Council on
Ionizing Radiation
Measurements &
Standards

29th Annual Meeting of CIRMS

"Trusting Radiation Science: Measuring what cannot be seen"

April 11-13, 2022 **Virtual Meeting**

E-Beam dose mapping:
What about modelling the "REAL" product?

Abbas Nasreddine, Thomas Deschler and Florent Kuntz

Aerial, 250 Rue Laurent Fries, 67400 Illkirch-Graffenstaden - France Phone: +33 3 88 19 15 15, Mail: florent.kuntz@aerial-crt.com

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feerix®

High energy E-beam (10 MeV) and X-rays (5 and 7 MV)

Medium Energy EB and XR (0.5 to 2.5 MeV or MV)
Low Energy EB (80 to 200 keV)
Low Energy XR (10 to 100 kV)

IAEA
International Atomic Energy Agency

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IAEA Collaborating Centre

for

Multidisciplinary Applications of Electron Beam and X Ray Technologies and Related Dosimetry for Radiation Processing and Food Irradiation

2021 – 2025

R&D, trials and Experimental/theoretical Training

Tool for material modification analysis :

NMR, HPLC-SEC, Gel fraction IRTF/NIRTF, EPR, DSC…

Activities in dosimetry

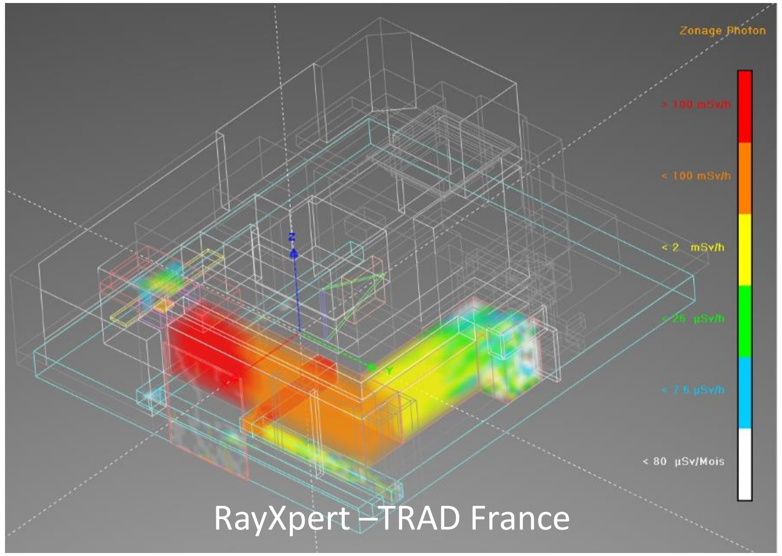
- Accredited Calibrations and measurements
- Development or dosimetry equipment
- Production of dosimeters
- Modelling/Simulation

cofrac ESSAIS
cofrac ETALONNAGE

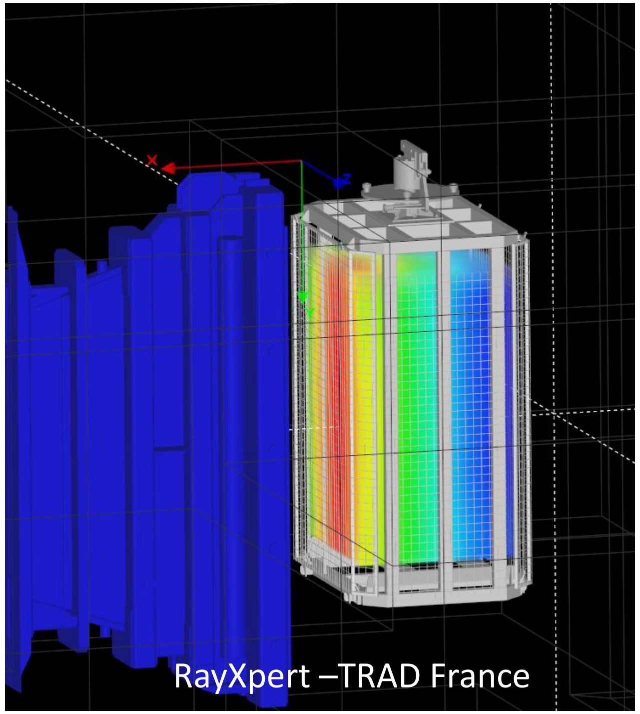
Industrial needs for MC simulation

- Irradiation installation shielding
- Field qualification
  - Source loading, shape, energy, uniformity,…
- OQ
- Help to MD manufacturers

Feasible with currently existing tools (Cad files or lines of codes)



RayXpert –TRAD France


RayXpert –TRAD France

Industrial needs for MC simulation

For EBeam applications mainly (low, medium, high energy)

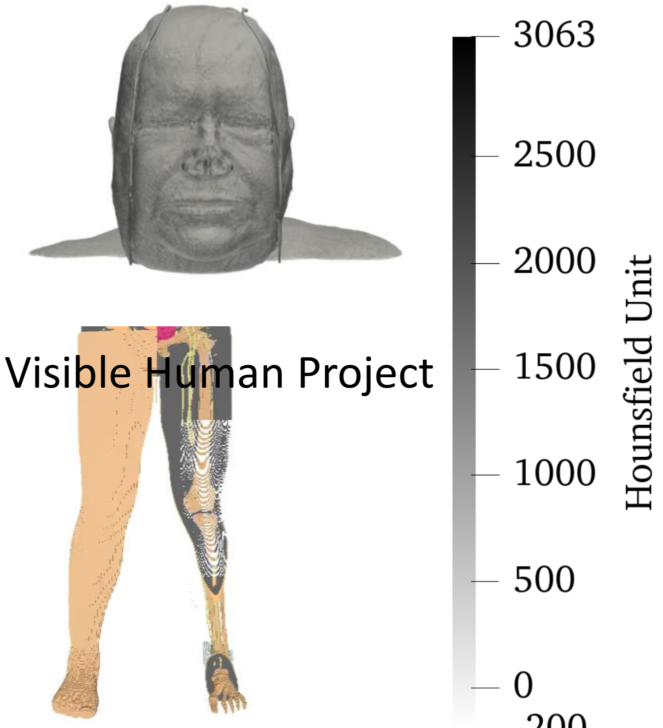
- Understand the process → a tool to visualize dose gradients, scattering effect, impact of voids, interfaces, …
- PQ → a tool which helps to map dose inside the product
  - product the most realistic possible
  - taking into account its variability
  - cold and hot spots in a reasonable time (for PQ dosimeters placement)

Great … but how?

→What can we learn from medical use of Monte Carlo simulations?

Patient representation in simulations

- How to represent patient in Monte Carlo simulations?
  - Realism is the key
- Mathematical phantoms
  - Approximation of patient…
- Anthropomorphic voxelized phantoms
  - Can be deformed to fit patient morphology
  - Organs already segmented
- CT scan patient images
  - in DICOM file format (*Digital imaging and communications in medicin*)
  - Example of Visible Human Project CT Datasets
  - Organ segmentation → complex task



Visible Human Project

XCAT Female Phantom

ADAM and EVA mathematical phantoms

Great … but what’s next?

→Can we use CT Scan images of MD for Monte Carlo simulations?

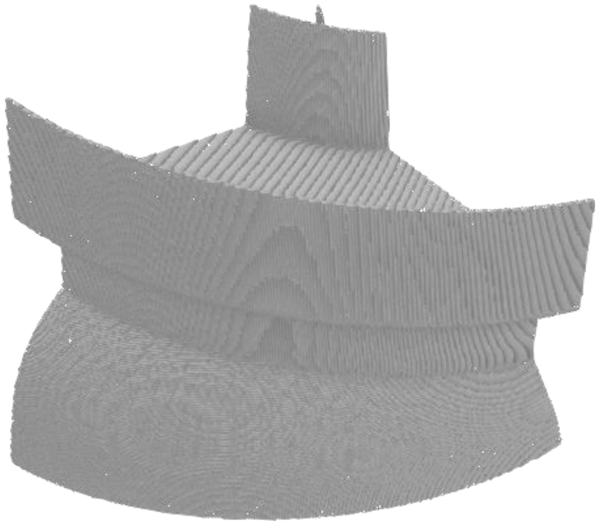
Examples …

Example 1: Low energy EB irradiation of Filter

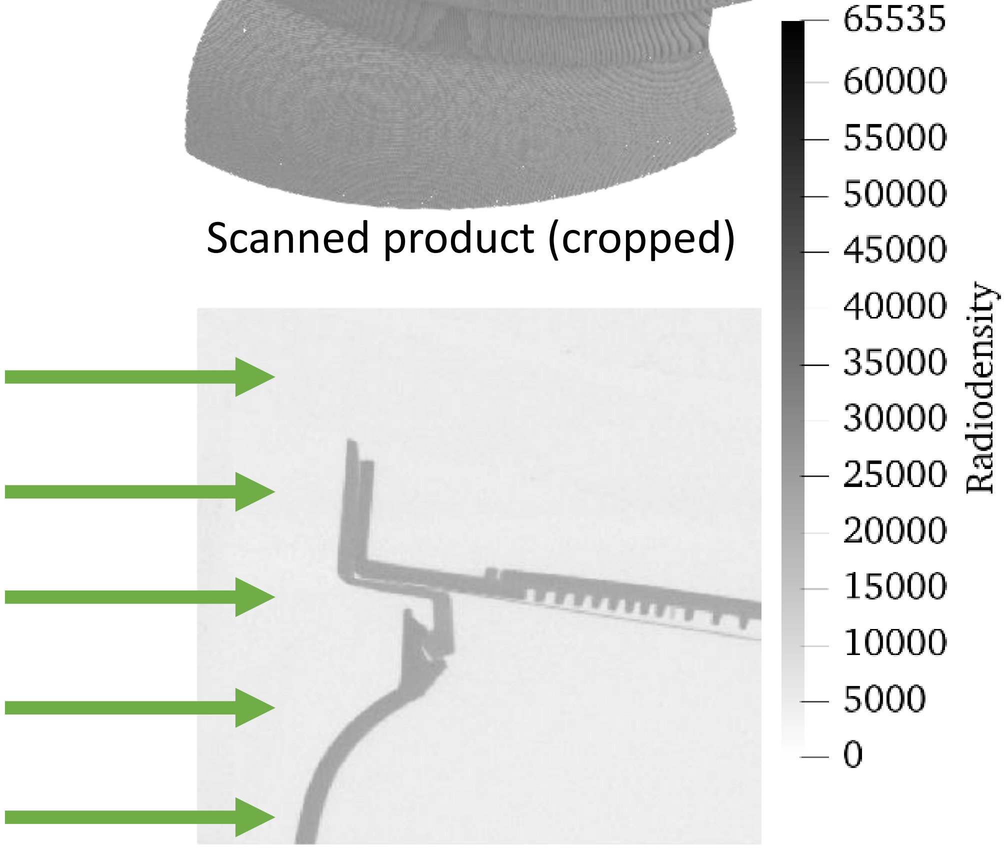
- Product acquired with CT scan of very good resolution
- Original voxel size: 32.4x32.4x32.4µm^3
- Original voxel count: near 4.5 billion
- Size of the file: 9 GB

  → **Need to resample image in order to optimize computing resources**
- Resampling to voxel size: 135.6x136.2x130.7µm^3
- New size of the file: 120 MB

  → **Way better**
- Segmentation using radiodensity of materials:
  - between 18k and 25k → Water with adapted density
  - other → Air
- Simulation:
  - Irradiation with a monoenergetic electron beam of 400 keV

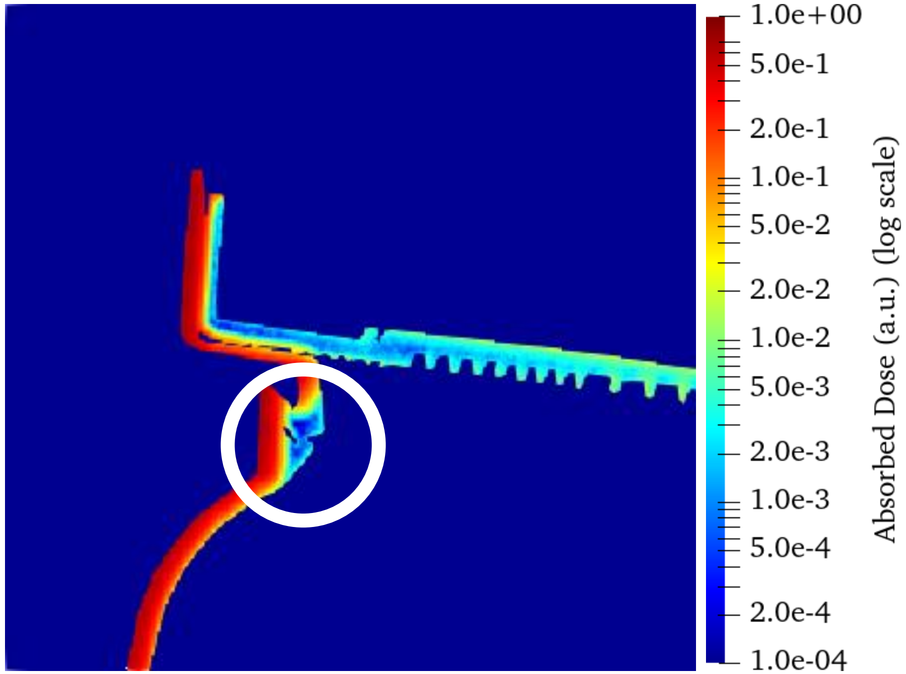


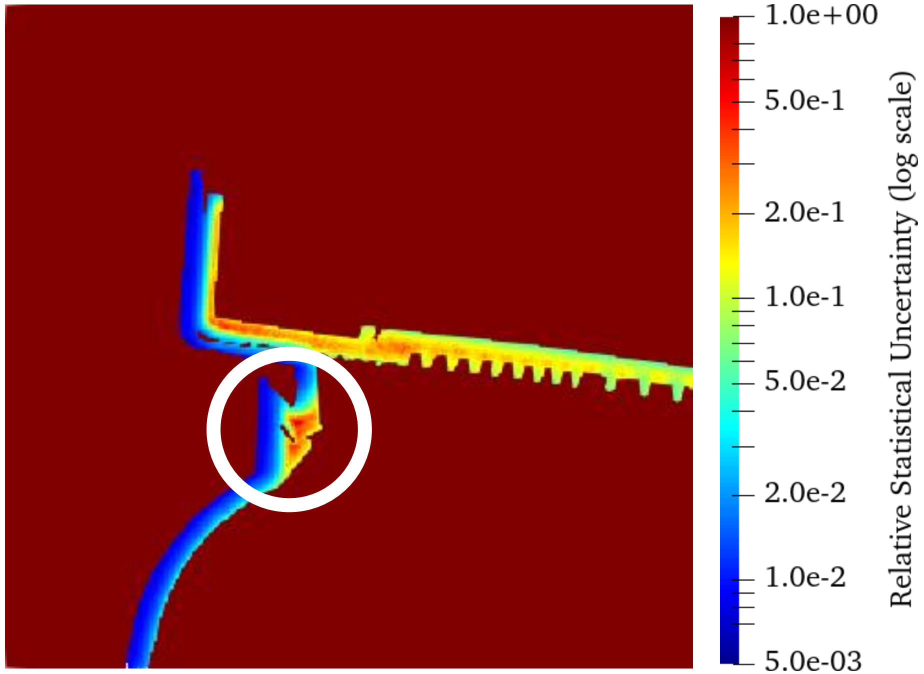
Scanned product (cropped)



Results

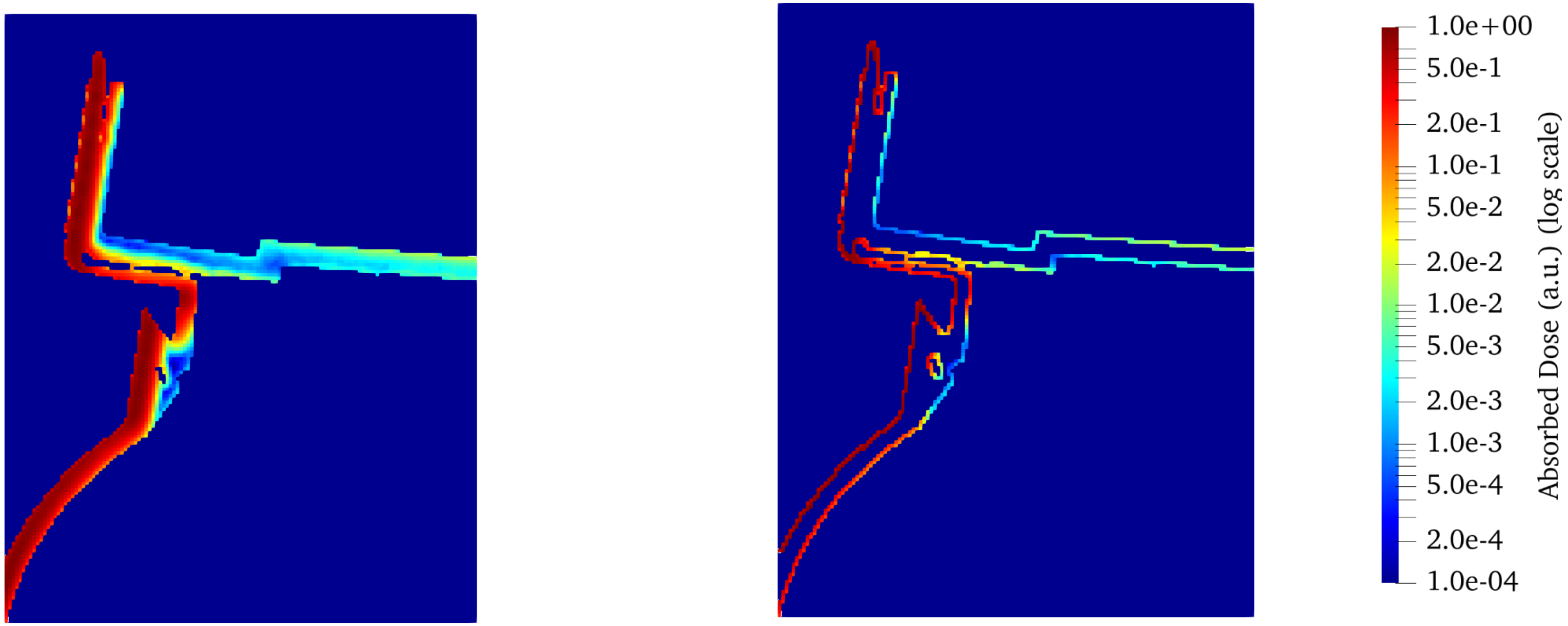
- 45 cores (Intel Xeon Platinum)
- Number of electrons: 2e8 per core
- (9e9 total)
- Simulation time: 360 h
- Actual duration: 8 h (parallelization)
- 2.5 GB of RAM per core (113 GB total)
- Very good uncertainty at entrance surface (< 5%)
- Dose distribution can easily be visualized (cold/hot spots)





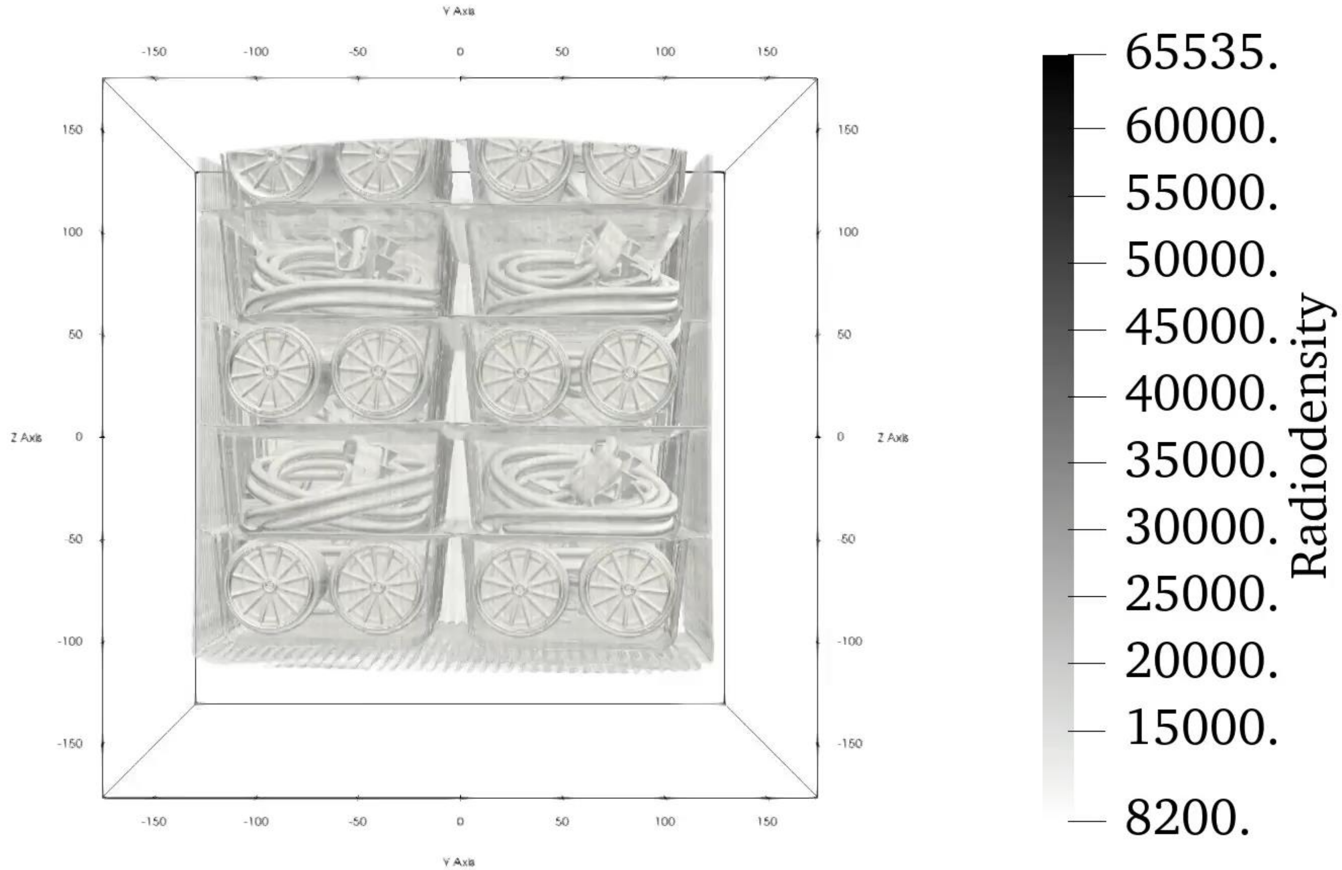
Outputs are depending on region of interest

Dmax (Dmin) considering the whole body (flesh) of the product vs …
… considering ‘skin’ only

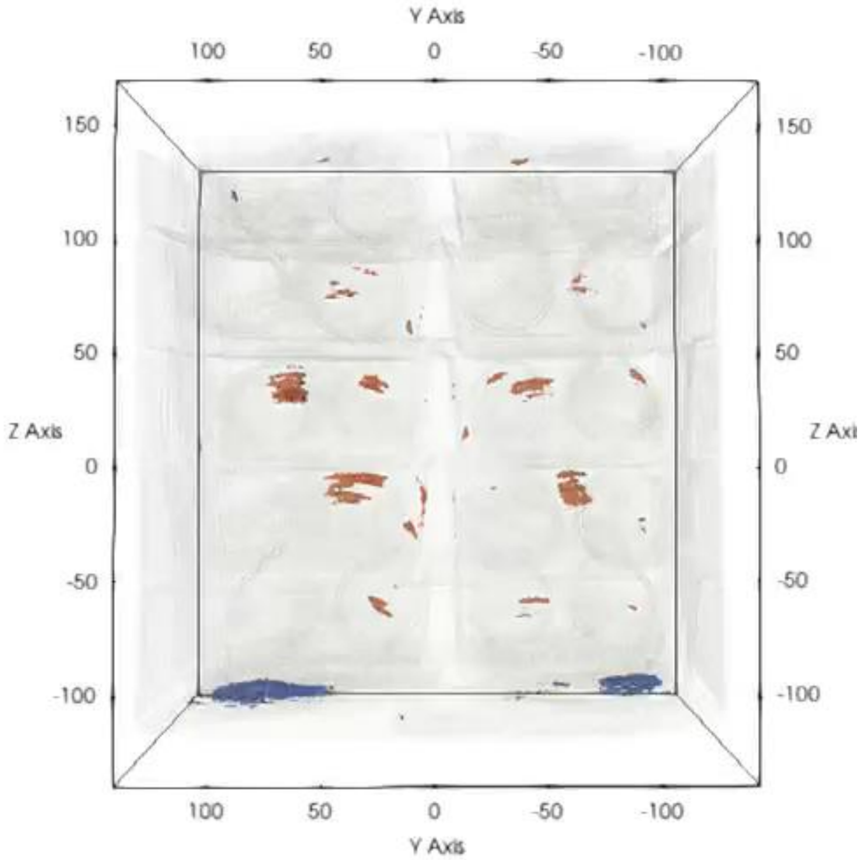


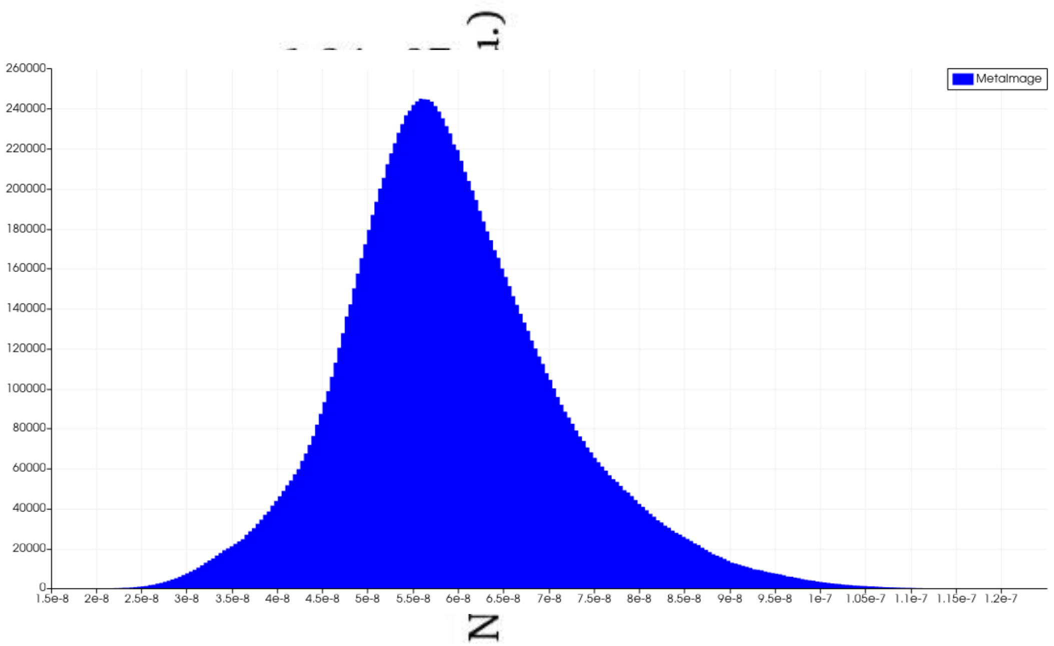
→ Location and values of extreme doses and dose distribution may change

Example 2: High energy EB irradiation of a sterility test device



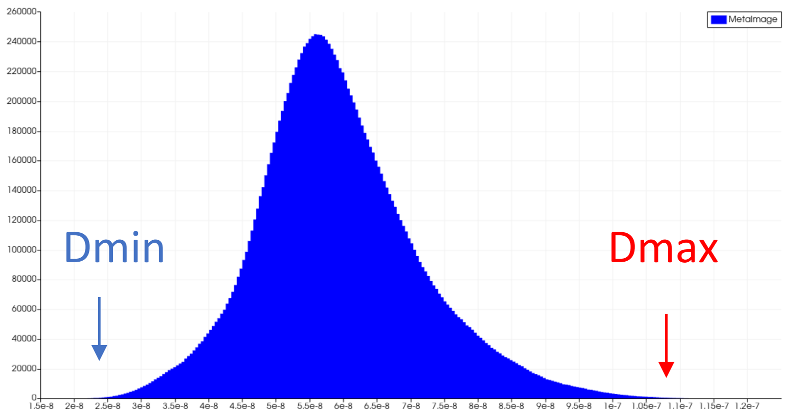
Example 2: High energy EB irradiation X Axis

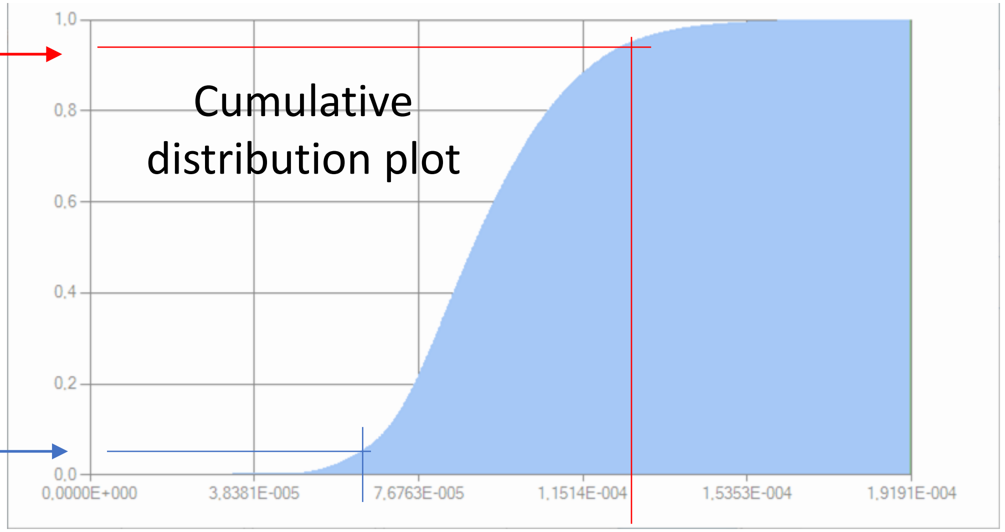




→ Dose in water (Bragg Gray Cavity Theory Dw = Dmed * Sw,med)

What about DUR ? (DUR= Dmax / Dmin)





Statistics

Sum:	1483.094583	Count:	16855449
Mean:	8.798903E-005	Std. Dev.:	1.794905E-005
Minimum:	2.774699E-005	Maximum:	1.832487E-004

☑ Exclude Zero

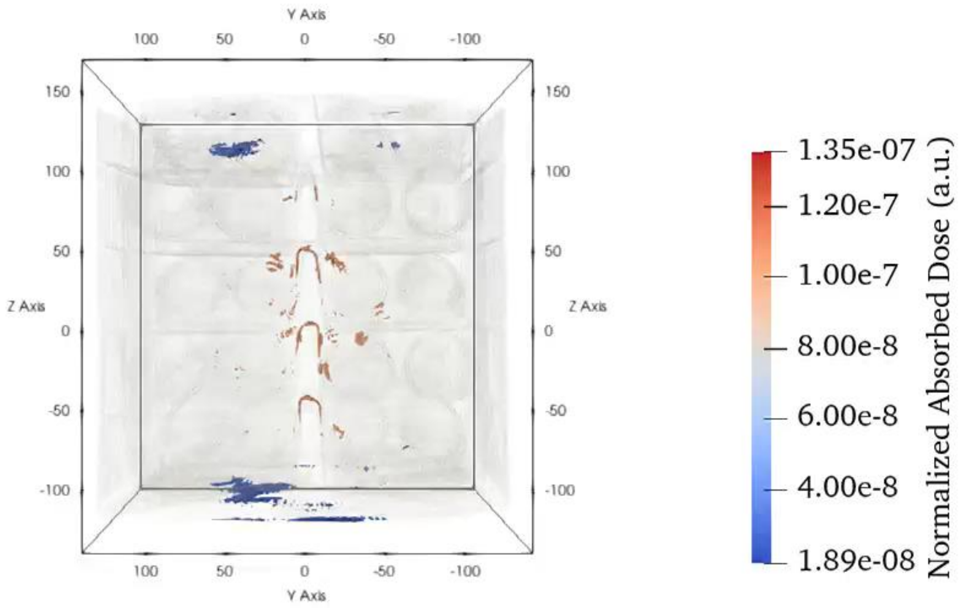
Dose Uniformity Ratio

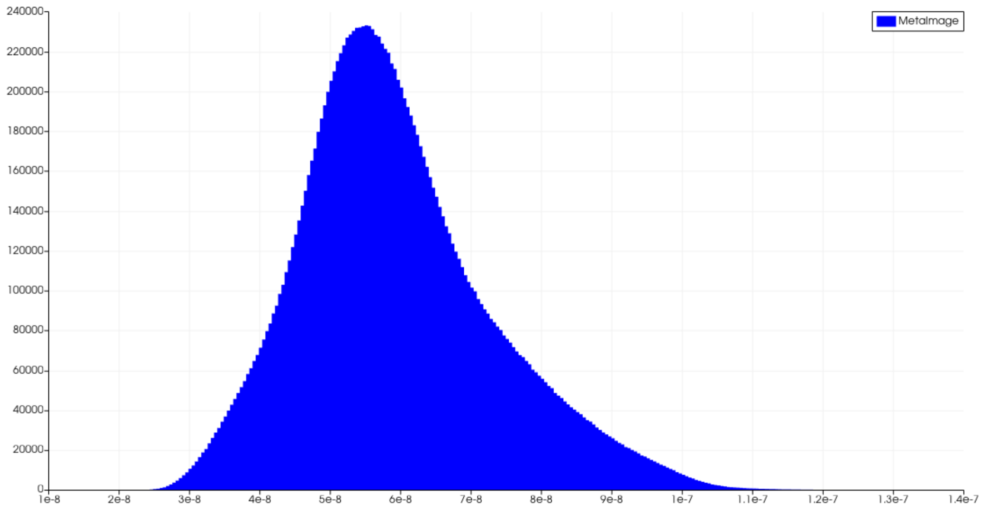
DUR: 6.604274

○ Min. Max. Ratio
◉ Percentile Value

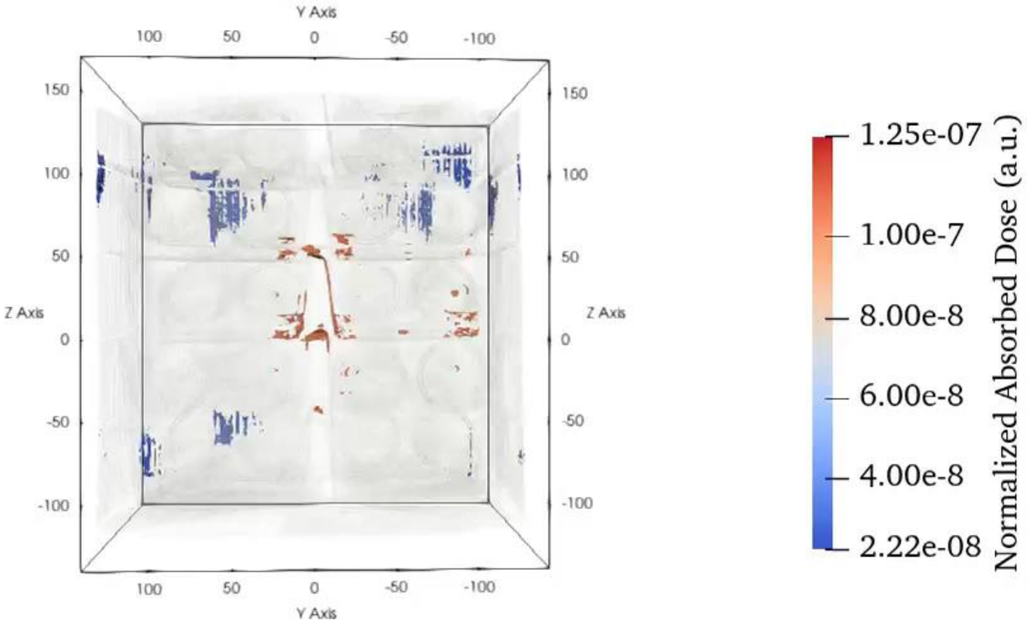
Min. Percentile (%):	5	Min. Percentile Value:	6.046813E-005	Min. Ratio (%):	117.926804
Max. Percentile (%):	95	Max. Percentile Value:	1.205765E-004	Max. Ratio (%):	34.200619
	Refresh	Percentile Value DUR:	1.994051		

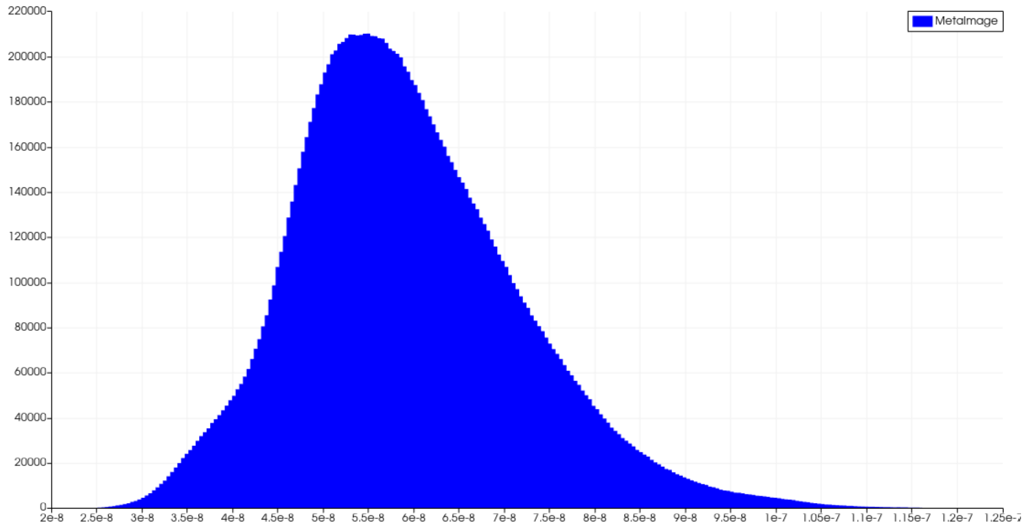
High Energy Ebeam irradiation Y Axis



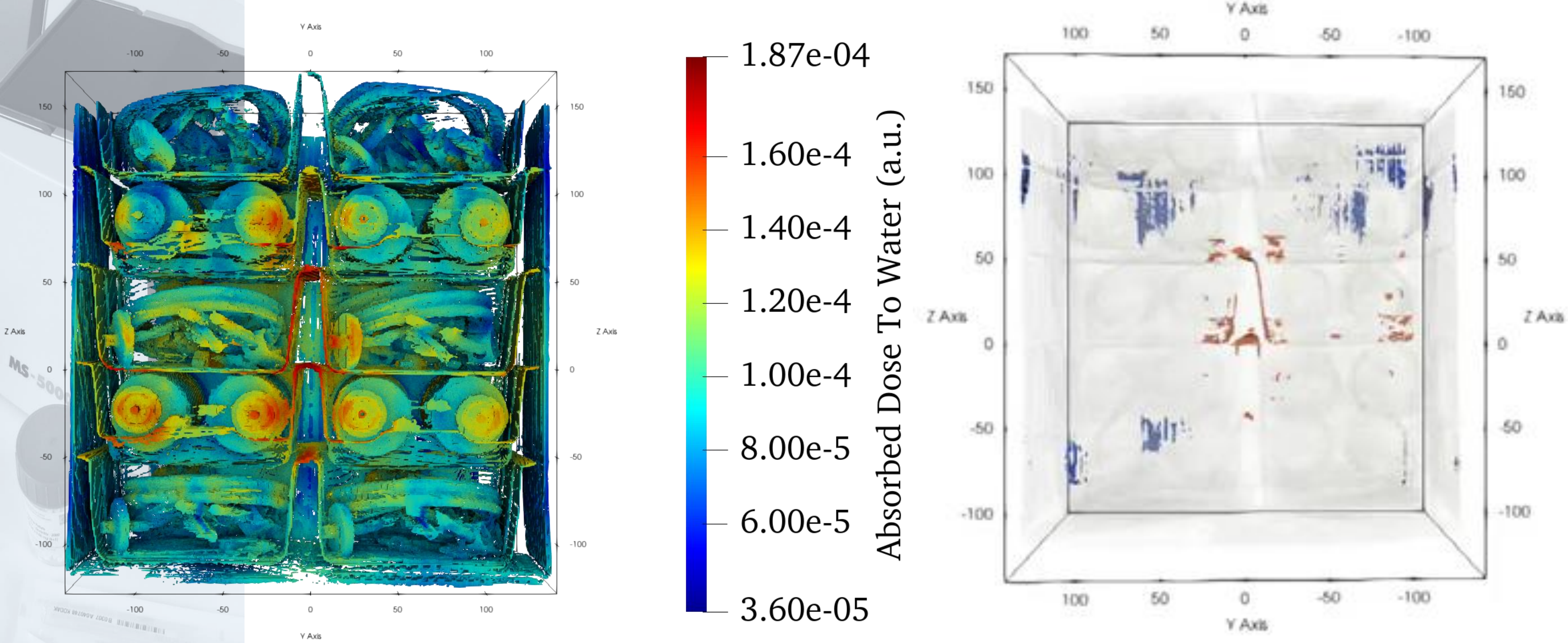


High Energy Ebeam irradiation Z Axis

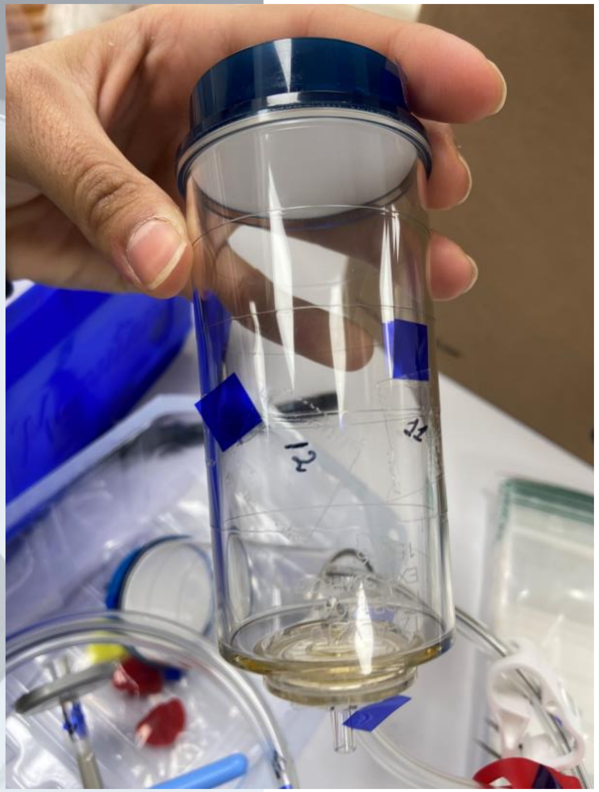




High Energy Ebeam irradiation Z Axis



High Energy Ebeam irradiation Z Axis



Irradiation orientation	DUR (1-99%)	DUR (5-95%)	DUR Exp.
X Axis	2.79	1.99	---
Y Axis	2.96	2.20	---
Z Axis	2.74	1.99	**1.93**

→ **Good agreement for 5-95% percentile**

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Conclusion: What are the limitations/challenges?

- Voxelized image resolution limitations:

  - Too low:
    - - blurry interfaces
    - - difficulties to segment product materials
    - + less time to converge

  - Too high:
    - - large memory consumption
    - - high computation time to converge
    - + high precision of dose maps

→Voxel resolution optimization is a key point to master

- Size of product may dictate the resolution
- Use more CPU cores or GPU based computation

Conclusion: What are the limitations/challenges?

- Segmentation of material by radiodensity:
  - Need for reference material while scanning the product
  - Need for automated segmentation

- Development of new tools:
  - GPU based computation
  - Auto segmentation
  - Image processing/editing
  - AI/e-learning for auto analysis
  - Procedure/guides

→ The project is launched at Aerial. Welcome to our partners!

Conclusion: Real product modelling raises many questions

- What should be the output(s) of the REAL product simulation?
  - Optimization of irradiation orientation/help to MD manufacturer
  - Location of min and max dose zones
  - Assessment of DUR
- Where do we need to 'measure' the dose?
  - Dmin in skin (and flesh) depending on location of contaminants
  - Dmax probably in flesh
- How to choose Dmin and Dmax?
  - Refer to what a dosimeter is capable of?
  - Consider minimum size, surface, volume of the dose zone?
  - 5% and 95% of cumulative distribution of dose?
- CT scan image with dosimeters?
  - Might be necessary for acceptance and validation of modelling
- Do we need to create a new or update a standard?
  - ASTM E2232-21 Standard Guide for Selection and Use of Mathematical Methods for Calculating Absorbed Dose in Radiation Processing Applications

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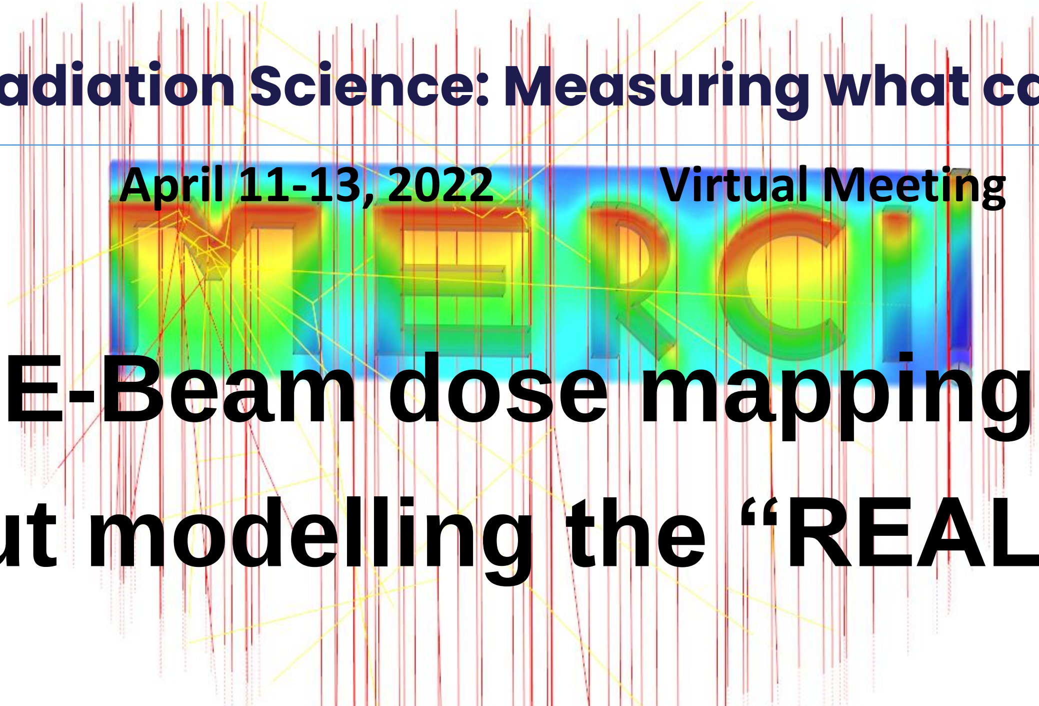

E-Beam dose mapping:

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Aerial

Abbas NASREDDINE
Ph.D, Research Scientist
a.nasreddine@aerial-crt.com

Thomas DESCHLER
Ph.D, Research Scientist
t.deschler@aerial-crt.com

Florent KUNTZ
Ph.D, Project Manager
florent.kuntz@aerial-crt.com

La bonne dose d'innovation*

* the best dose of innovation