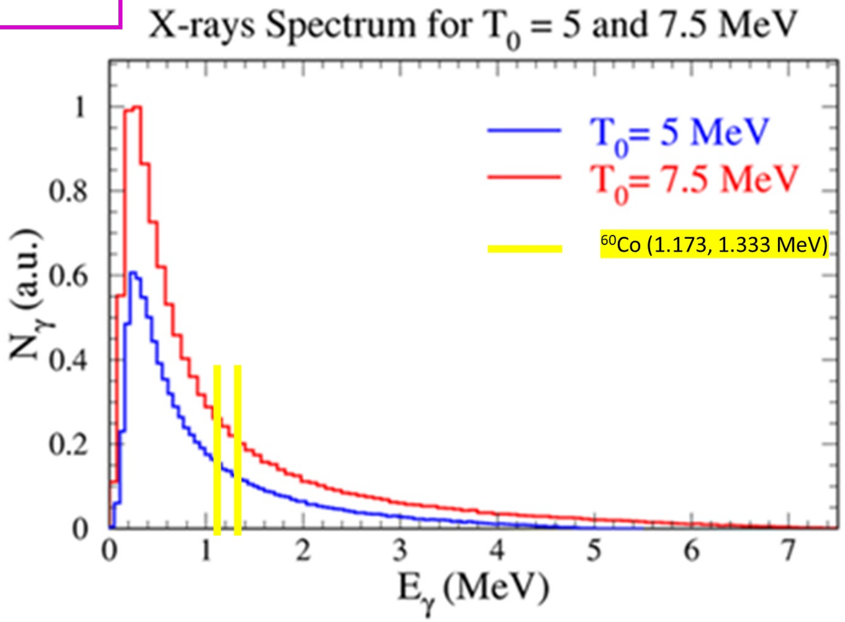


Pair production



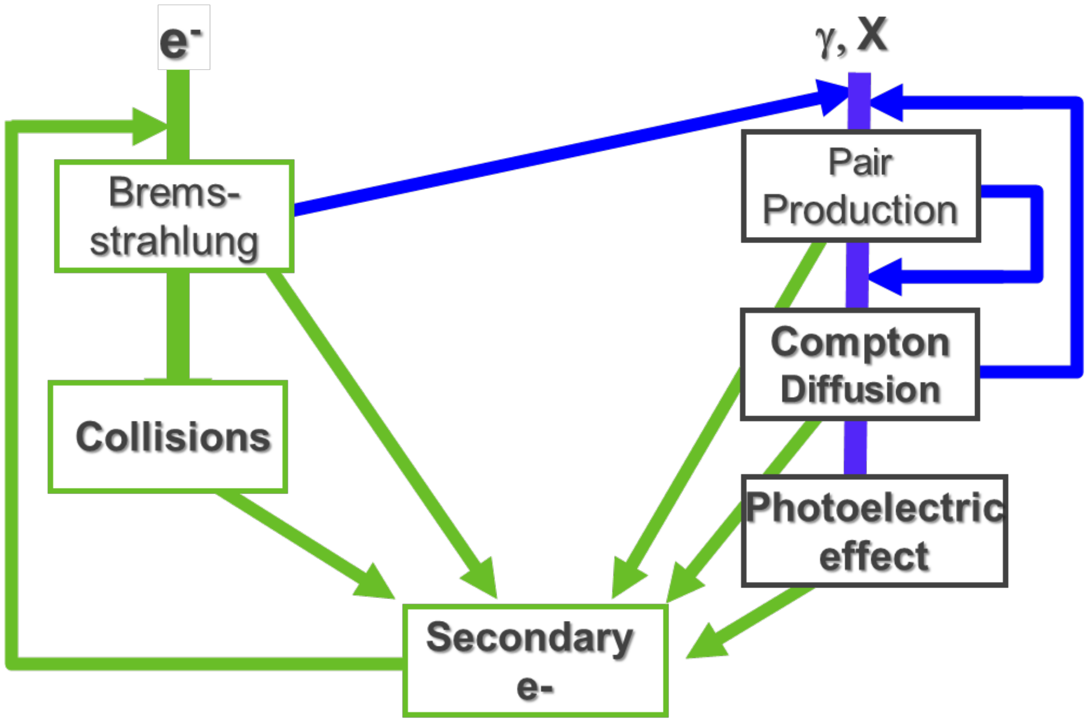
e- emission



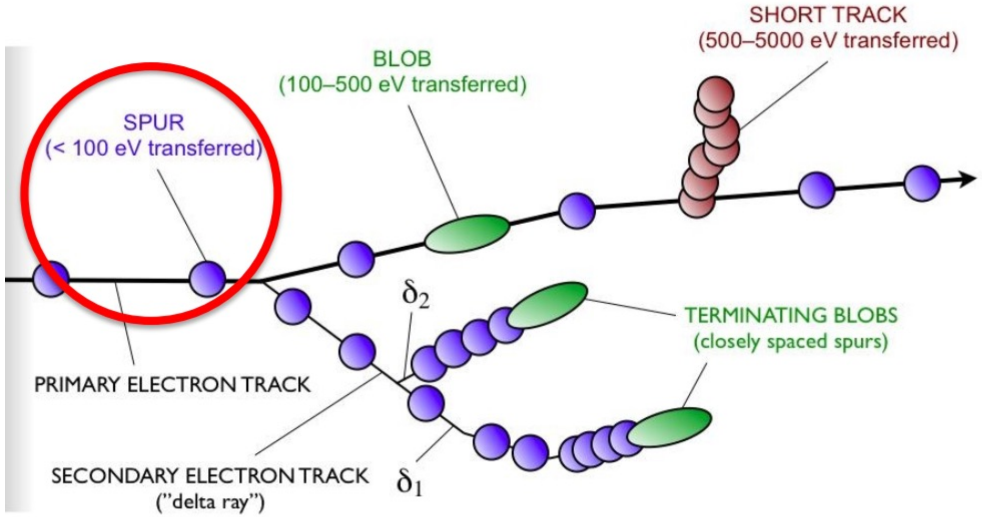


➔ **Compton scattering dominates**

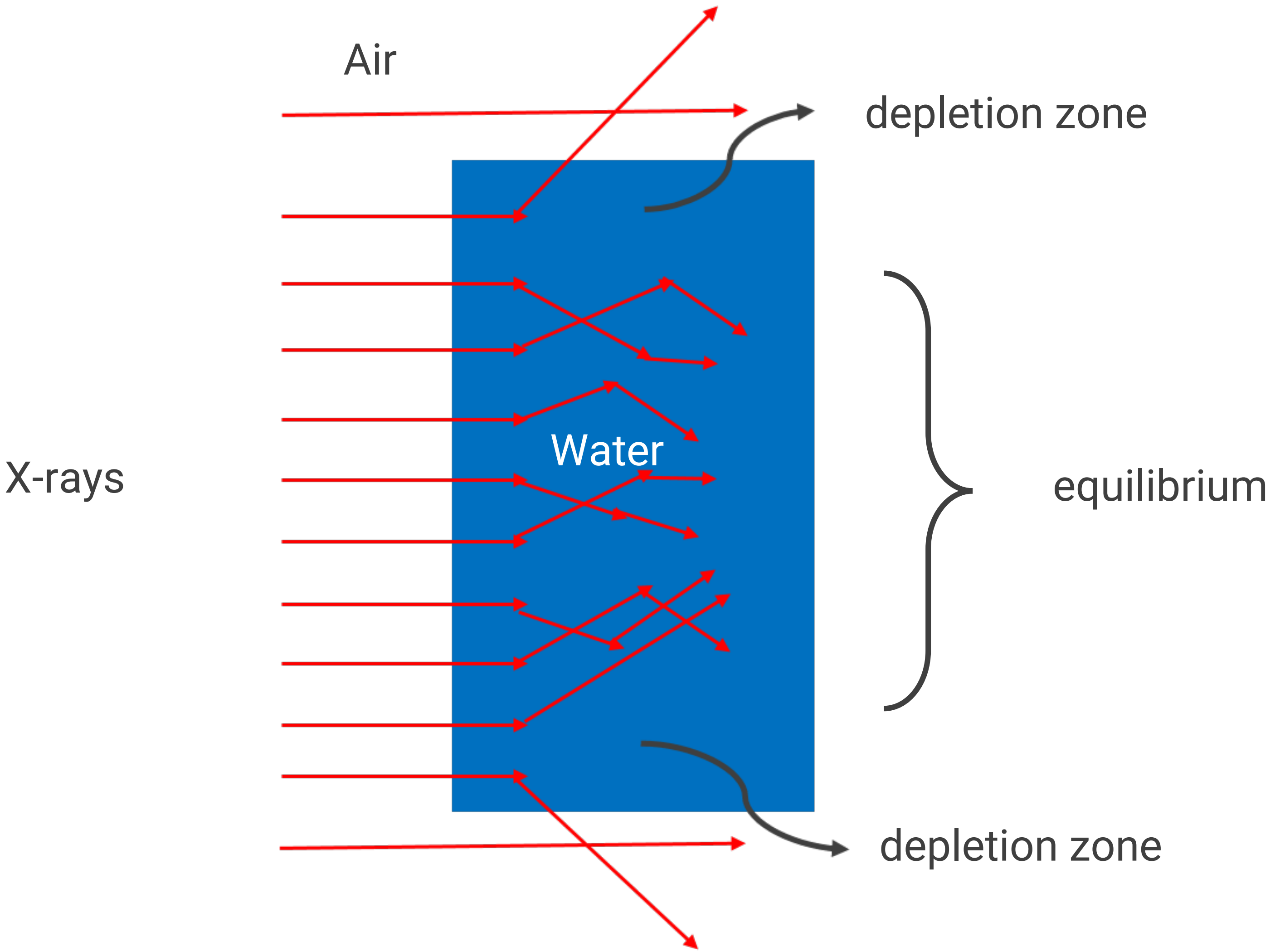
Particle–matter interactions: e- and photons



Final dose deposition mainly by very low energy electrons, in SPURS and BLOBS



Particle-matter interactions: edge effect



Principle of Monte Carlo simulation

Based on randomness

- Generate source particles
- Follow their tracks one by one
- Simulate interactions with matter based on the model and physics tables
- Generate secondaries
- Follow secondaries the same way
- Save & output selected physical values

  ➔ energy (dose) deposition in specified volumes

Monte Carlo simulations: the main actors

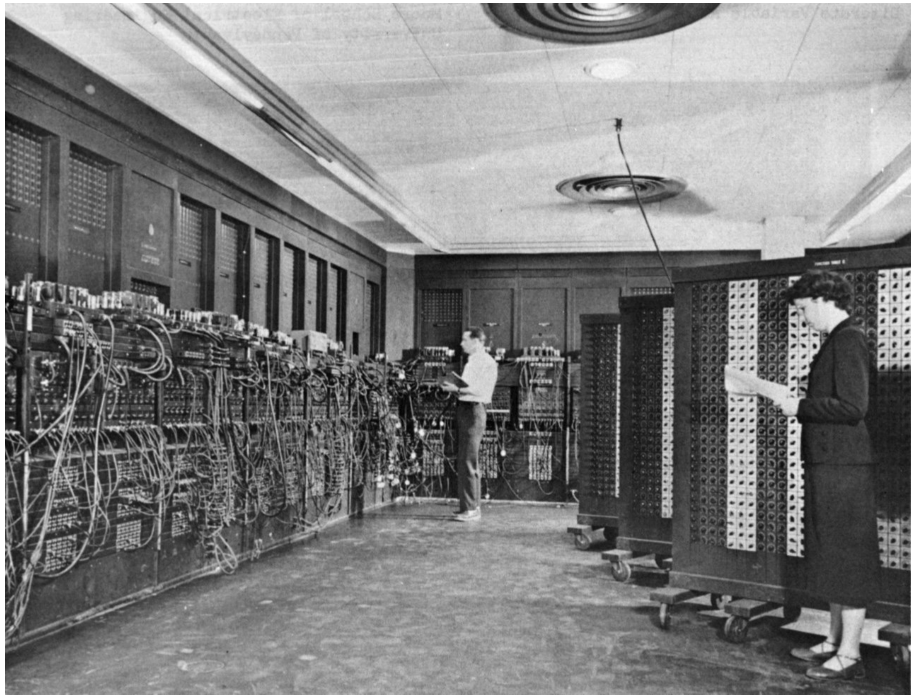
Closed Source
Free use
Controlled access

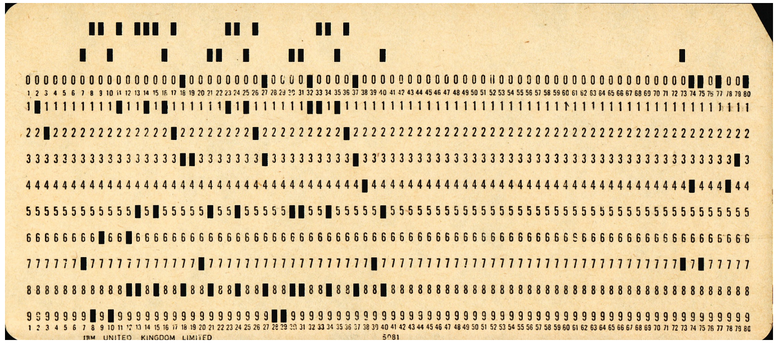
Open Source

Open Source

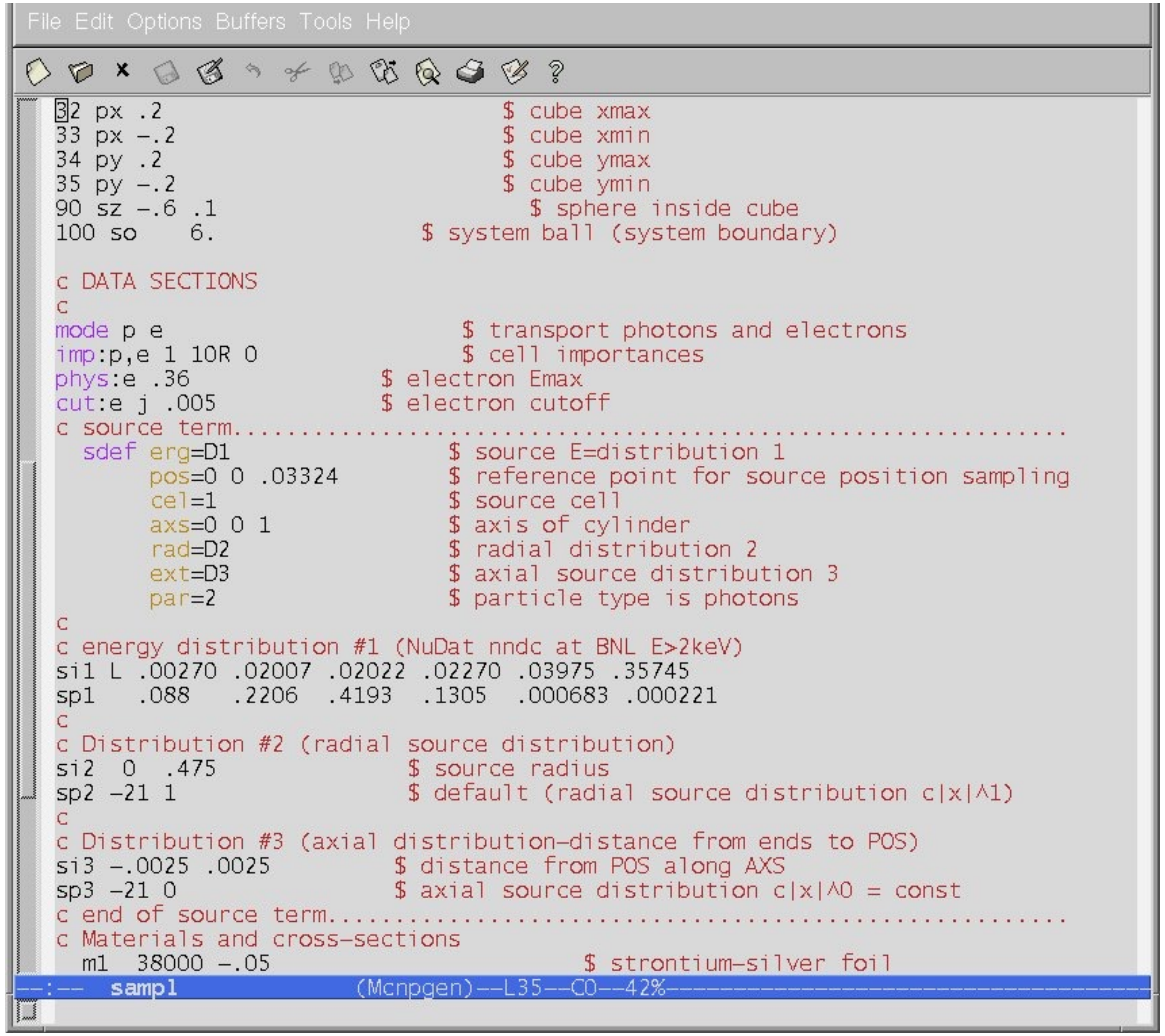
Commercial

MCNP: since 1946-1948



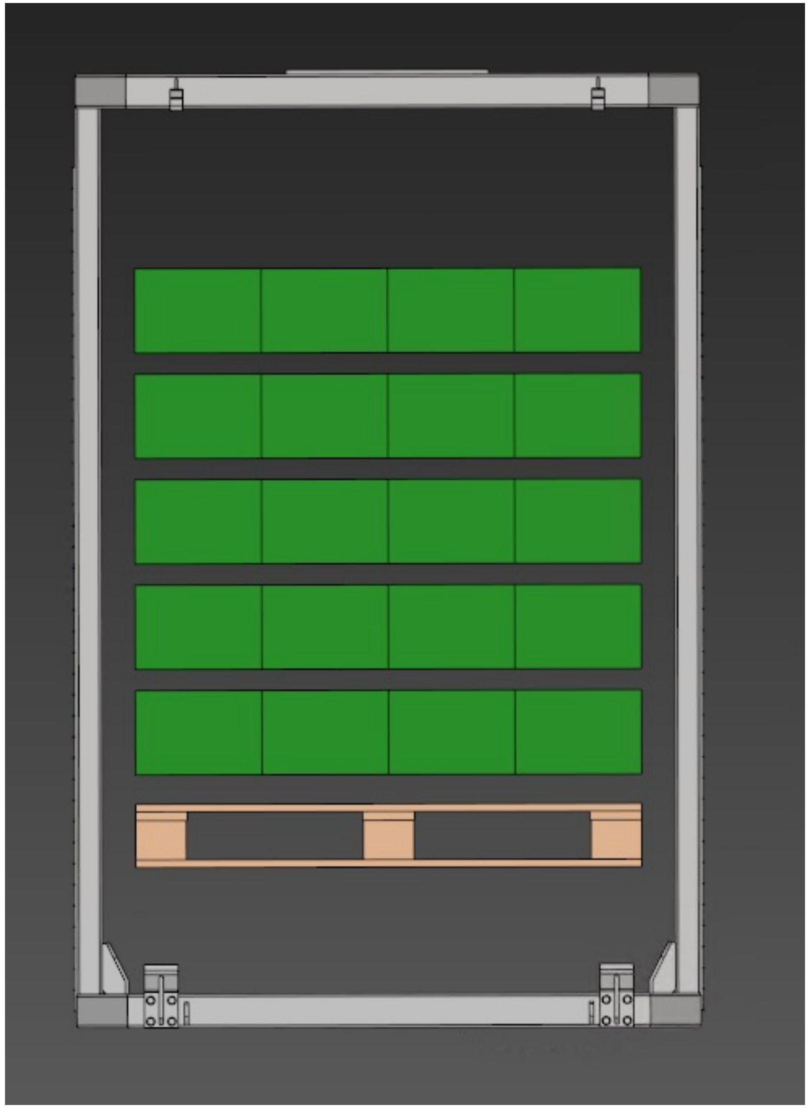


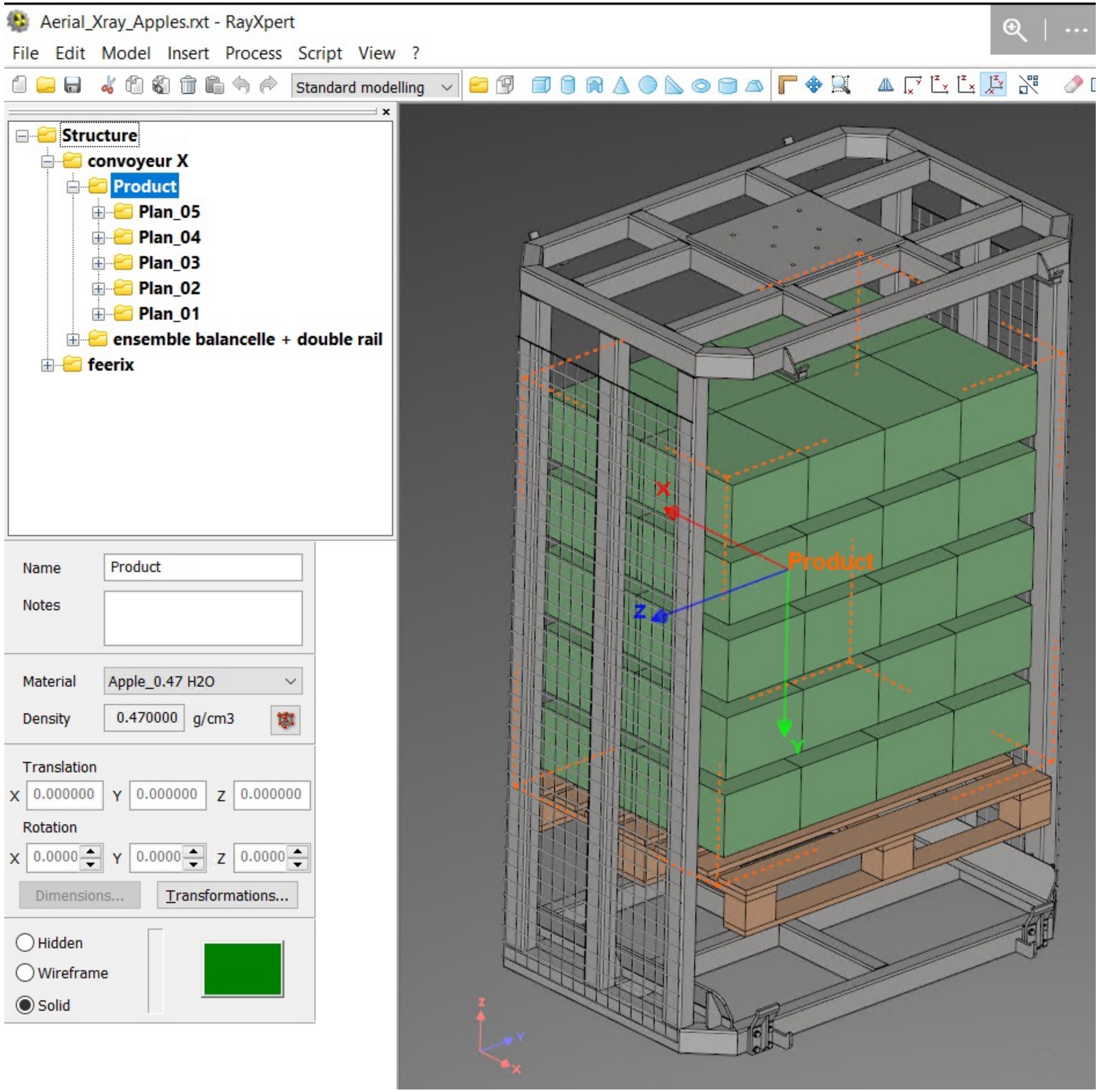
Fortran 90

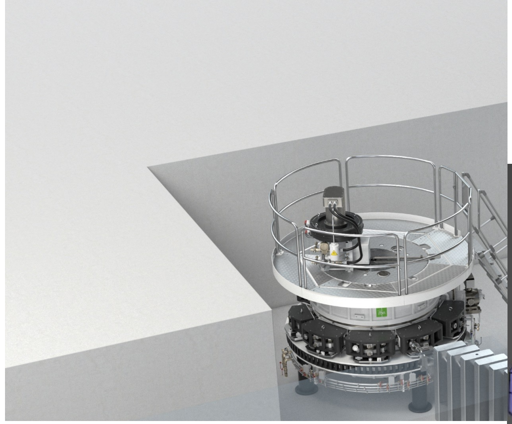


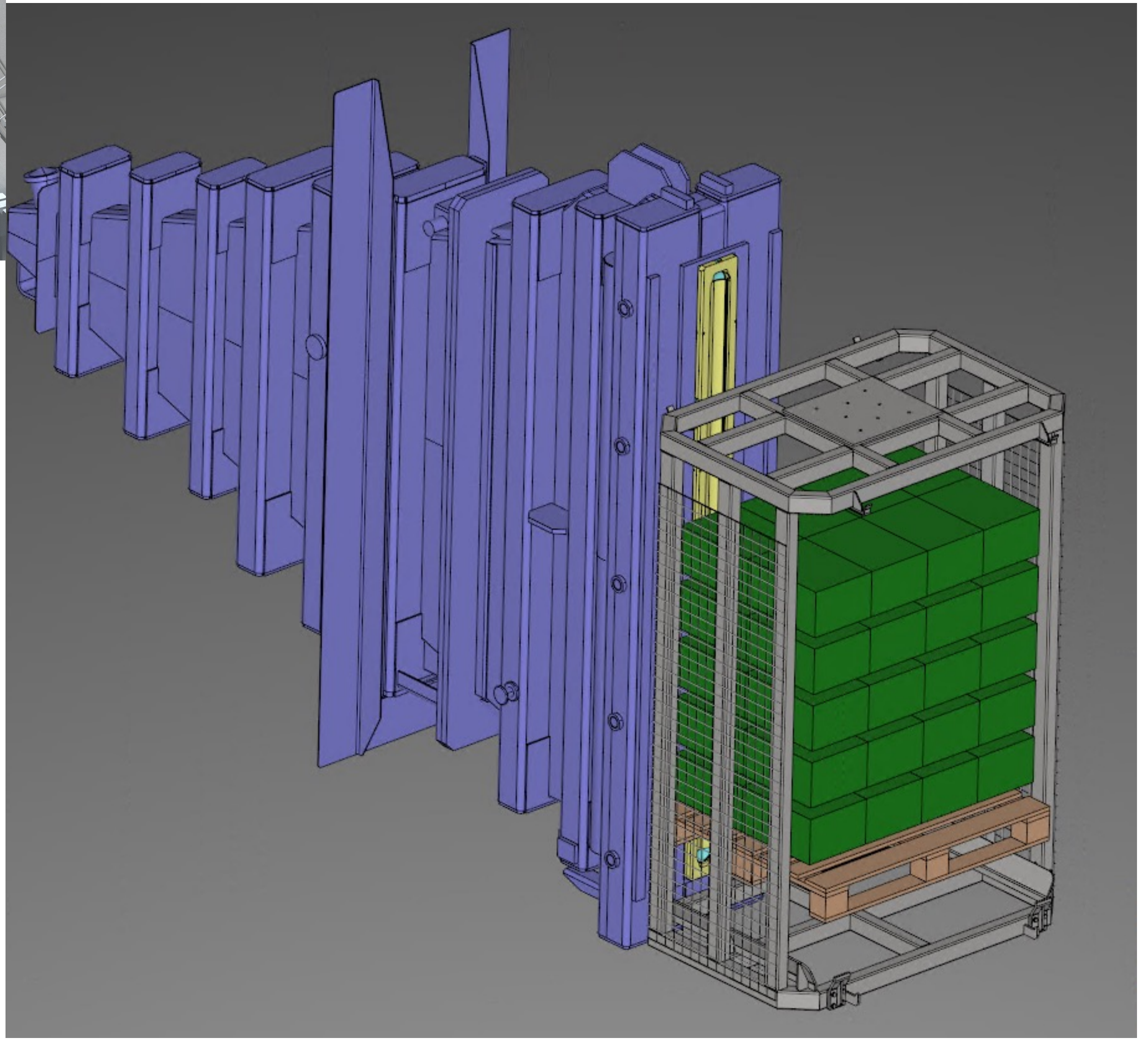
RayXpert: accessibility for everyone

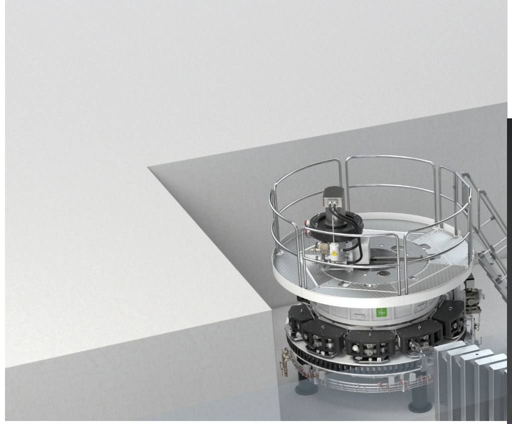
modelisation

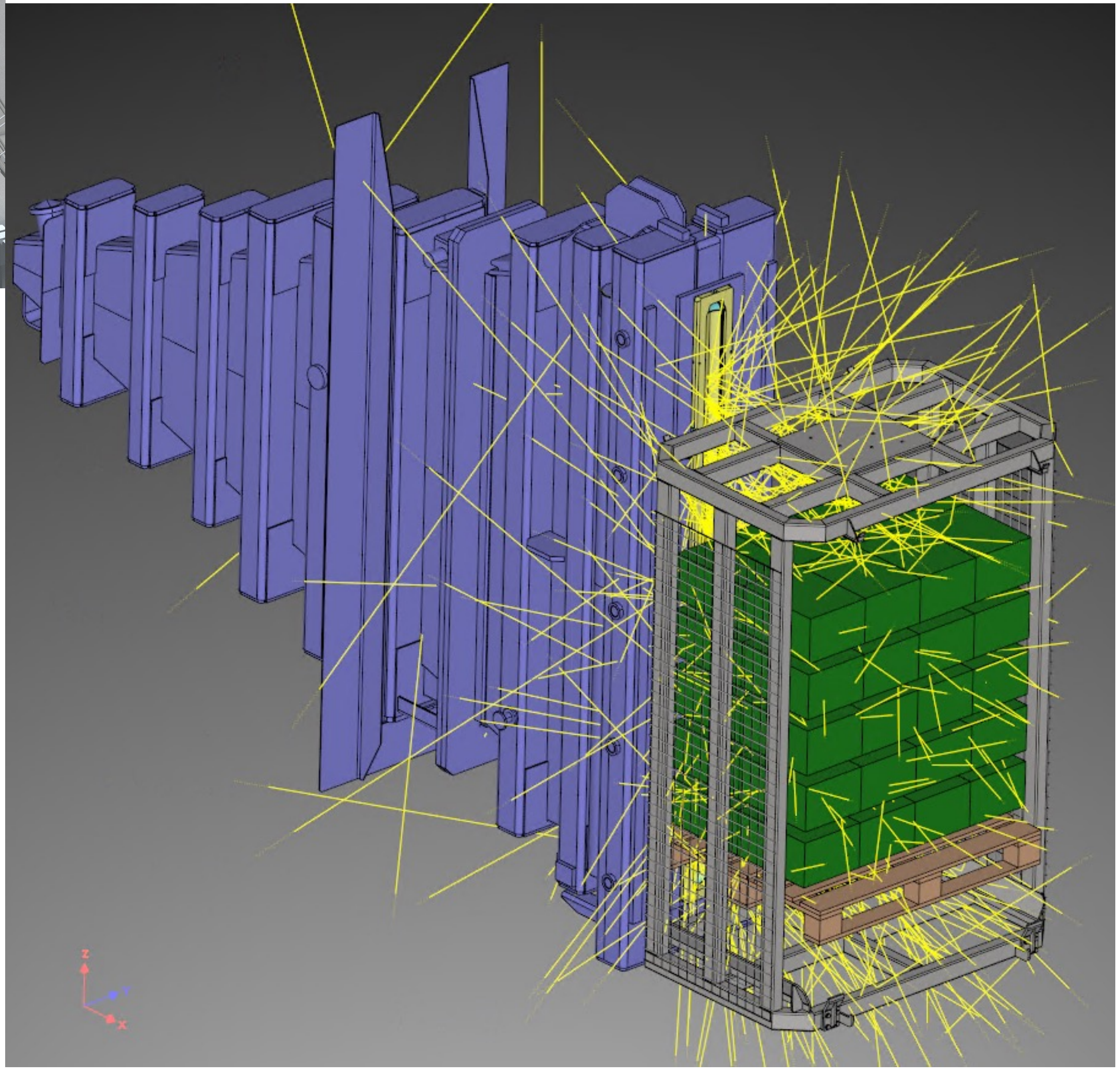


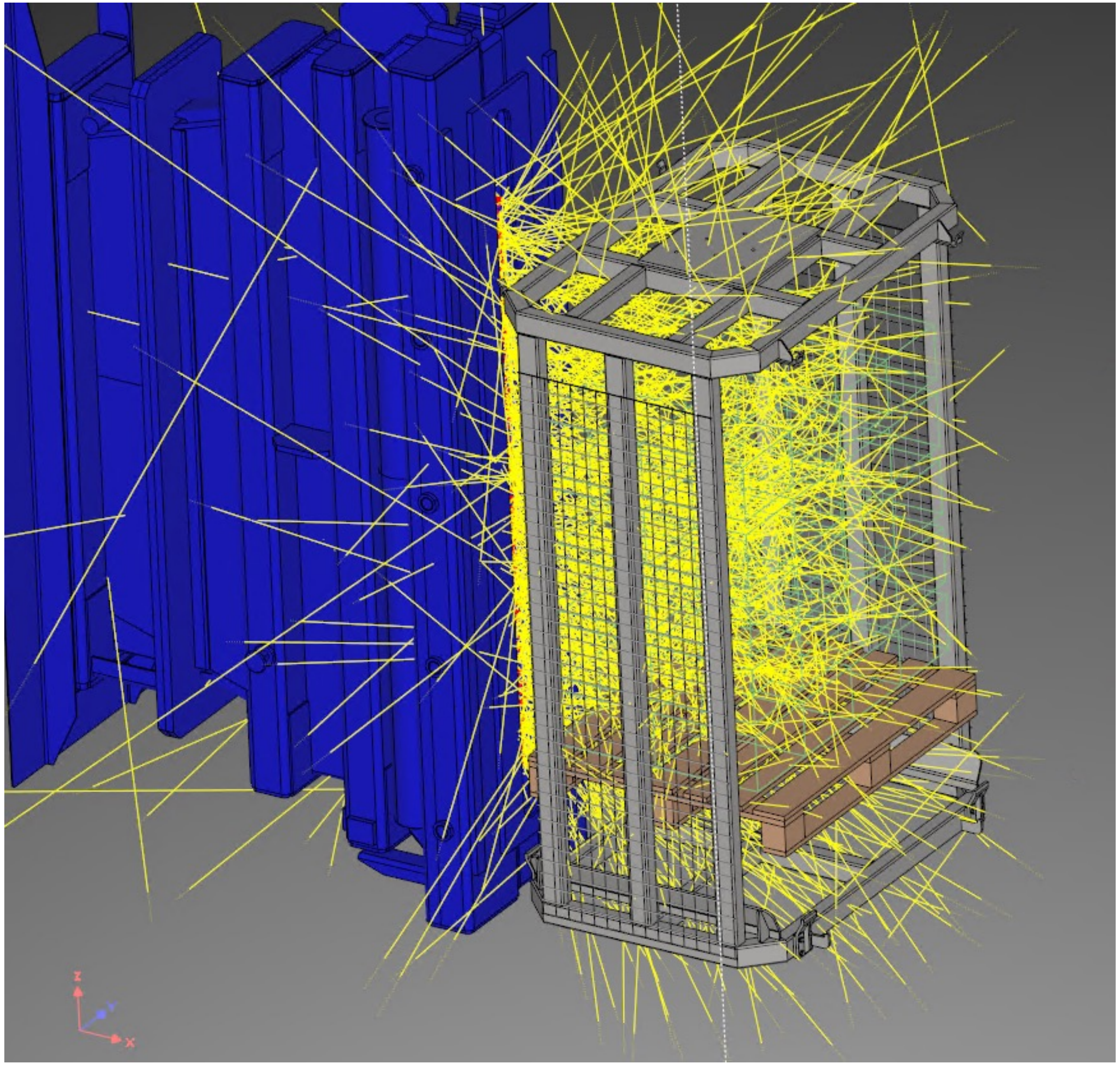

Aerial_Xray_Apples.rxt - RayXpert
File Edit Model Insert Process Script View ?
Standard modelling
Structure
convoyeur X
Product
Plan_05
Plan_04
Plan_03
Plan_02
Plan_01
ensemble balancelle + double rail
feerix
Name
Product
Notes
Material
Apple_0.47 H2O
Density
0.470000
g/cm3
Translation
X 0.000000 Y 0.000000 Z 0.000000
Rotation
X 0.0000 Y 0.0000 Z 0.0000
Dimensions...
Transformations...
Hidden
Wireframe
Solid
Product

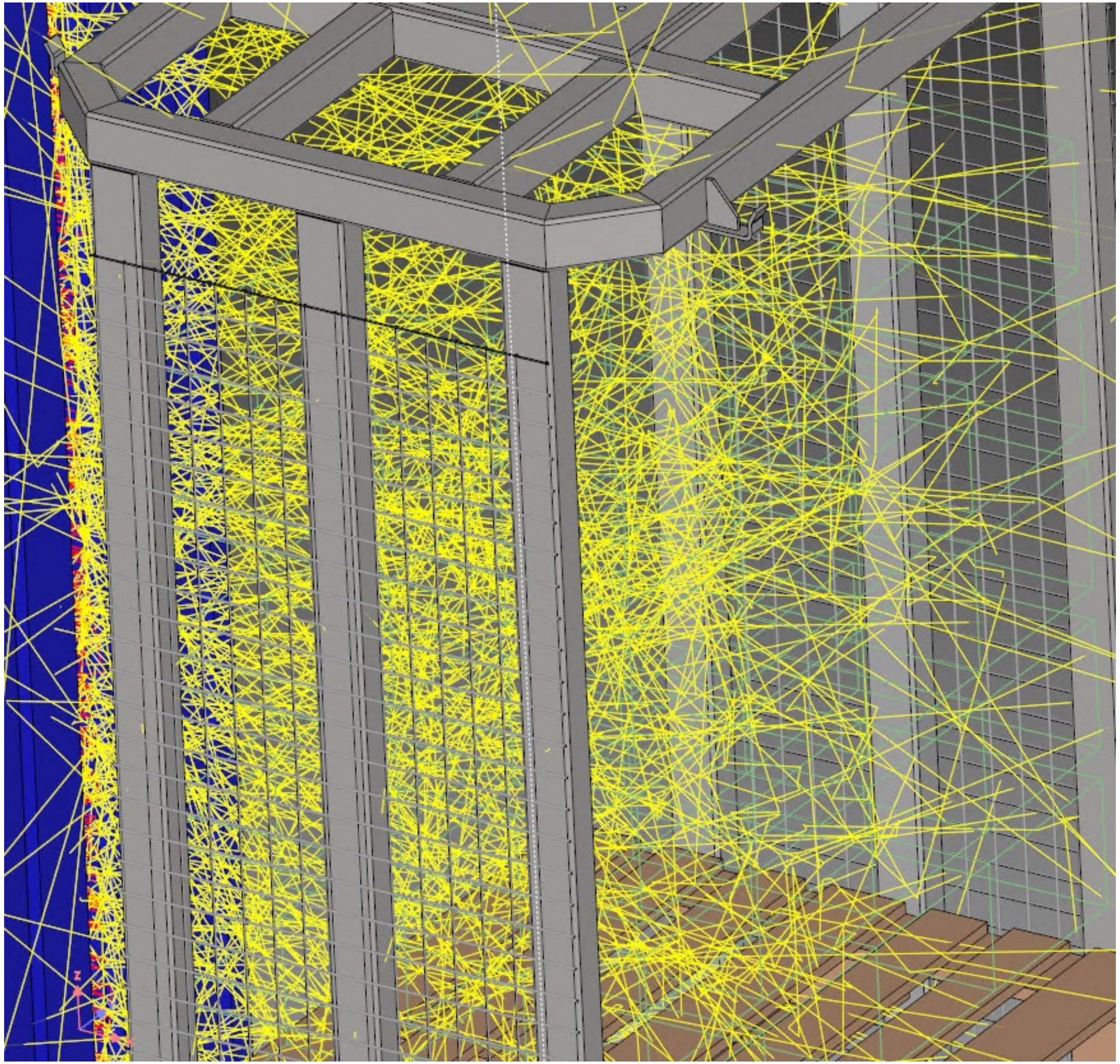


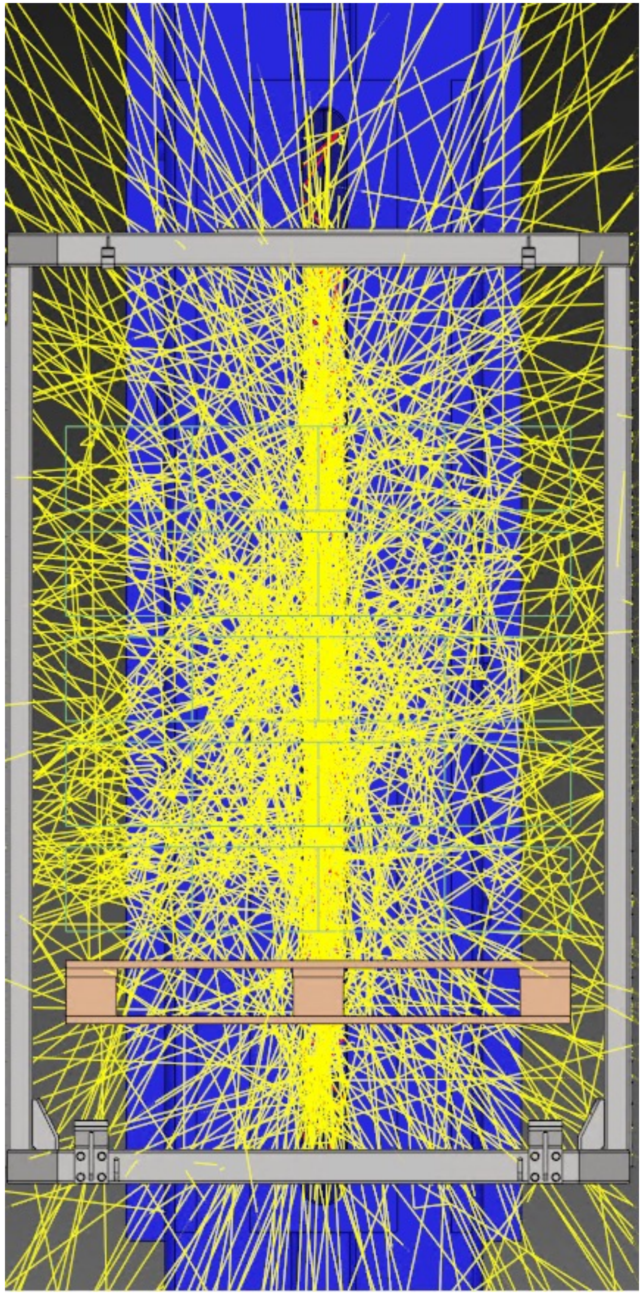


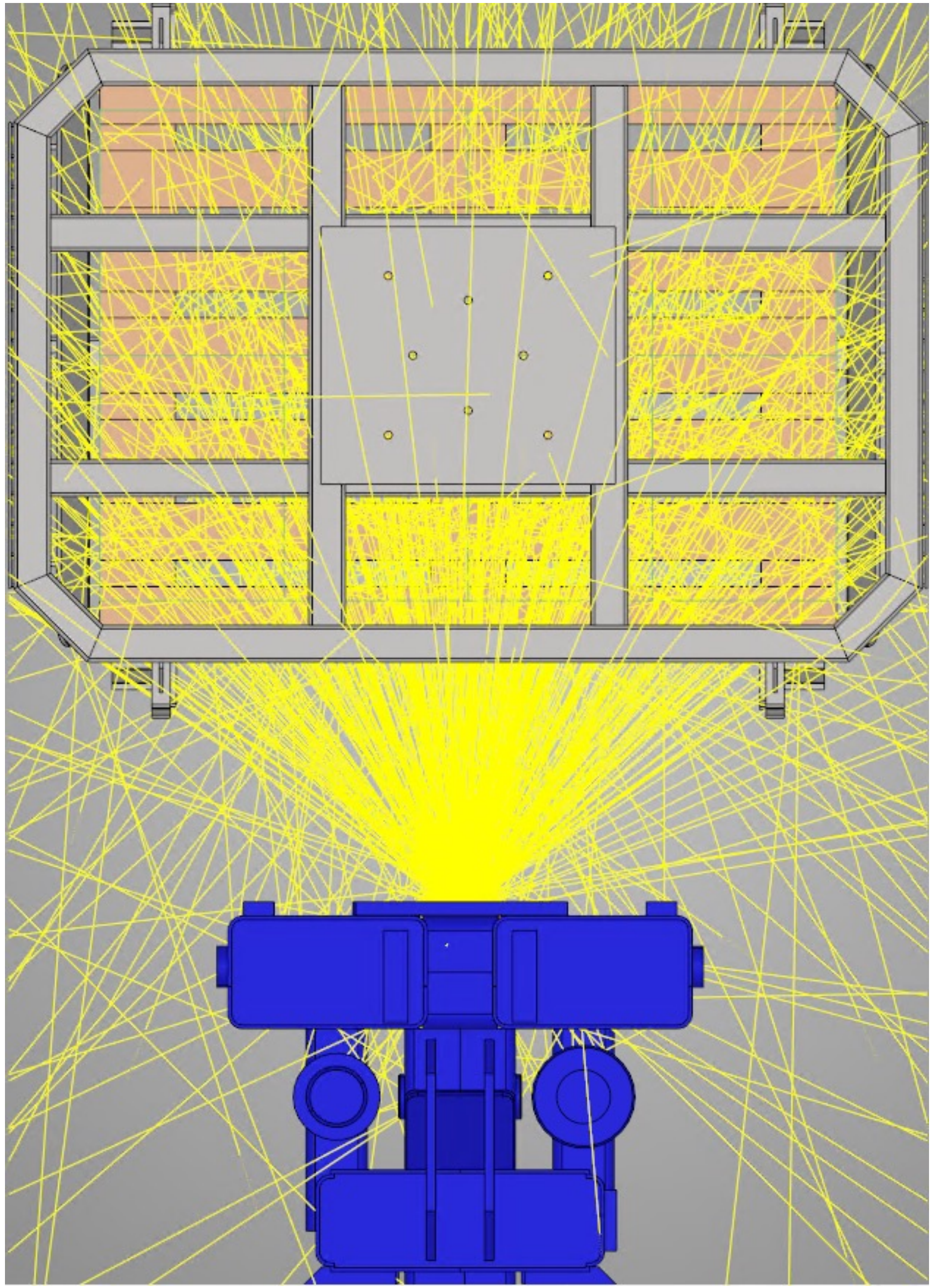




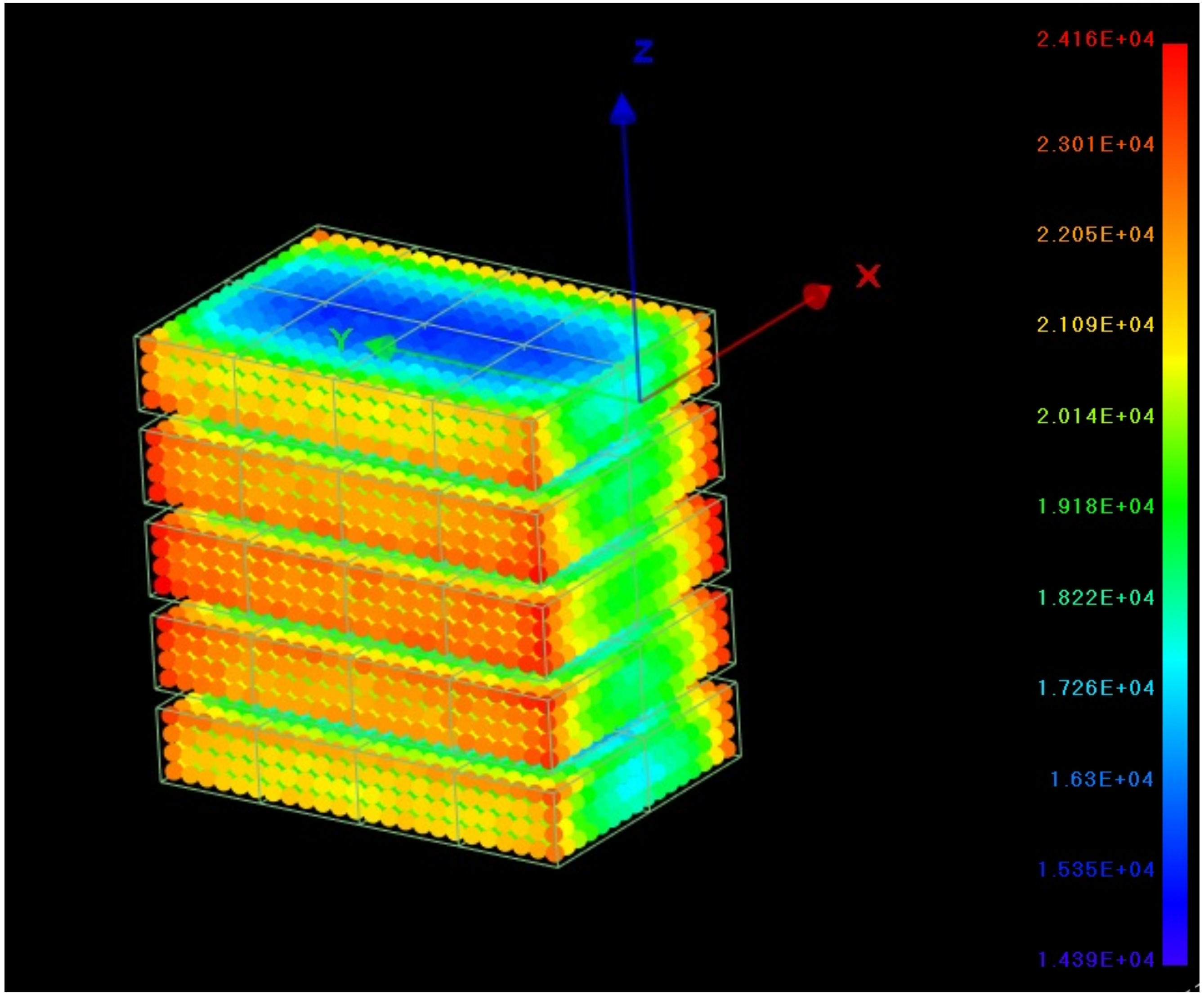




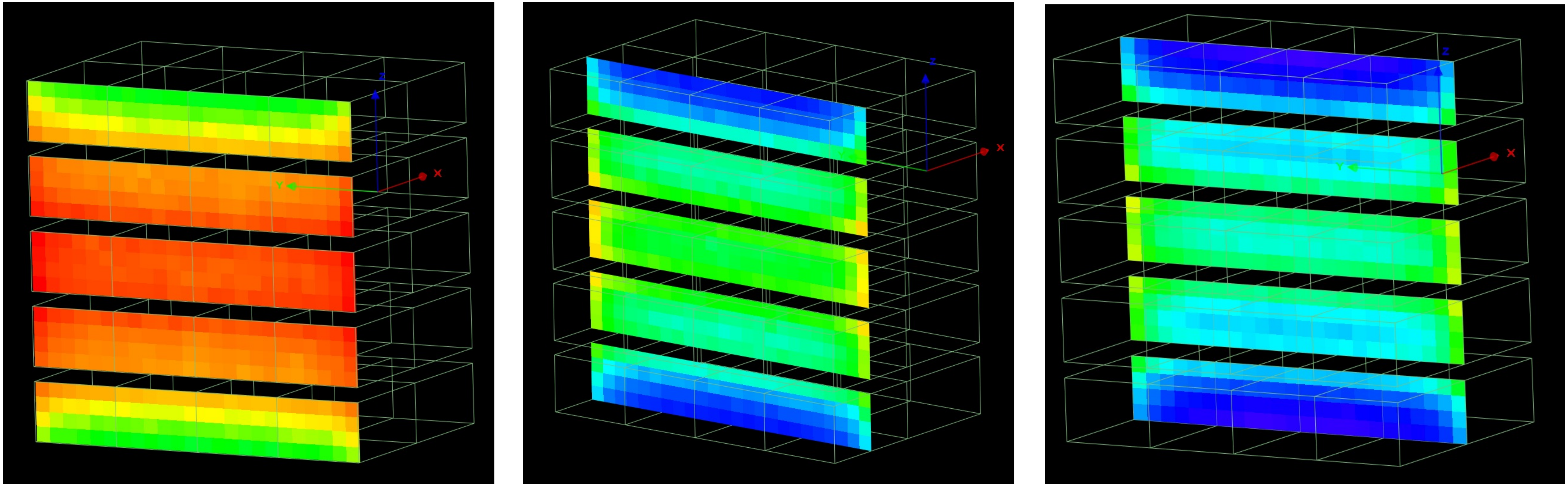




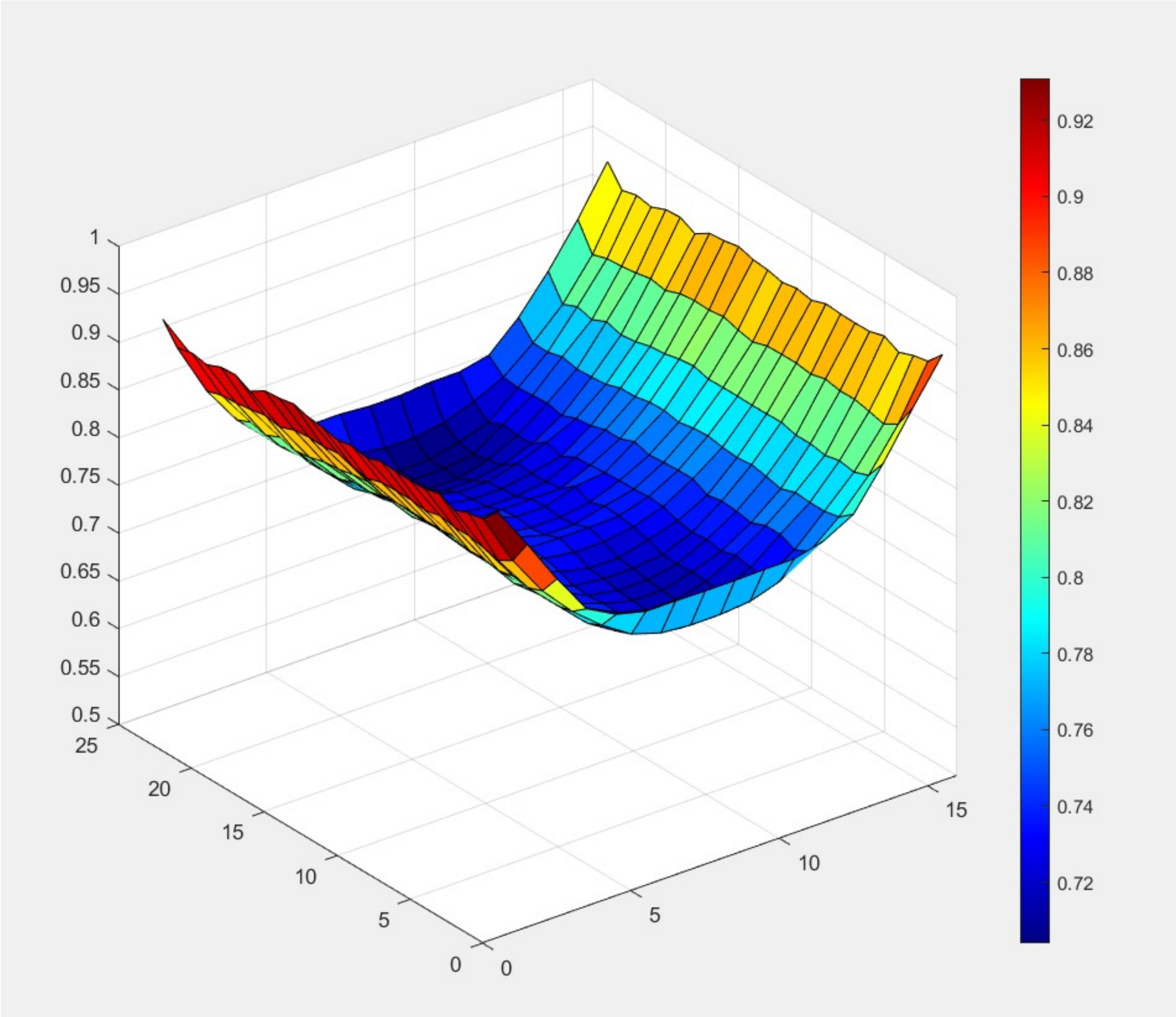
Output: 3D map of dose deposition



Output: 2D planes



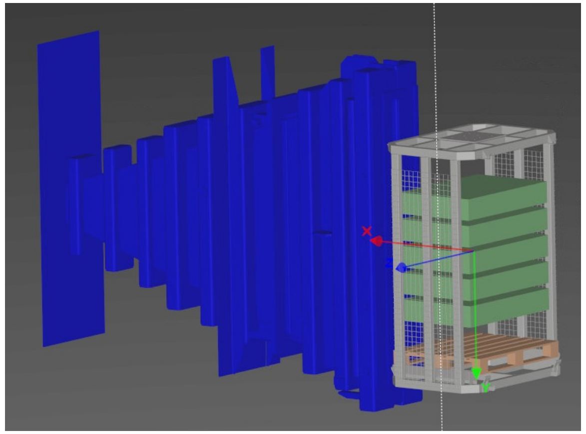
Output: export to any data manipulation tool



DUR (max/min) = 1.68

How well does it fit reality ?

Simulations
MCNP + RayXpert

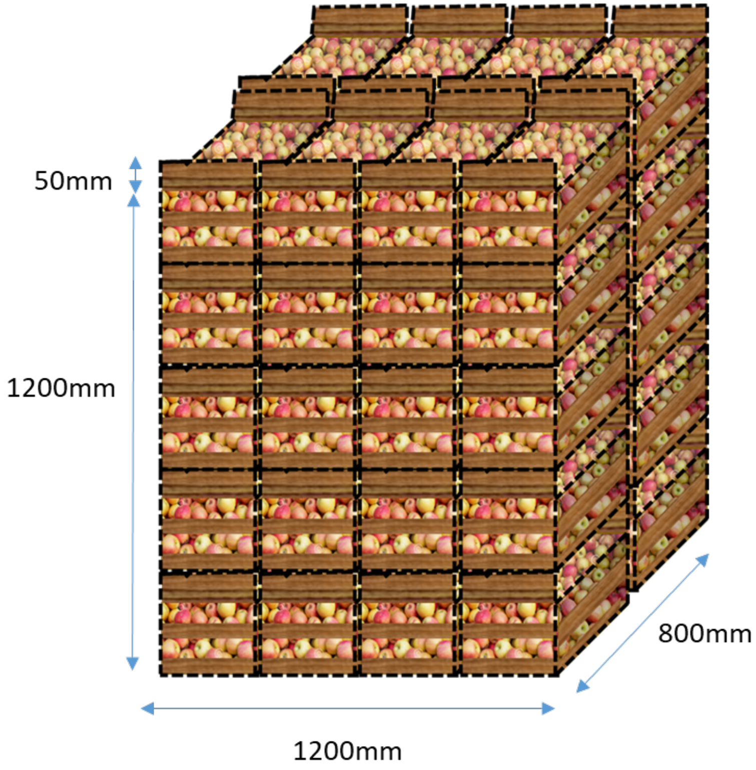


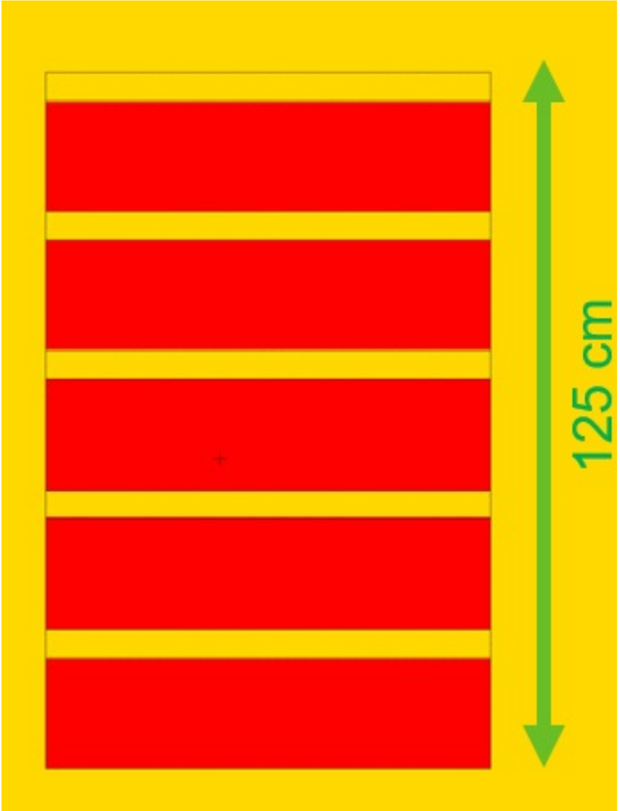
Dose mappings
@ Aerial

DUR (Dose Uniformity Ratio)

	Dose mapping	MCNP	Err(%)	RayXpert	Err(%)
Apples 5 MeV	1.69	1.77	4.5%	-	-
Apples 7 MeV	1.62	1.66	2.4%	1.68	3.5%
Mangoes 5 MeV	2.87	3	4.3%	-	-
Mangoes 7 MeV	2.56	2.5	-2.4%	-	-

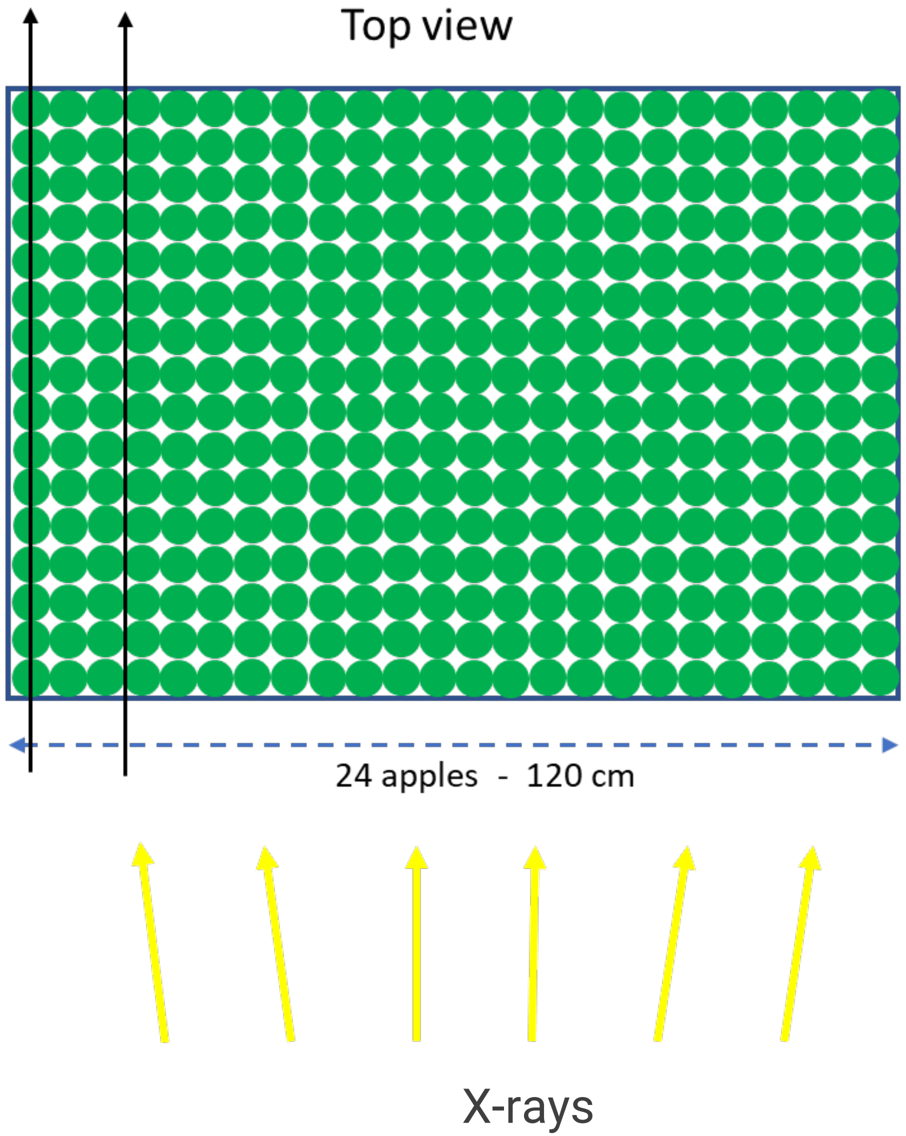
What about the product arrangement ?



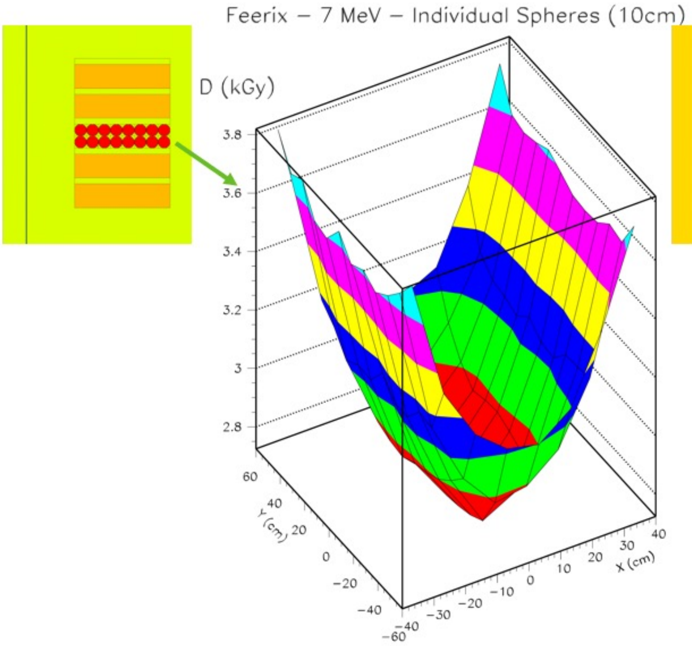


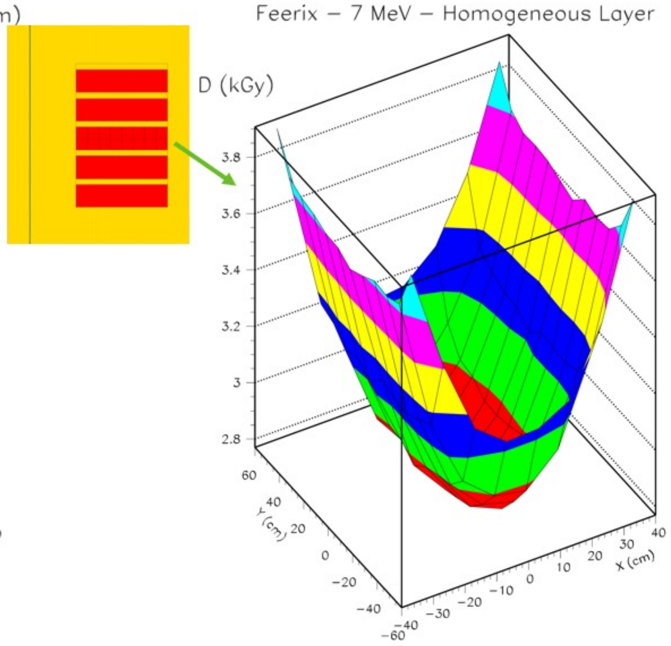
5 cm air gaps in between crate layers
Apple density: 0.9 g/cm³
Crate avg. density : 0.47 g/cm³
Pallet avg. density : 0.38 g/cm³

What about the product arrangement ?



MCNP: spheres vs uniform crates

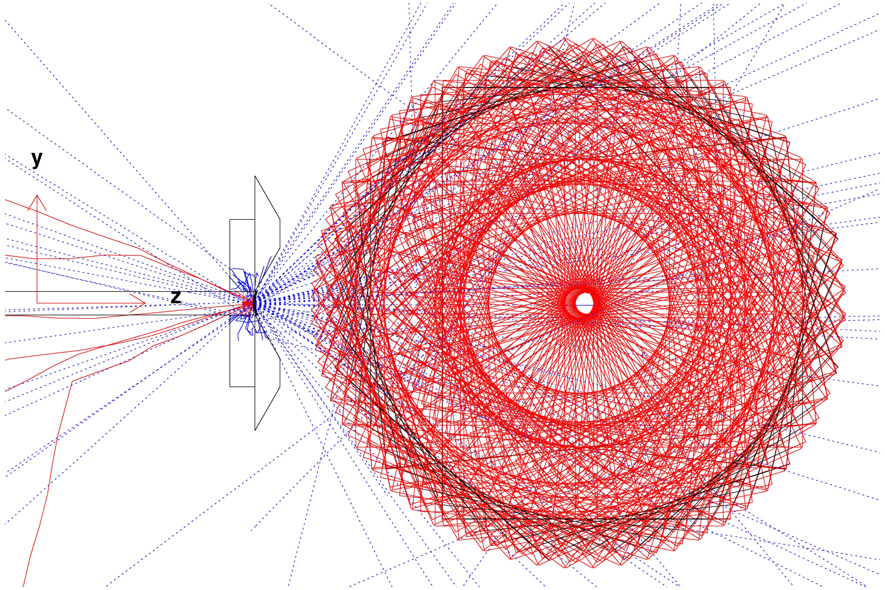


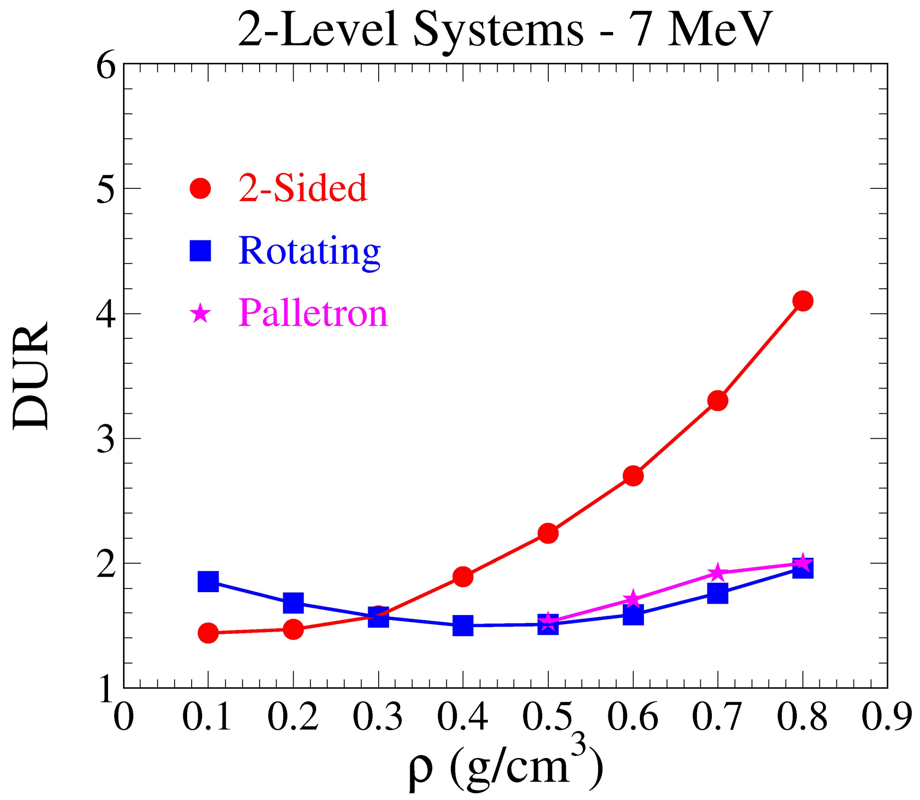


For X-ray irradiations, the detailed structure of the product is not a critical factor and what really matters is the average density of the product.

Results for various configurations

Rotational system: 360° continuous irradiation for high densities





Conclusions

- MC simulations are accurate and reliable
- MC simulations can provide the achievable dose uniformity for a specific product, conditioning, and process:
  - Product
    - average density
    - pallet depth
    - pallet height
  - Process
    - beam energy / spectrum
    - scan length
    - parallelism

  } ➔ DUR
- Inversely: MC simulations can help finding the most efficient process under constraints.

  Examples:
  - Max DUR + fixed scan length ➔ max. pallet dimensions
  - Max DUR + fixed pallet dimensions ➔ required overscan

Thanks.

www.ifis2021.com

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