



François Vander Stappen (IBA)

Monte Carlo simulations applied to food irradiation



Outline

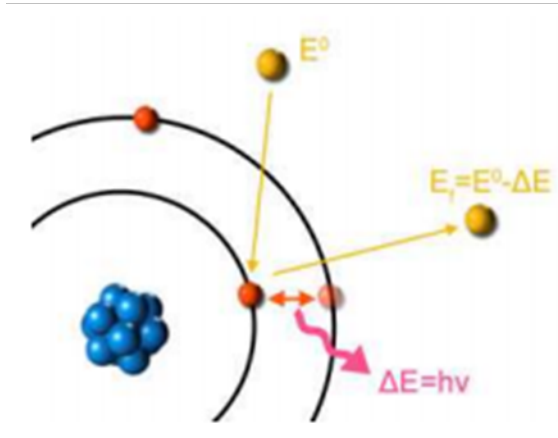
- Why do we need Monte Carlo ?
 - a bit of physics
- How does it work & available tools
- Practical example: apple pallet
- Results



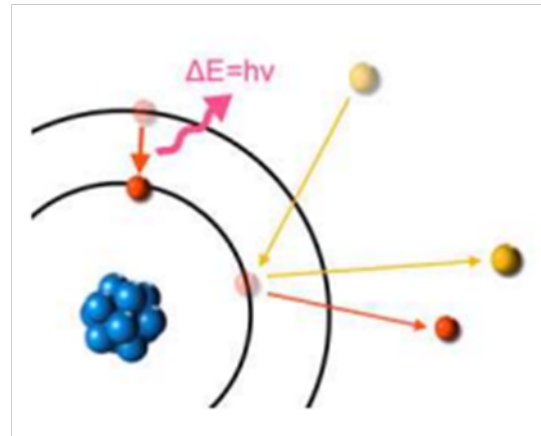
Particle-matter interactions: electrons

Collisions

Excitation



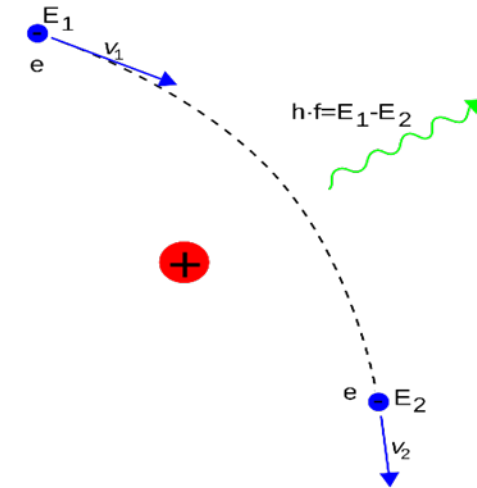
Ionisation



Secondary electron emission

→ Energy (dose) deposition

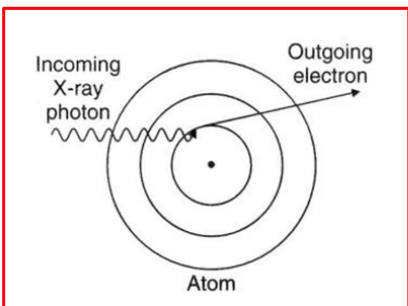
Bremsstrahlung



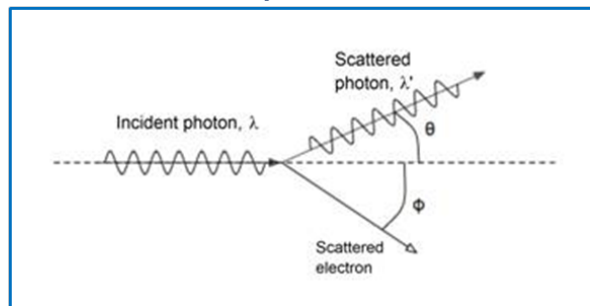
→ X-ray production

Particle-matter interactions: photons

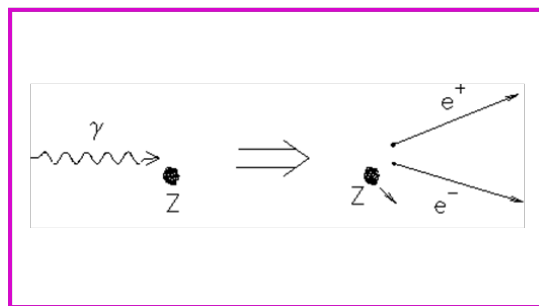
Photoelectric effect



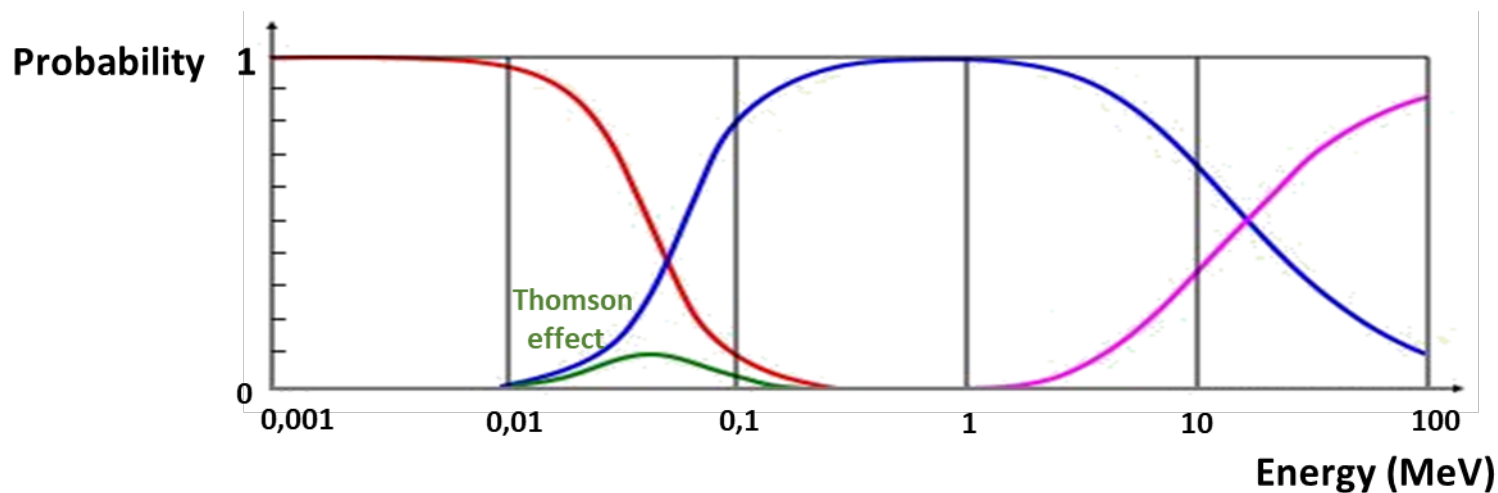
Compton effect



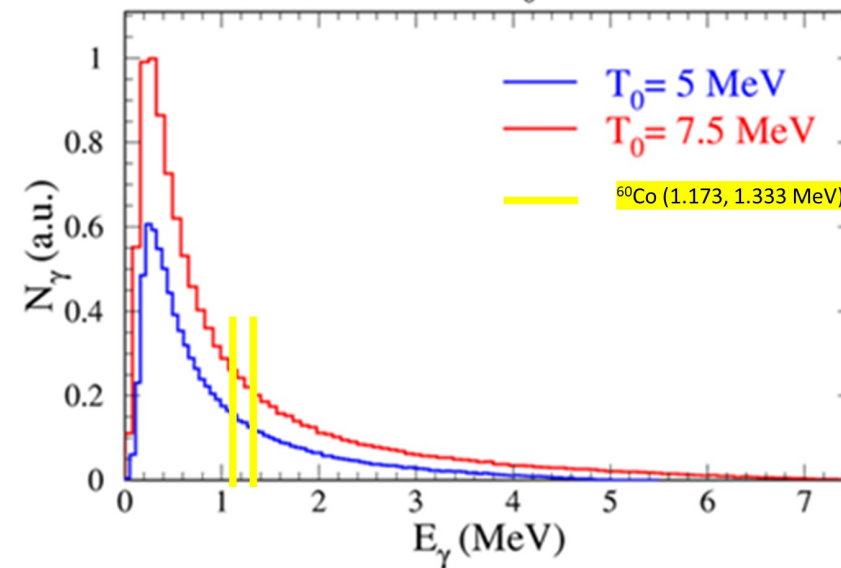
Pair production



e- emission

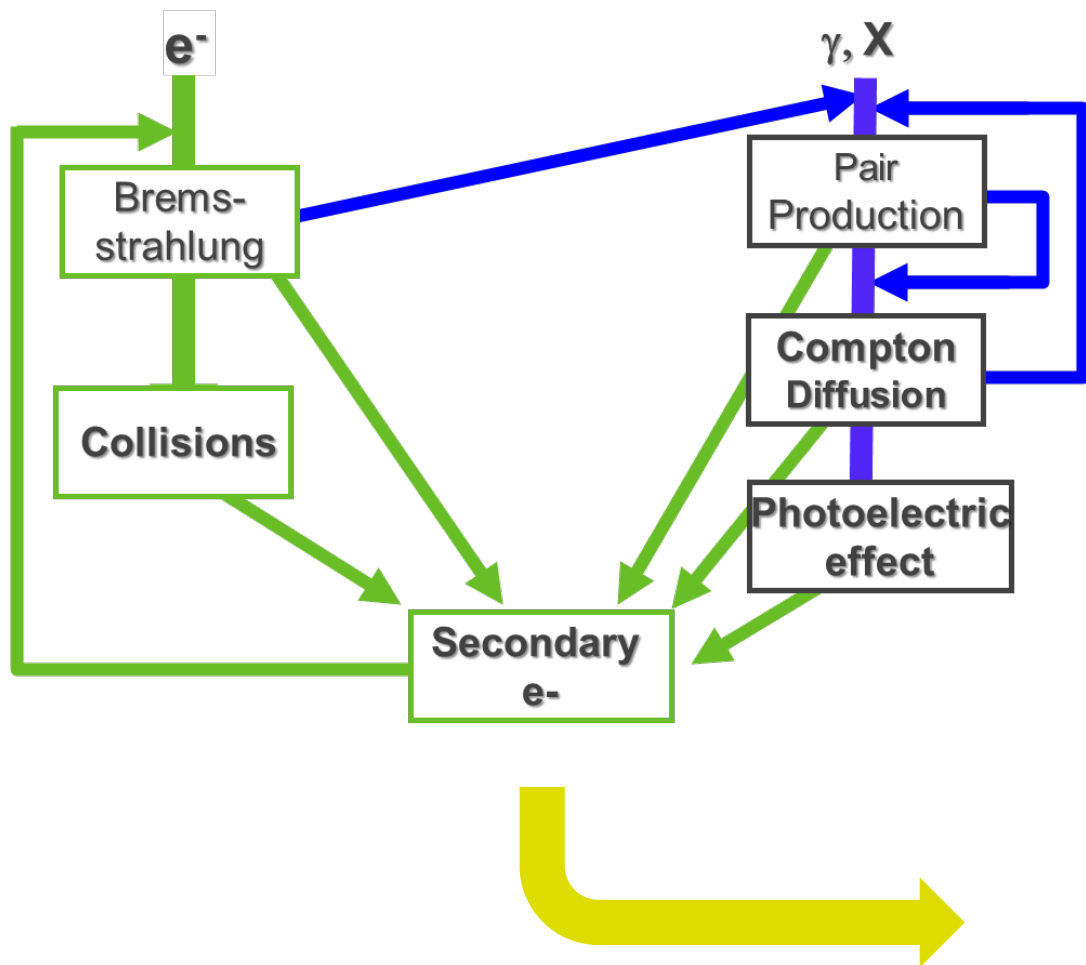


X-rays Spectrum for $T_0 = 5$ and 7.5 MeV

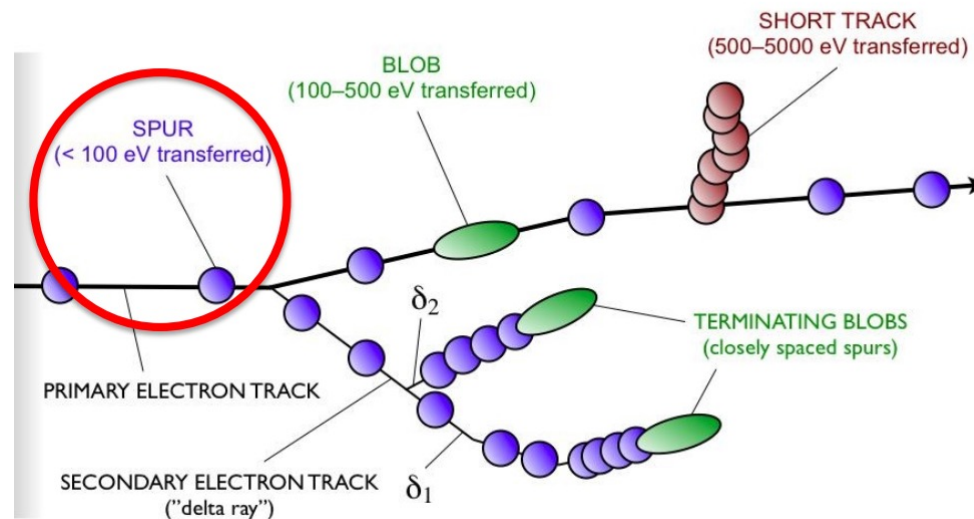


→ **Compton scattering dominates**

Particle-matter interactions: e- and photons

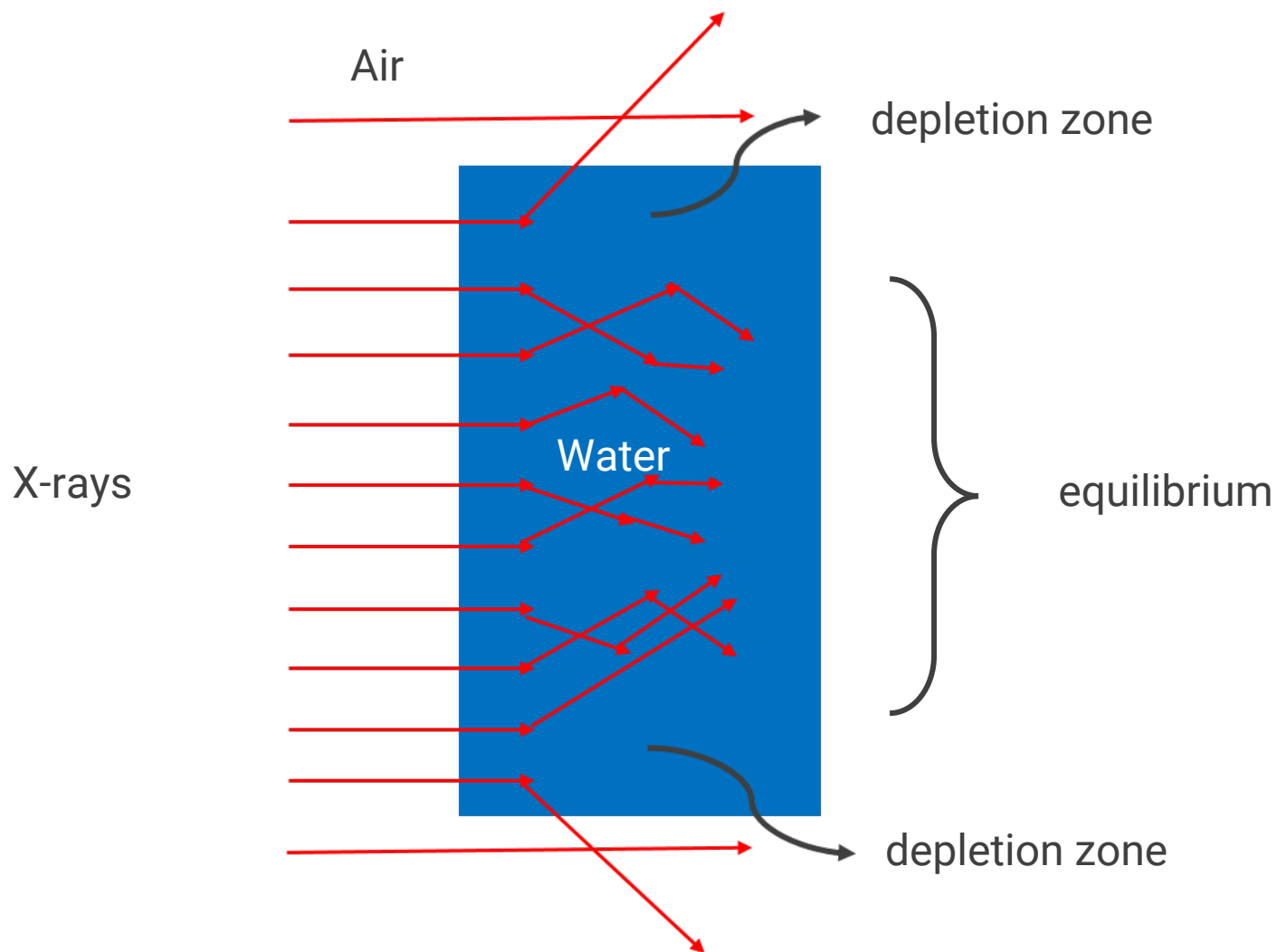


Final dose deposition mainly by very low energy electrons, in SPURS and BLOBS





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

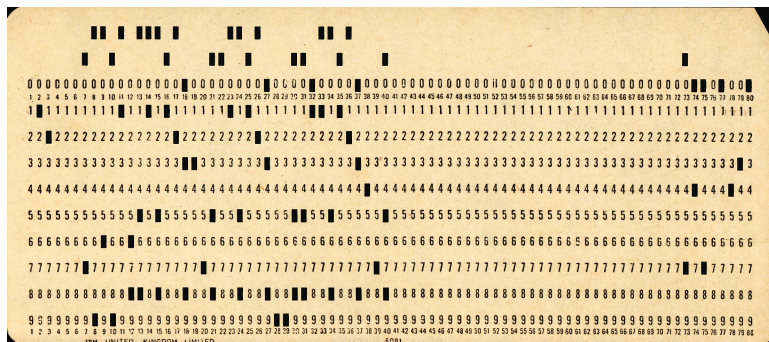
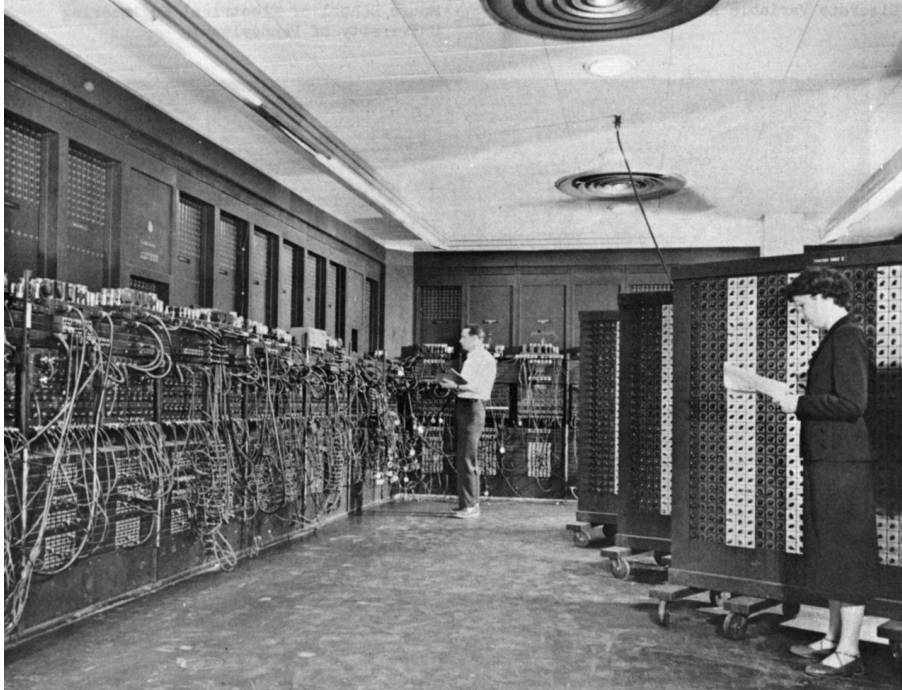
Open Source

Commercial



MCNP: since 1946-1948

Fortran 90



```

File Edit Options Buffers Tools Help
[Icons]
32 px .2          $ cube xmax
33 px -.2        $ cube xmin
34 py .2         $ cube ymax
35 py -.2       $ cube ymin
90 sz -.6 .1    $ sphere inside cube
100 so 6.       $ system ball (system boundary)

c DATA SECTIONS
c
mode p e          $ transport photons and electrons
imp:p,e 1 10R 0  $ cell importances
phys:e .36       $ electron Emax
cut:e j .005     $ electron cutoff
c source term.....
  sdef erg=D1     $ source E-distribution 1
       pos=0 0 .03324 $ reference point for source position sampling
       cel=1      $ source cell
       axs=0 0 1  $ axis of cylinder
       rad=D2     $ radial distribution 2
       ext=D3     $ axial source distribution 3
       par=2      $ particle type is photons

c
c energy distribution #1 (NuDat nndc at BNL E>2keV)
si1 L .00270 .02007 .02022 .02270 .03975 .35745
sp1 .088 .2206 .4193 .1305 .000683 .000221
c
c Distribution #2 (radial source distribution)
si2 0 .475      $ source radius
sp2 -21 1      $ default (radial source distribution c|x|^1)
c
c Distribution #3 (axial distribution-distance from ends to POS)
si3 -.0025 .0025 $ distance from POS along AXS
sp3 -21 0      $ axial source distribution c|x|^0 = const
c end of source term.....
c Materials and cross-sections
  m1 38000 -.05 $ strontium-silver foil

:--- samp1 (Mcnpgen)---L35---CO---42%-----

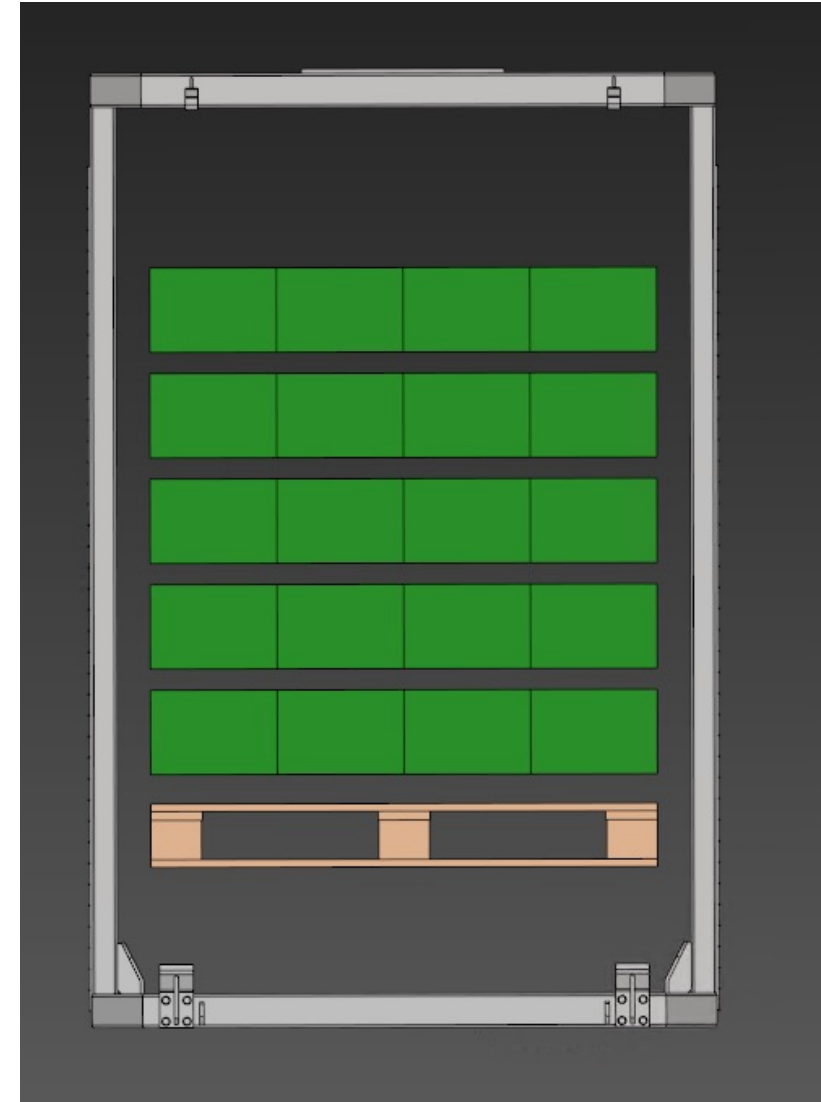
```

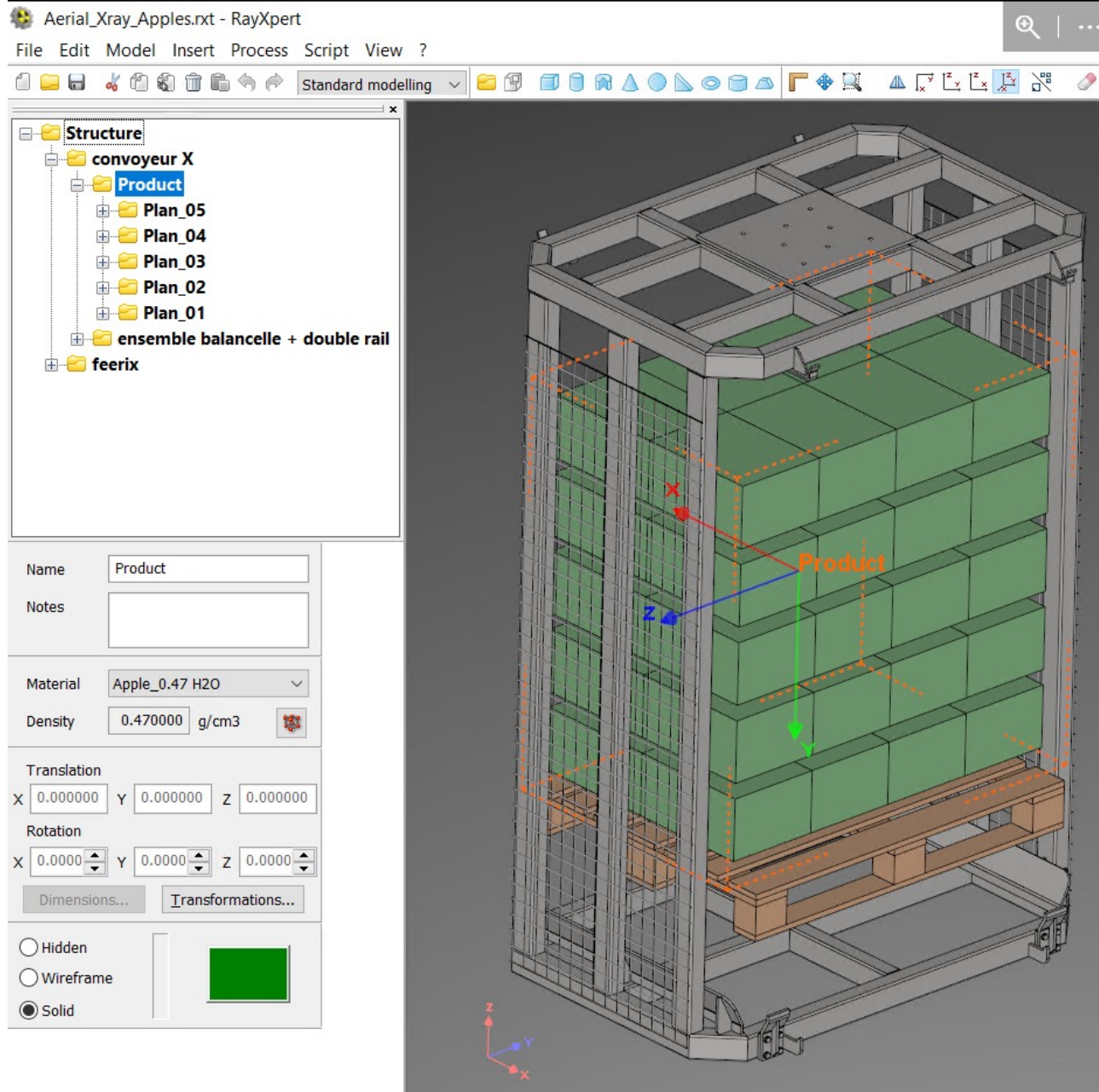


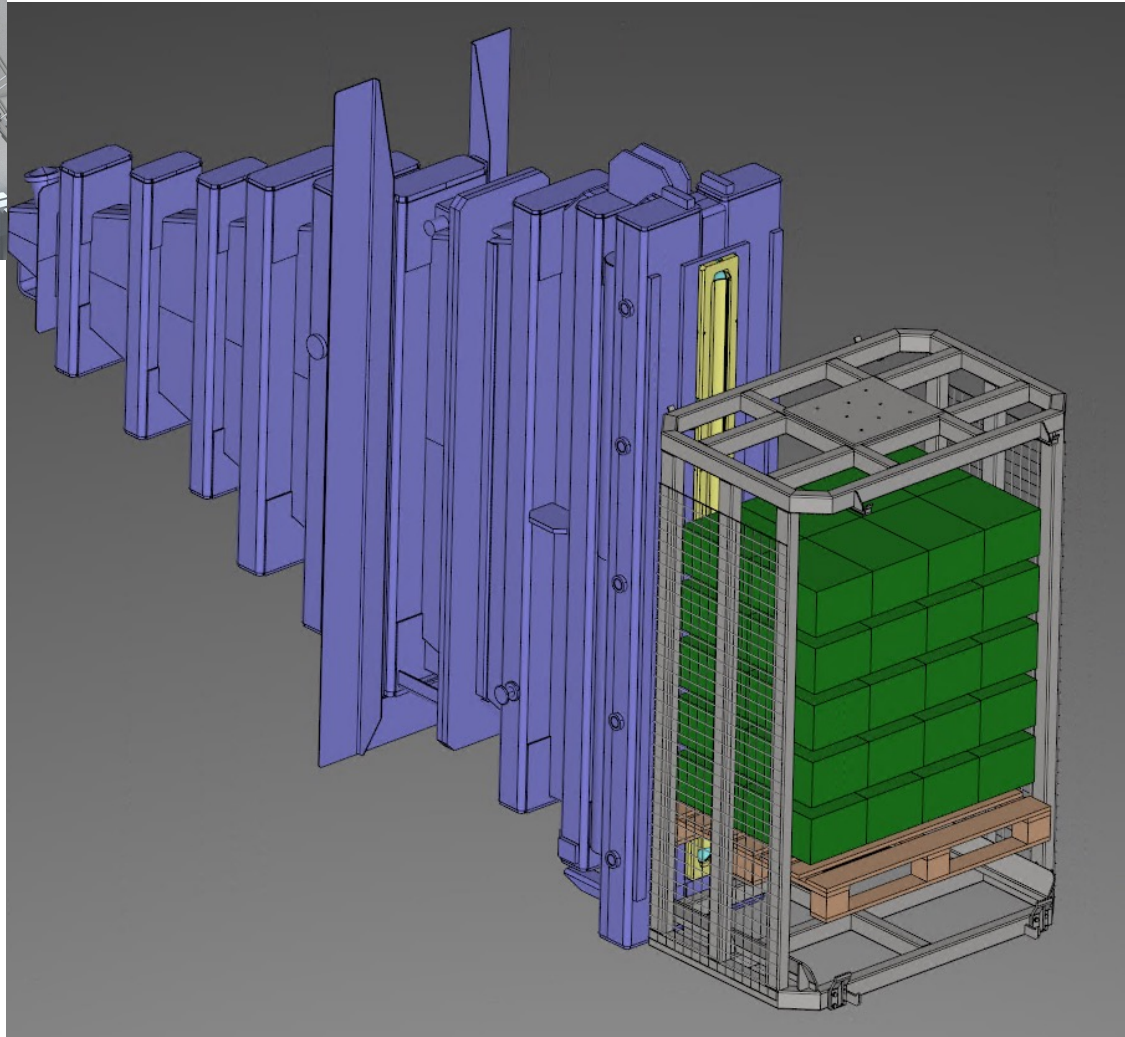
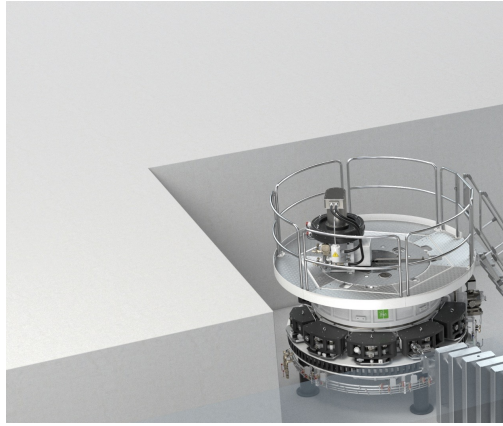
RayXpert: accessibility for everyone

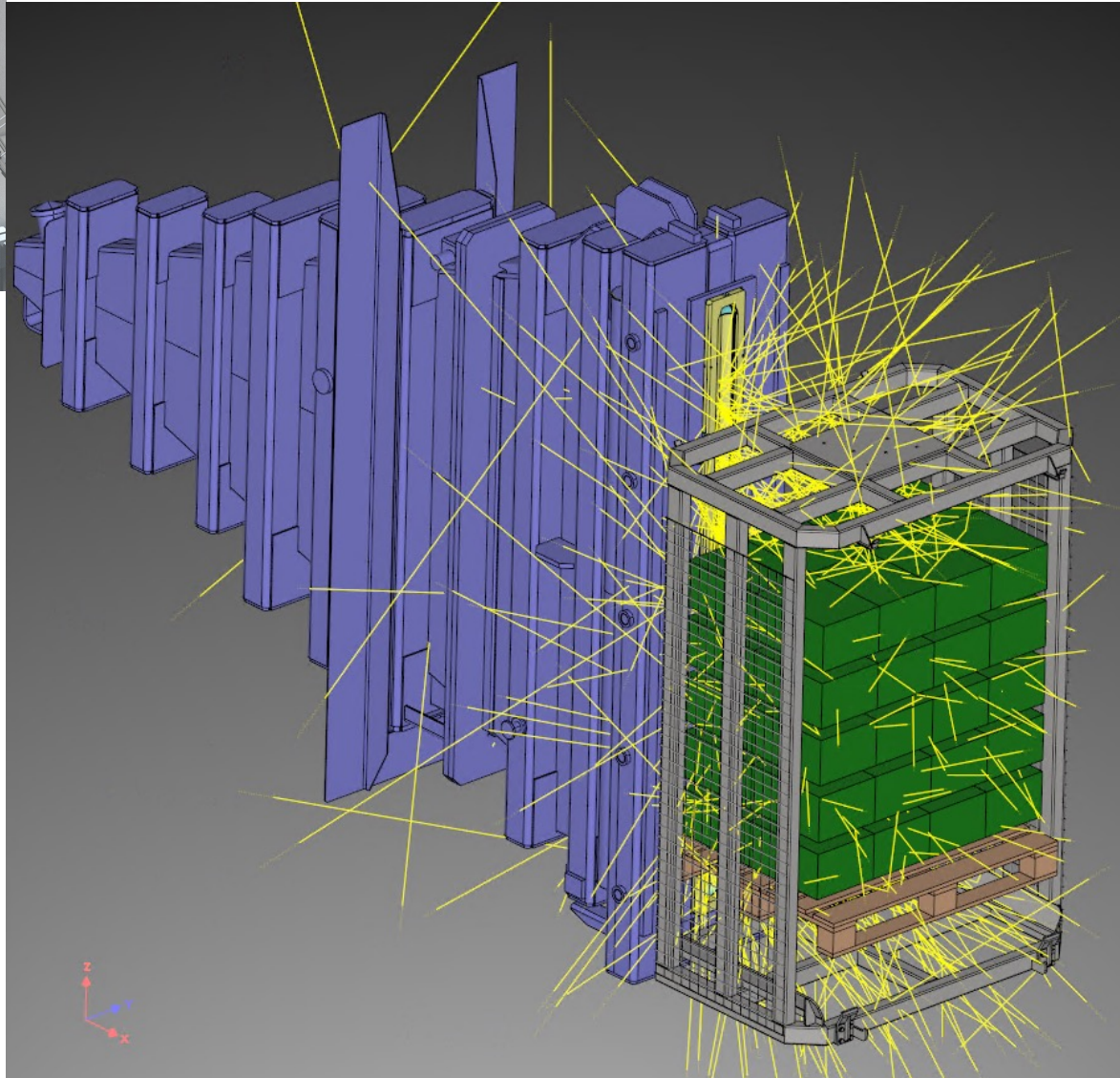
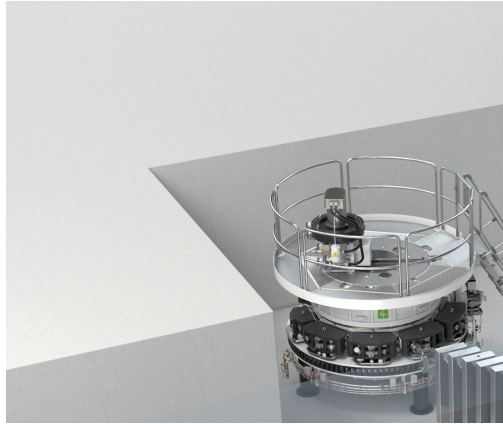


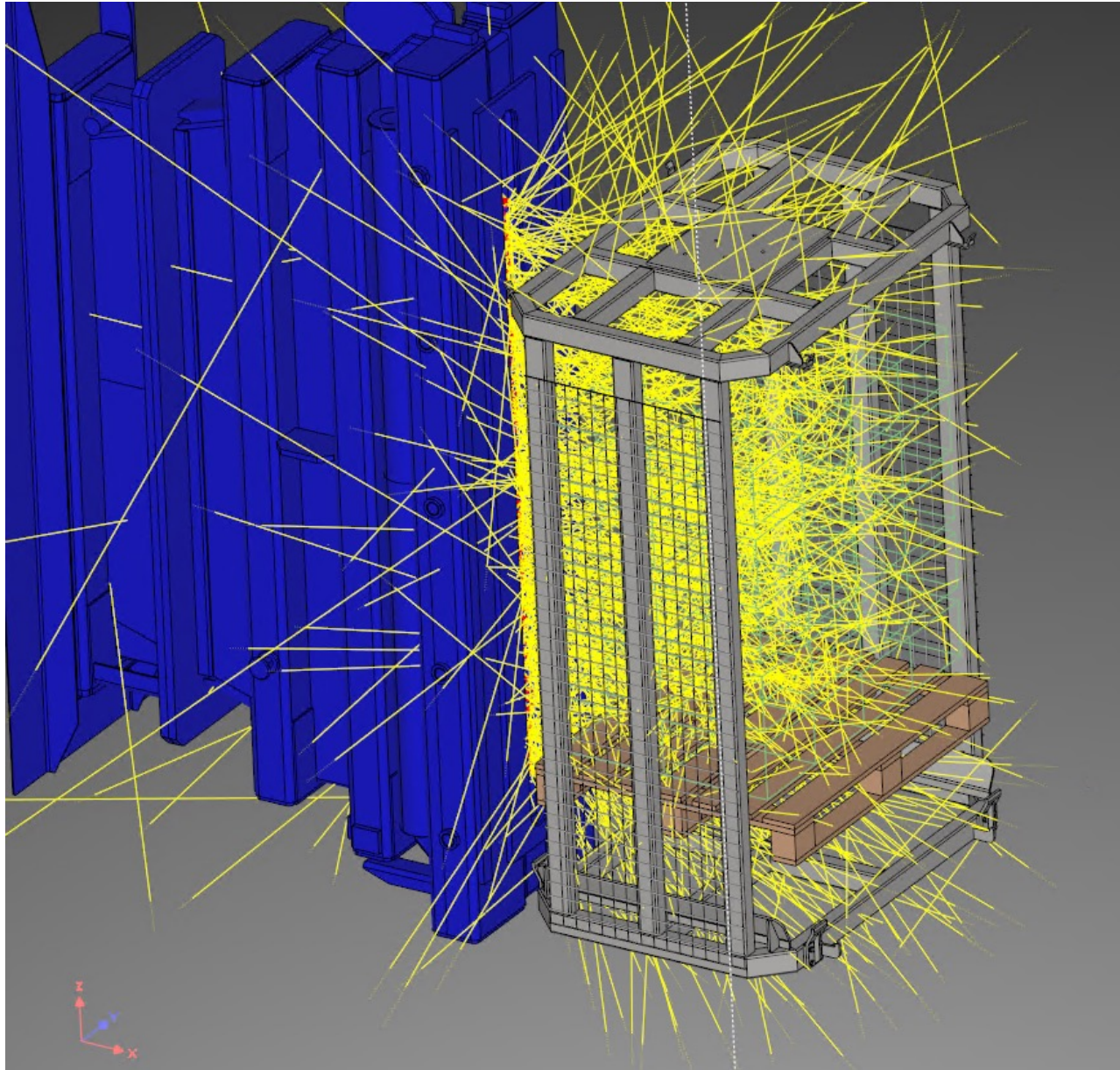
modelisation

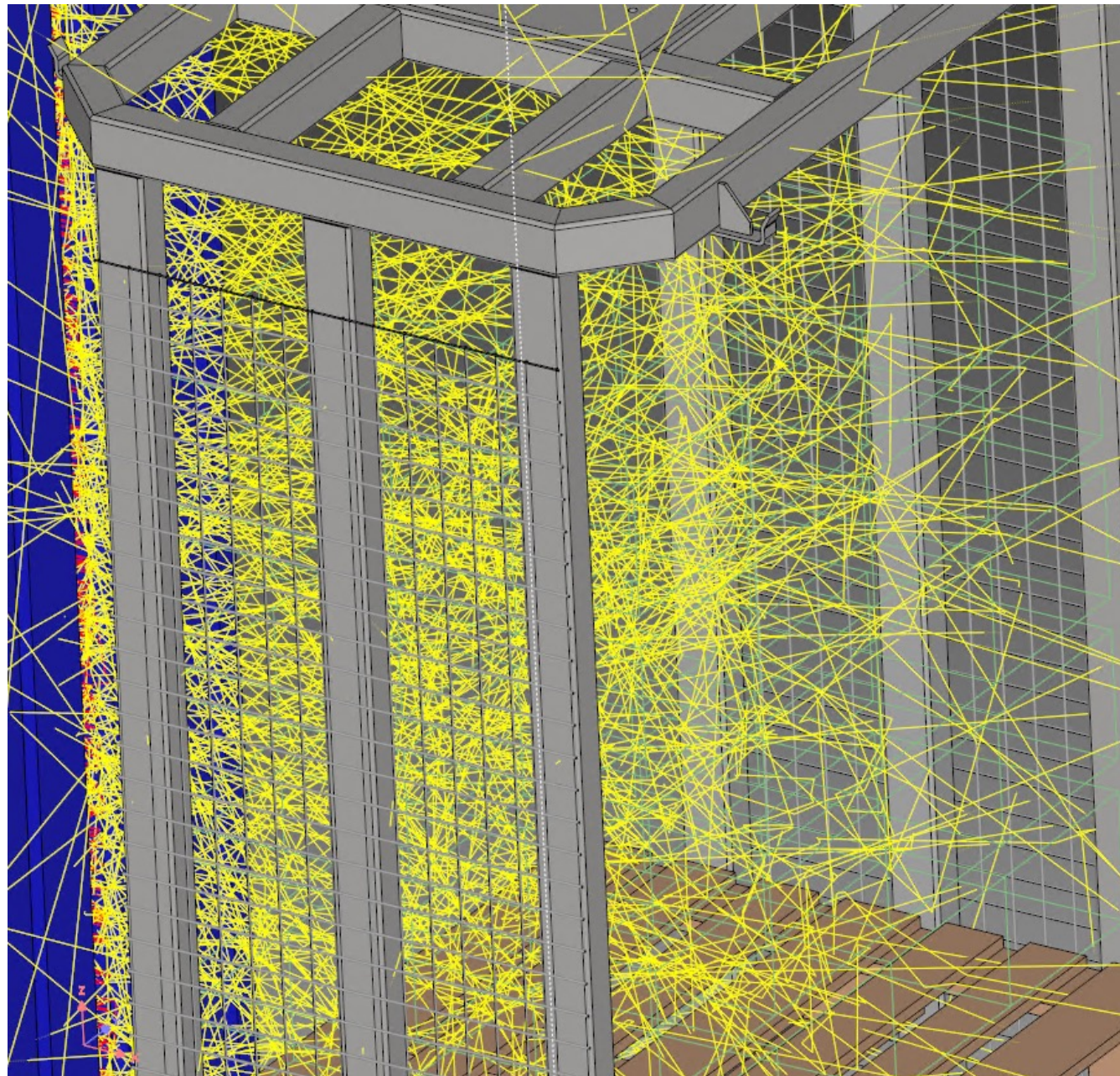


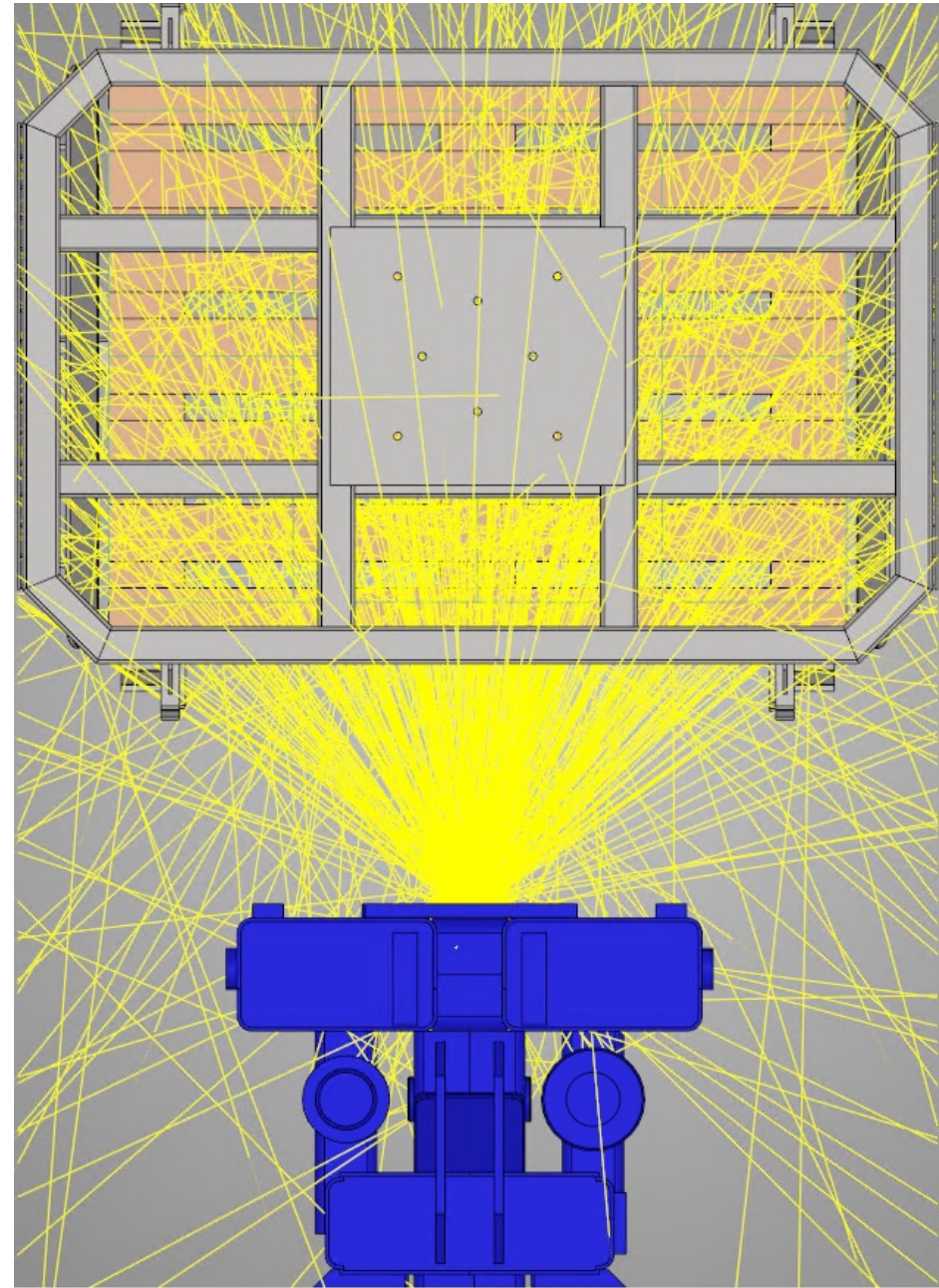
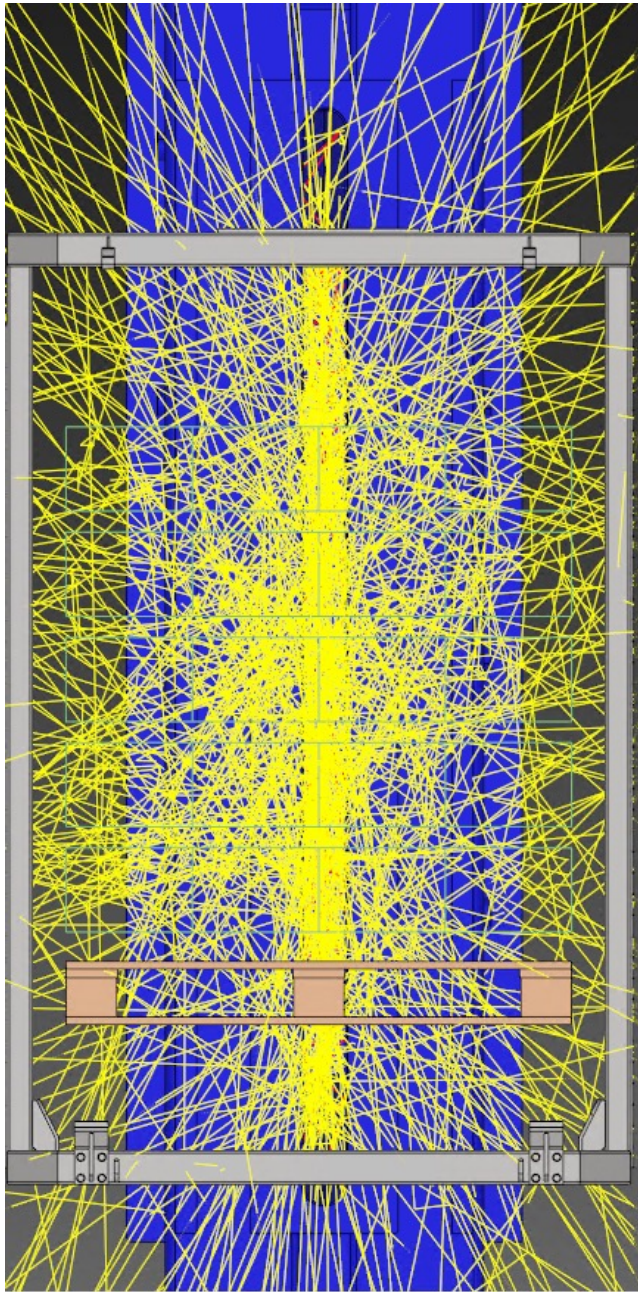






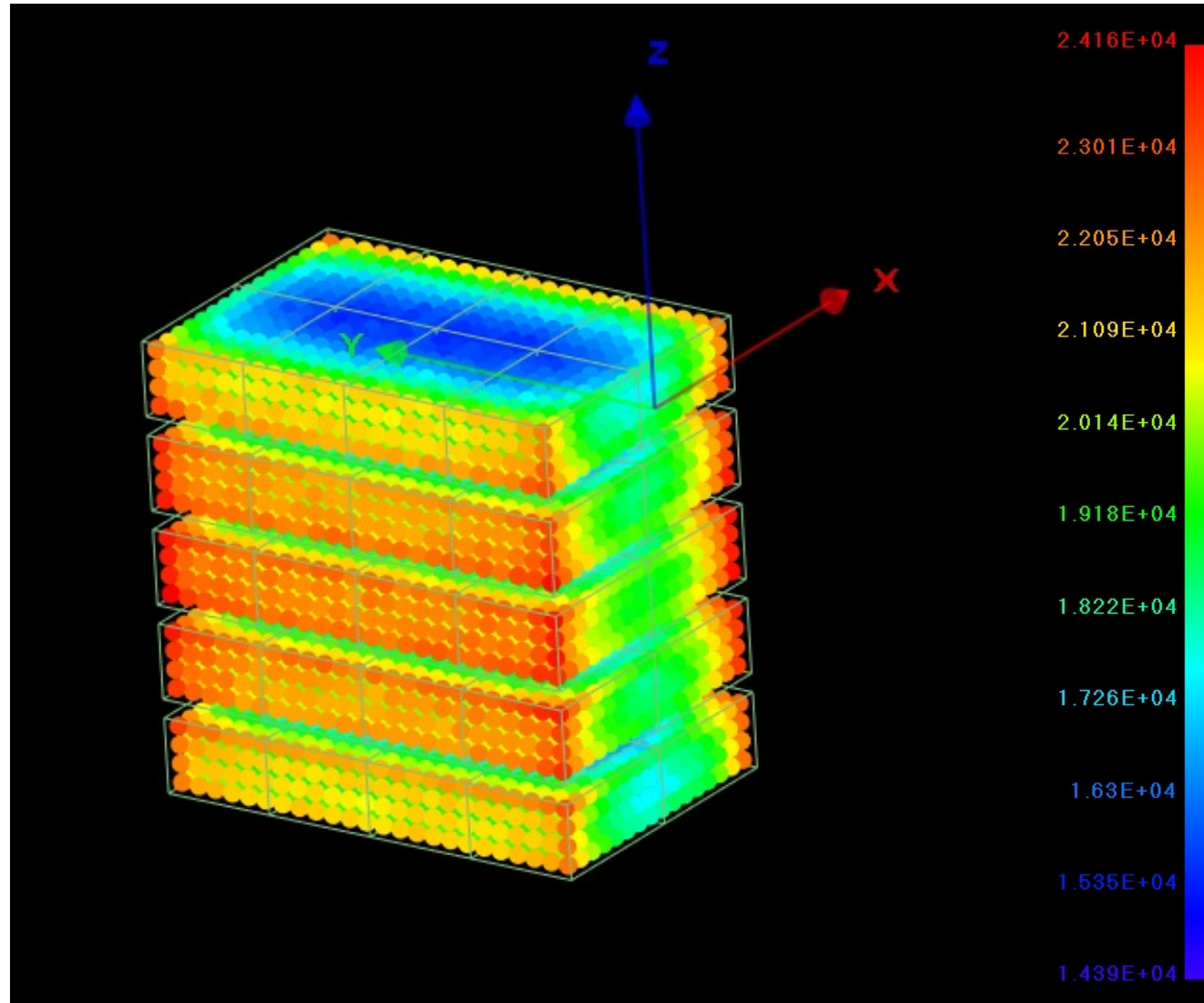






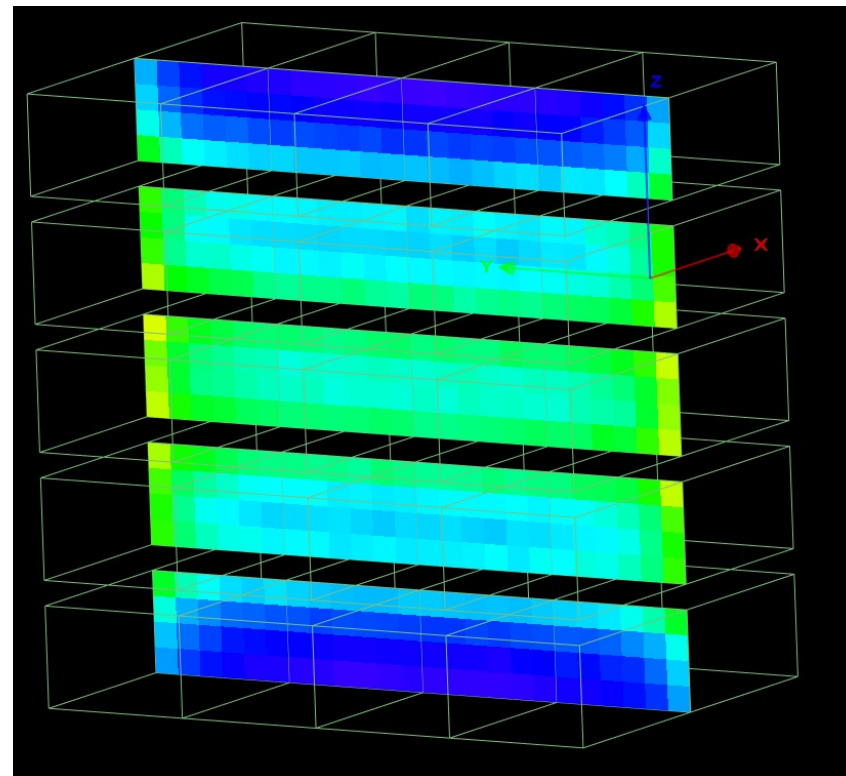
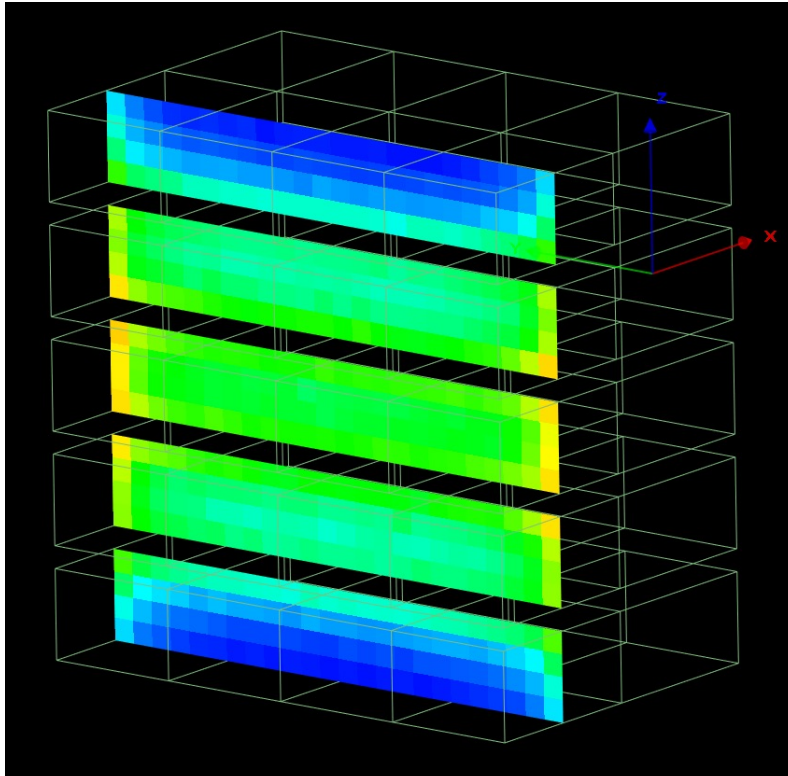
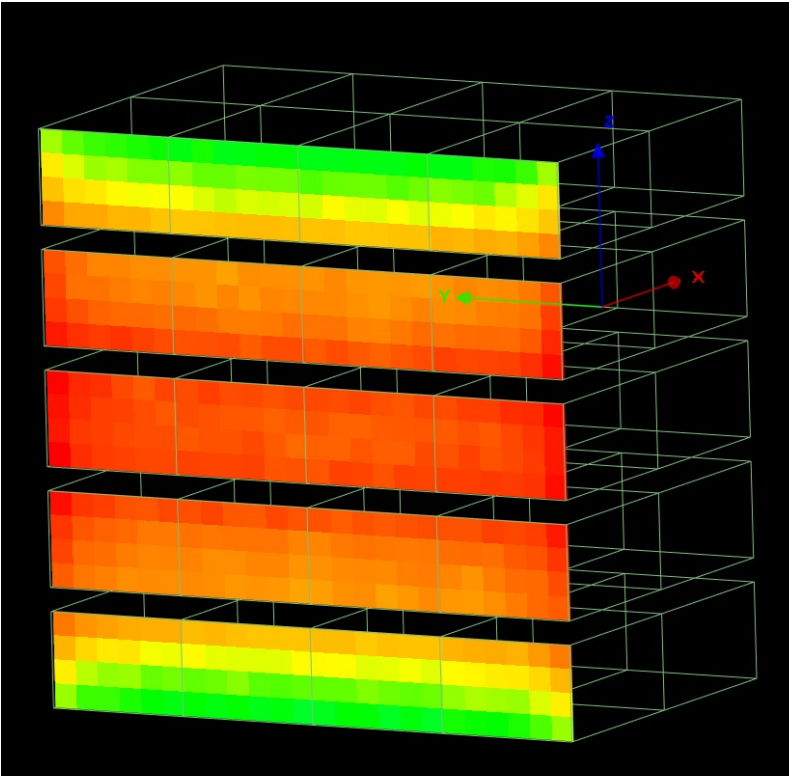


Output: 3D map of dose deposition



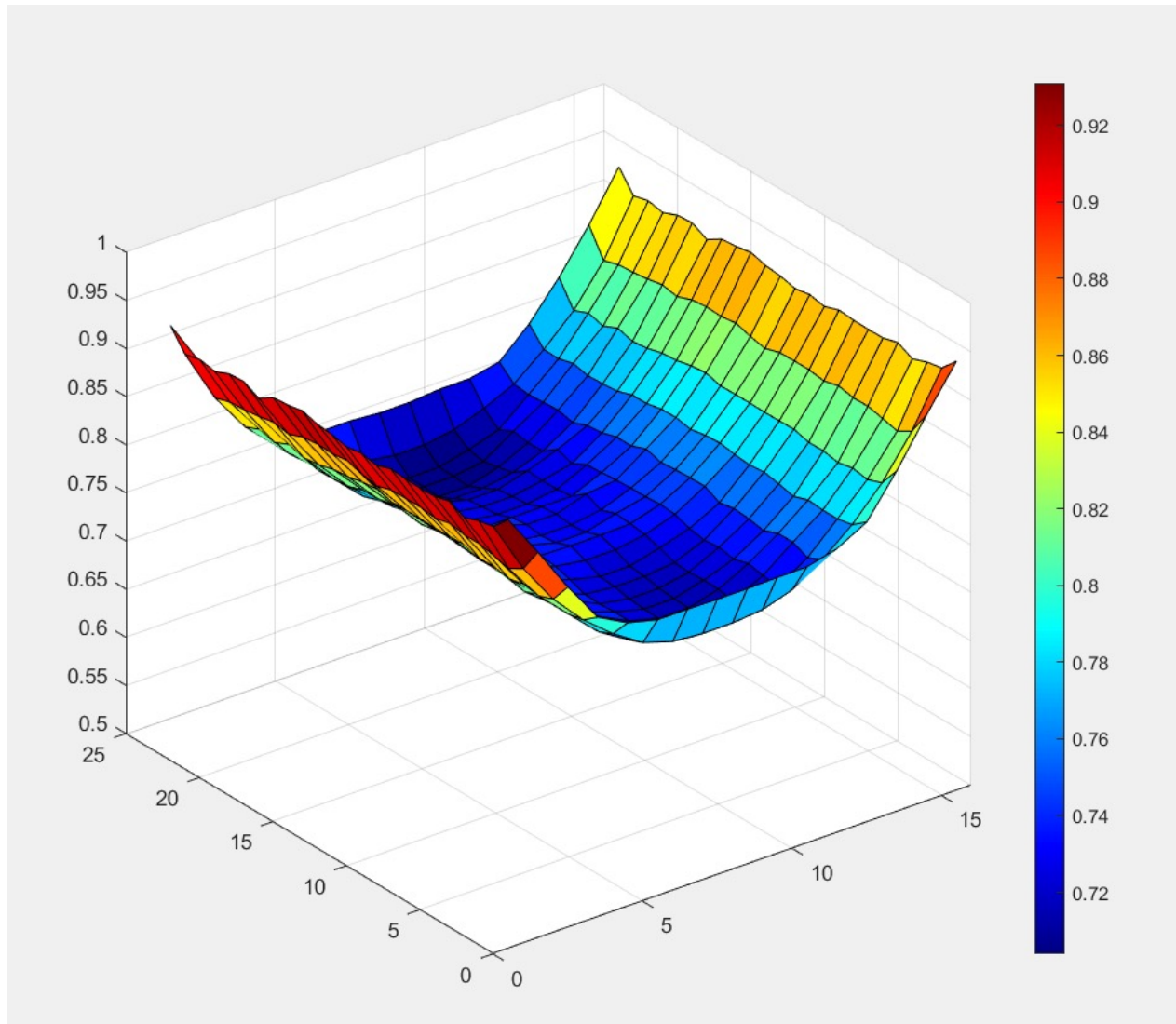


Output: 2D planes





Output: export to any data manipulation tool

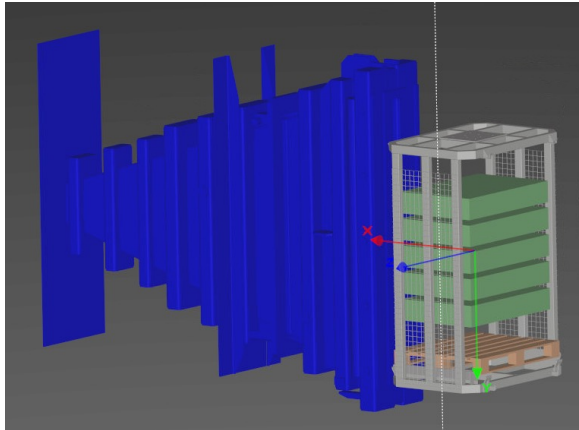


DUR (max/min) = 1.68



How well does it fit reality ?

Simulations
MCNP + RayXpert



Dose mappings
@ Aerial



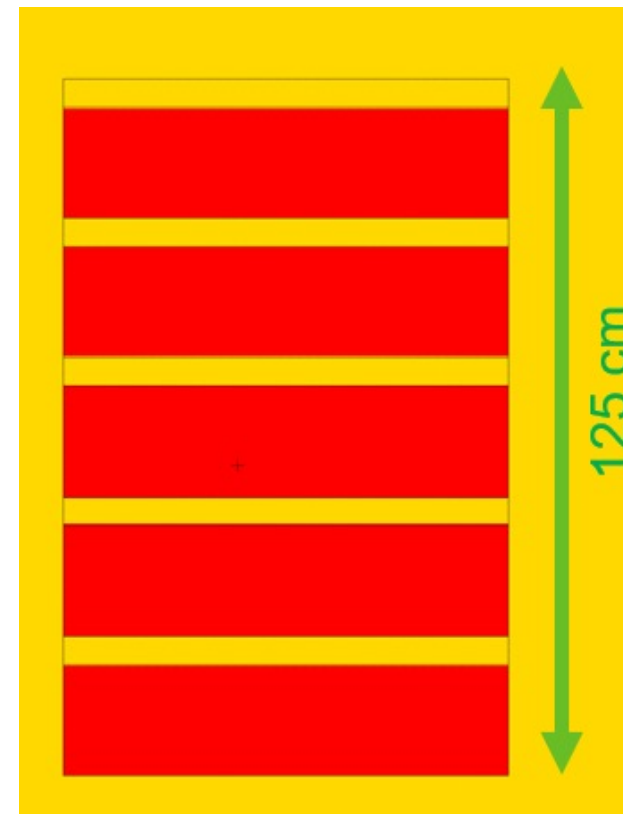
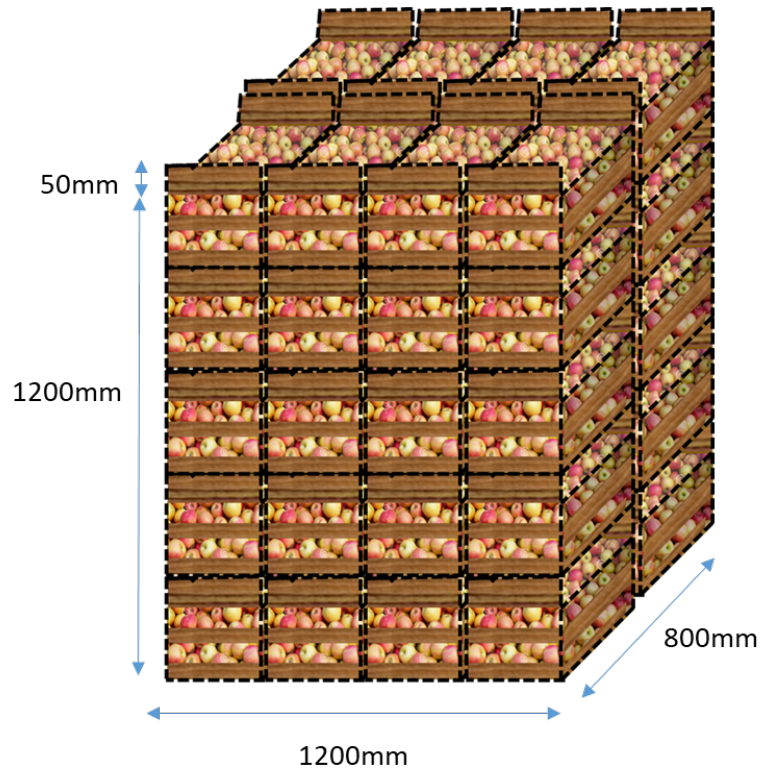
**SPOILER
ALERT!**

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%	-	-

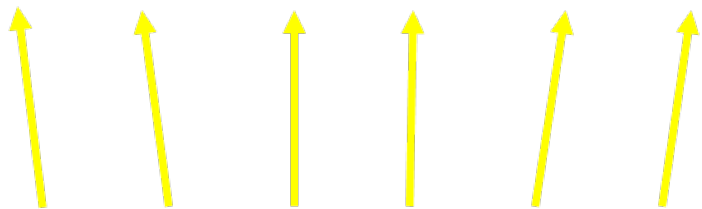
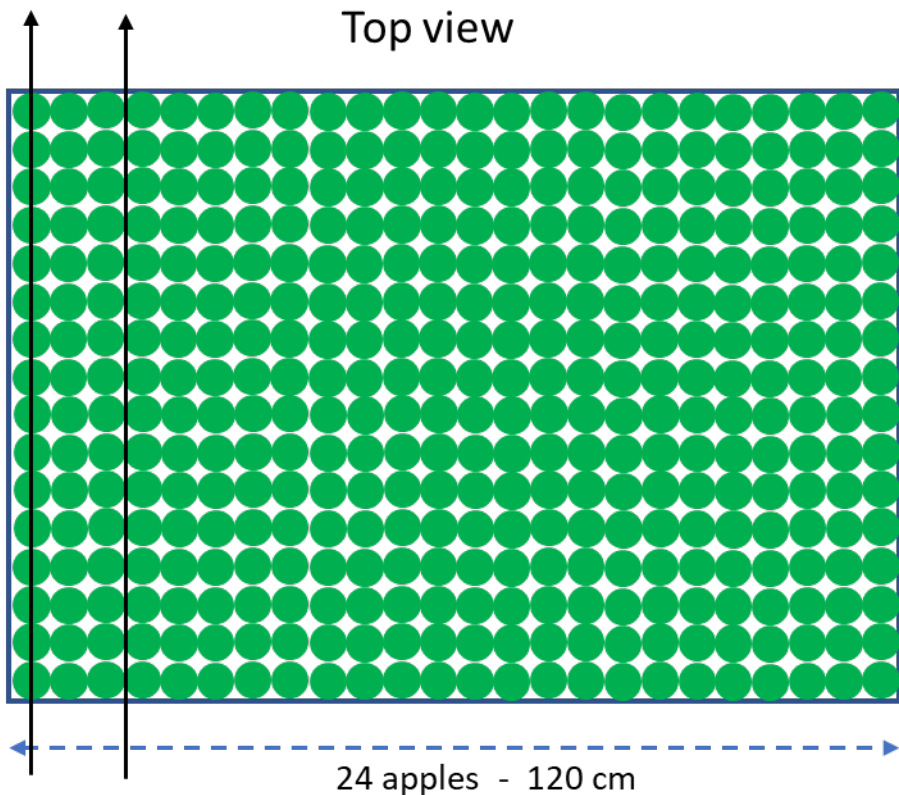


What about the product arrangement ?



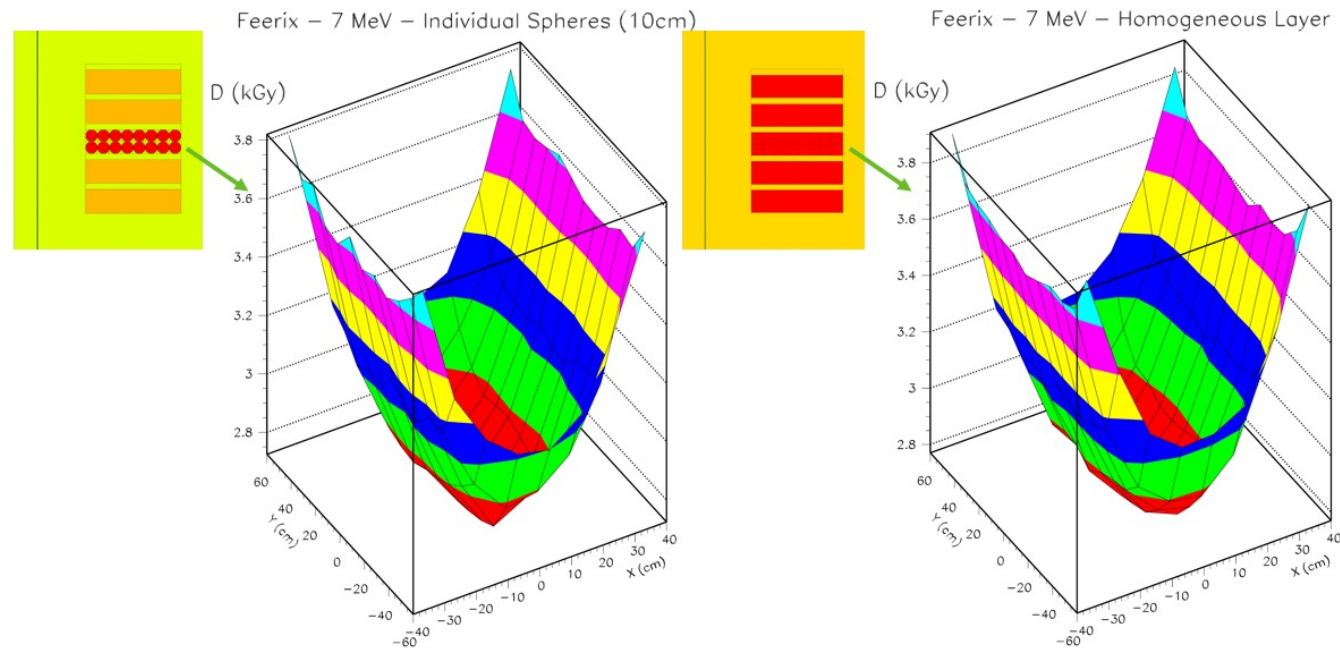
5 cm air gaps in between crate layers
Apple density: 0.9 g/cm^3
Crate avg. density : 0.47 g/cm^3
Pallet avg. density : 0.38 g/cm^3

What about the product arrangement ?



X-rays

MCNP: spheres vs uniform crates

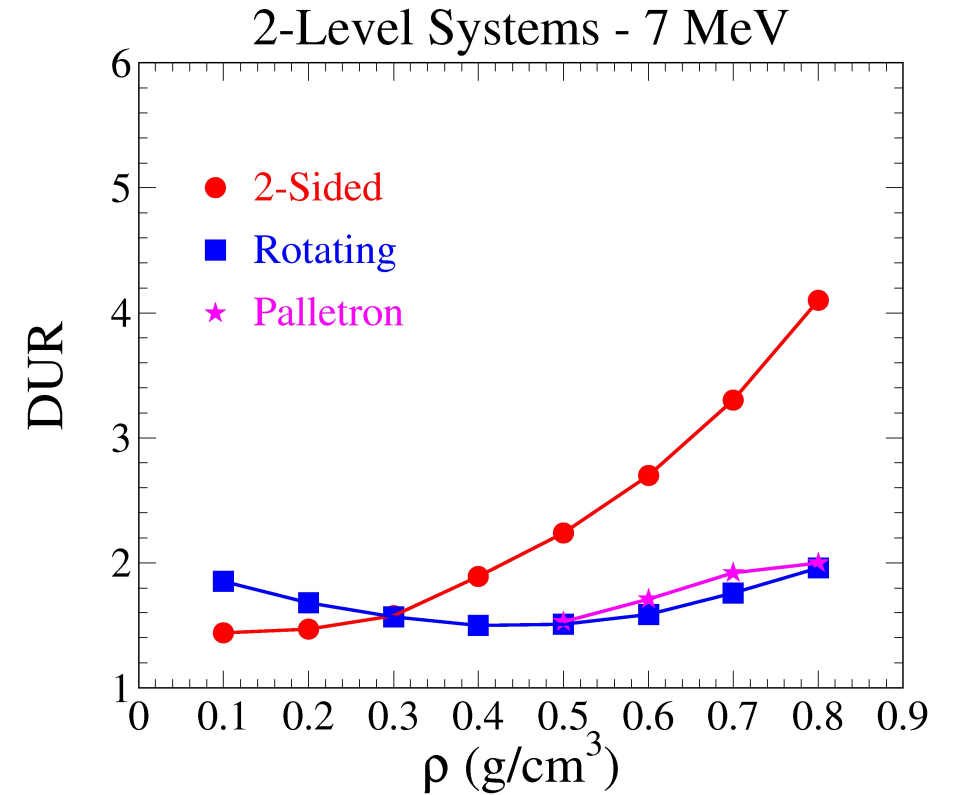
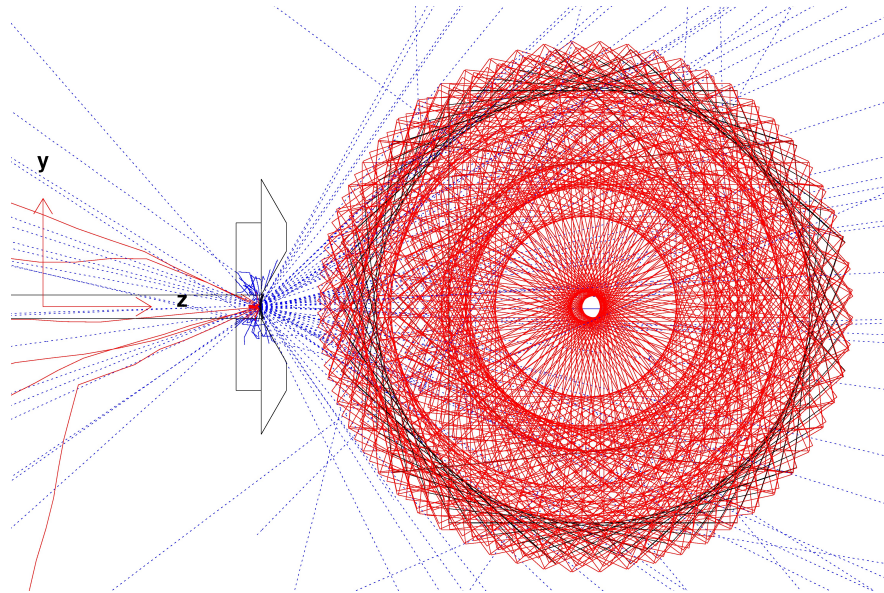


For X-ray irradiations, the detailed structure of the product is not a critical factor and what really matters is the average density of the product.



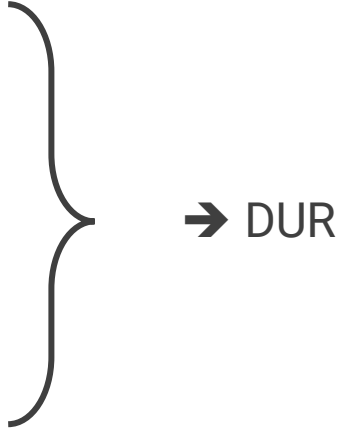
Results for various configurations

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

A stylized white apple logo with a yellow stem and leaf, set against a yellow background. The logo is partially cut off by the right edge of the slide.

Thanks.

 www.ifis2021.com

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