Dose Mapping in Industrial Irradiation

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IBA

CIRMS Annual Meeting

October 23rd 2007

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Outline

- **Introduction:**
  - Dosimetry
  - Monte Carlo Radiation Transport Codes
- **Dose Mapping in Gamma Irradiation Vault**
- **Dose Mapping in X-ray Irradiation Systems**
- **Dose Mapping in E-beam Irradiation Systems**
  - Irradiation of boxes
  - Irradiation of fiber spools
- **Conclusions**

Dosimetry

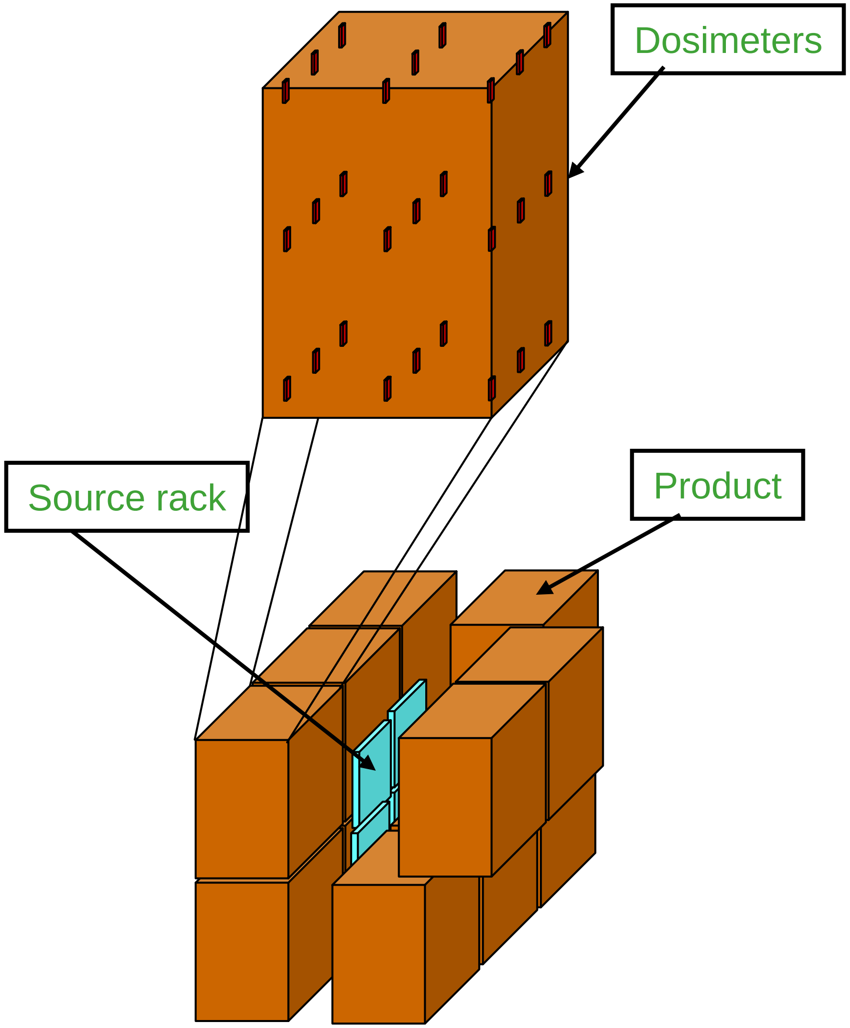
- **In industrial irradiation, radiation doses usually range between 1 kGy and 100 kGy.**
- **This kind of dose can be measured by many types of dosimeter (~15 standard practices found in ASTM).**
- **The most commonly used among them:**
  - Radiochromic dyed dosimeters (Far West, Gafchromic);
  - PMMA dyed dosimeters (Red-perspex, Gammachrome);
  - Alanine-EPR dosimeters (pellets, film);
  - Cellulose triacetate (CTA) film dosimeters.
- **These dosimeters allow the measurement of absorbed doses at point-like locations or along a line (CTA).**

Monte Carlo Simulations

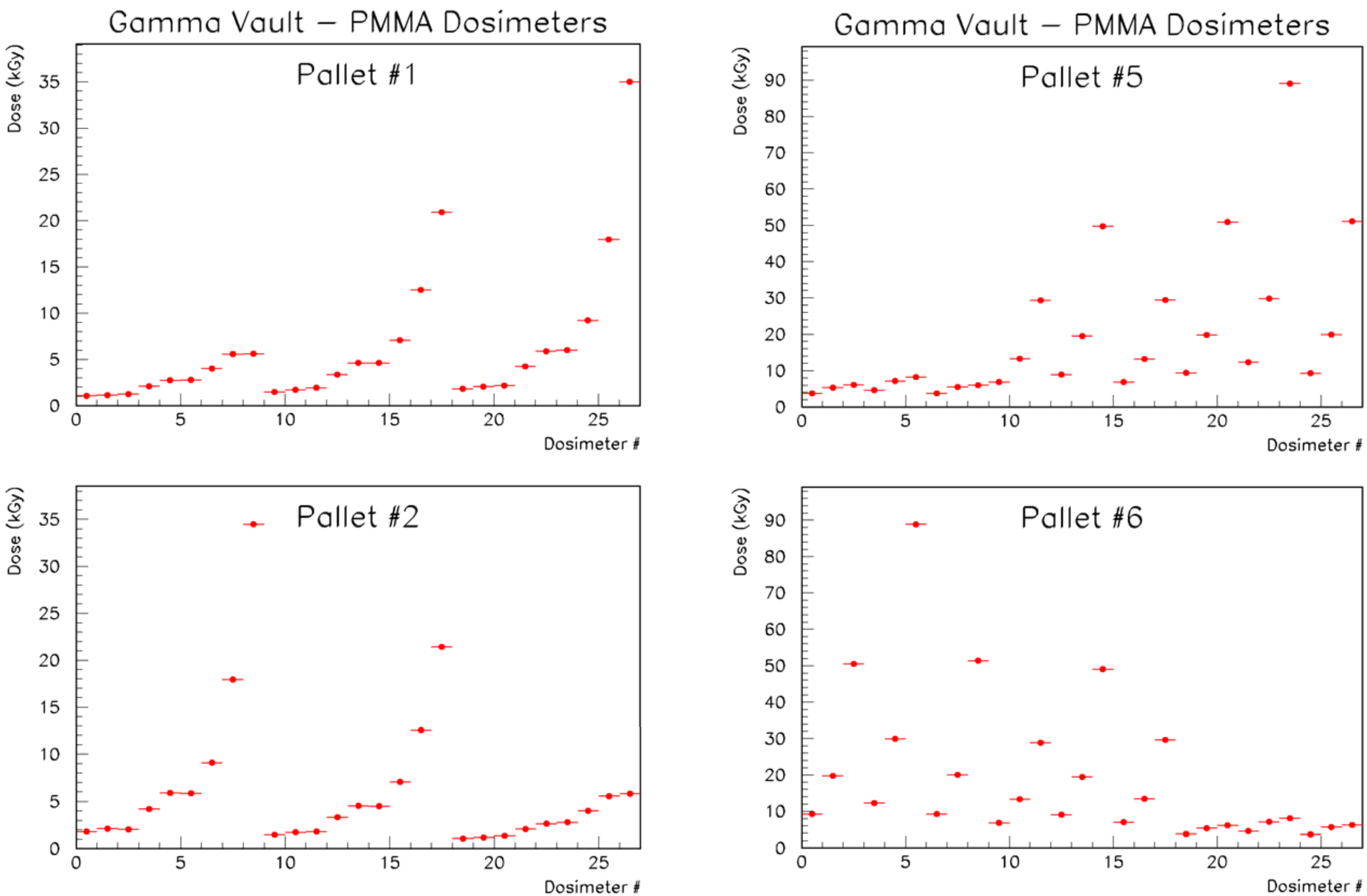
- **GEANT (Geometry and Tracking)**
  - Developed at CERN to simulate High-Energy Physics experiments.
  - Transport of electrons, photons and protons.
  - Computation of total cross sections and generation of final state particles based on physics models.
  - Basic treatment of nuclear reactions based on the GEISHA and FLUKA packages
  - First version written in 1974, last version 3.21 released in 1994.
- **MCNPX (Monte Carlo N-Particle eXtended):**
  - Developed at Los Alamos National Laboratory
  - Extension of MCNP4B for accelerator physics
  - Transport of all particles (n,e, γ, protons, ''heavy ions'', pions…)
  - Experimental nuclear data up to 20 MeV (150 MeV)
  - Possibility to mix nuclear data and models (Mix & Match)
  - Last official version 2.5.0 released in June 2005.

Simplified Gamma Vault Modeling

- Benchmarking exercise in the framework of the Modelling group of the electron/gamma irradiation panel.
- Modelling of simplified gamma irradiation vault using MCNPX.
- Goal: compute dose rates obtained in PMMA dosimeters located in a 3 x 3 x 3 array. Compare ''Modelling time'' and results between different MC codes such as MCNPX, GEANT4, EGS,…
- Dose rates are computed in static configuration where boxes do not move in time.

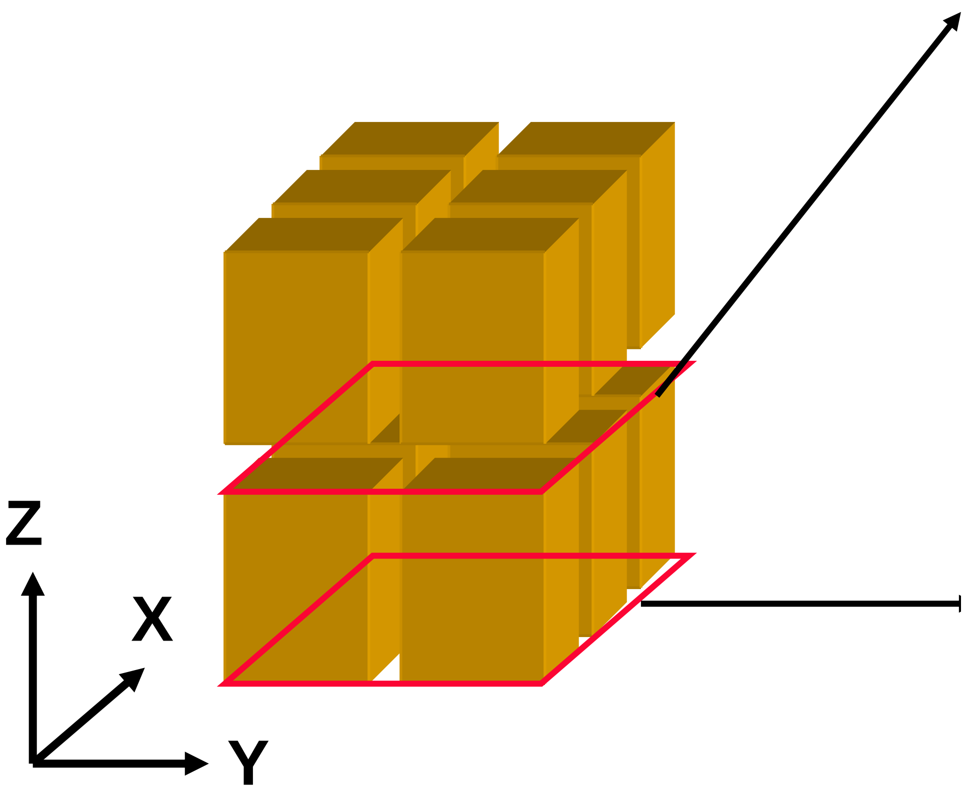


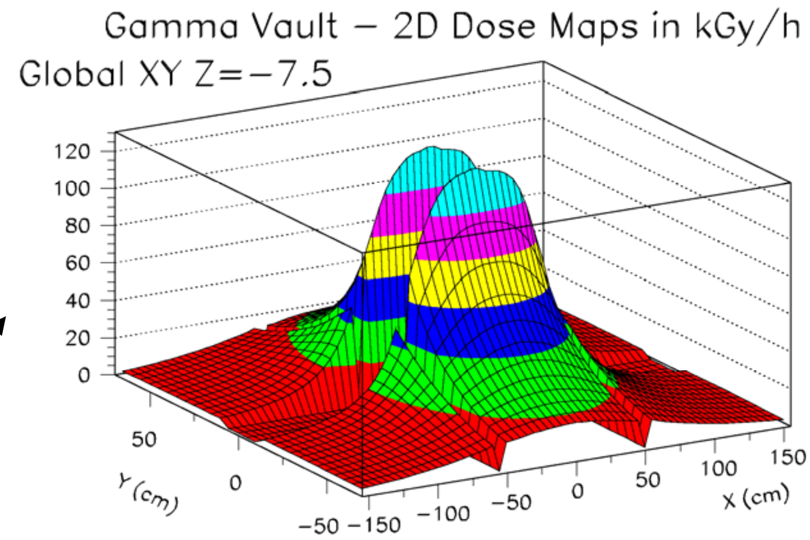
Dose Rates in Individual Dosimeters

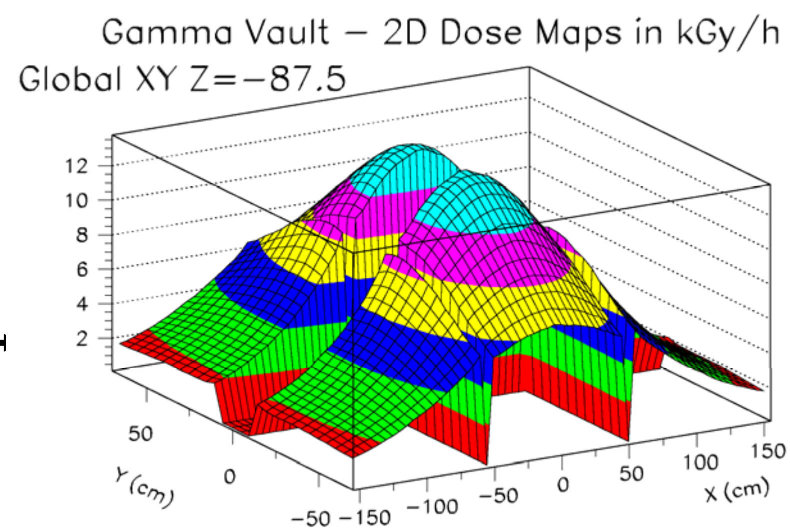


MC Study: 2D Dose Mappings (1)

MCNPX Mesh Tallies allow to evaluate 2D dose mappings anywhere in the geometry







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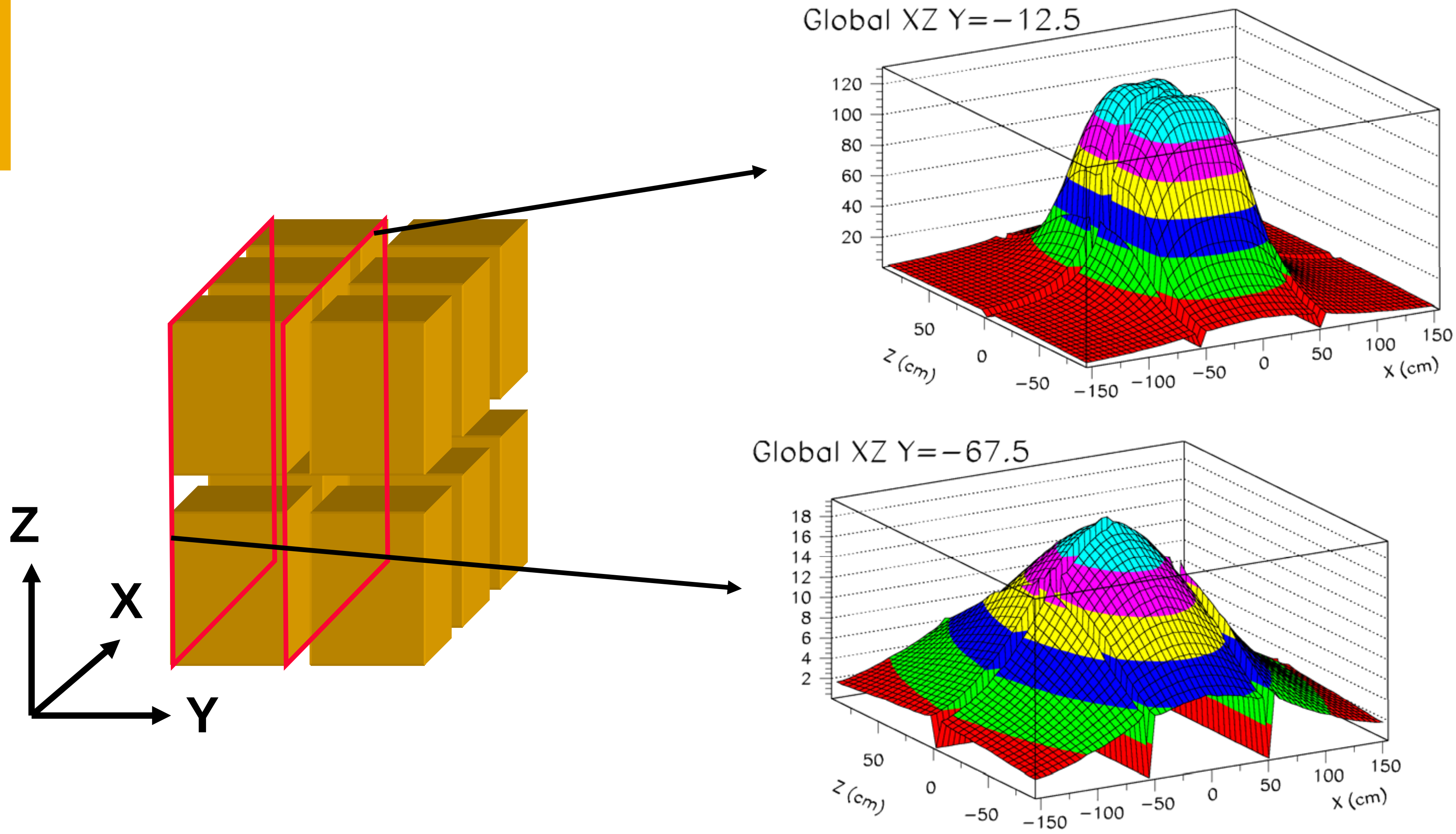
MC Study: 2D Dose Mappings (2)



Design of a High Dose Uniformity X-Ray System for Food Irradiation

- **MDS Nordion and IBA have developed a new concept for advanced pallet irradiator, called the Palletron™ .**
- **That system is based on a high-energy X-ray source, using 5 to 7 MeV electron beam accelerators.**
- **System designed to treat standard pallets (40"x48"x72") without depalletization →**
  - Save packing/unpacking time and efforts
  - Limit the product handling to a minimum
  - Preserve pallet integrity during treatment
  - Improve treatment capacity
- **Developed for food products with high density (up to 0.8 g/cm^3), this pallet irradiator must achieve a DUR better than 1.5 in all cases.**
- **X-ray properties allow the obtention of very good dose uniformity while preserving a high treatment capacity.**

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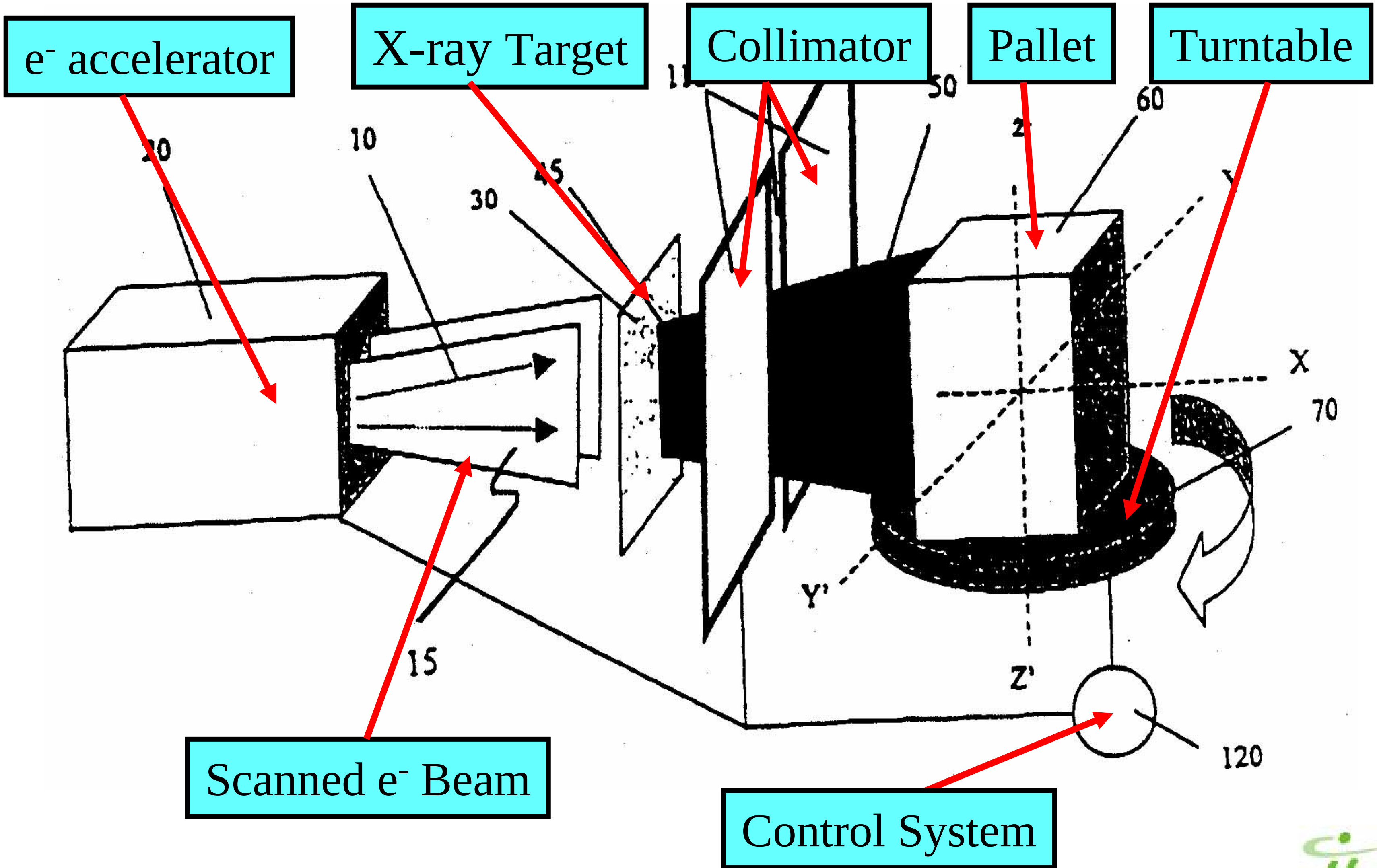
The Palletron™: Main Elements



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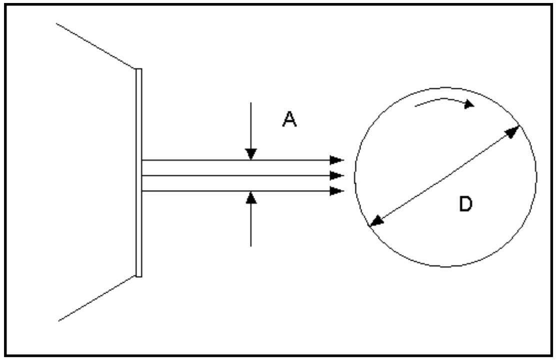
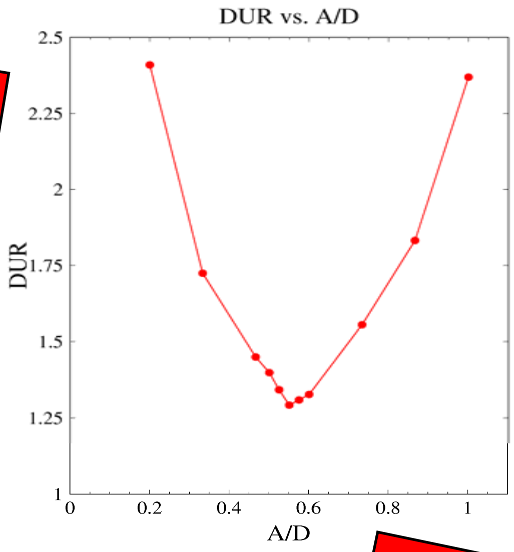
The Palletron^{TM}: Basic Concept

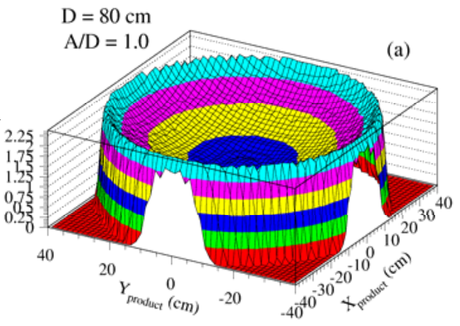
Cylinder irradiation by X-rays



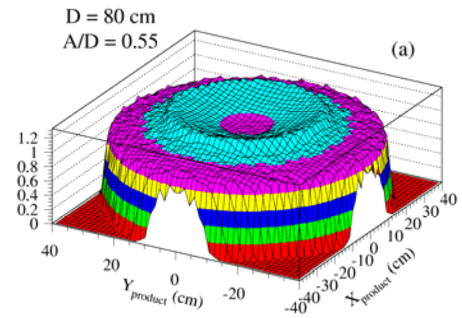
D= 80 cm / ρ= 0.8

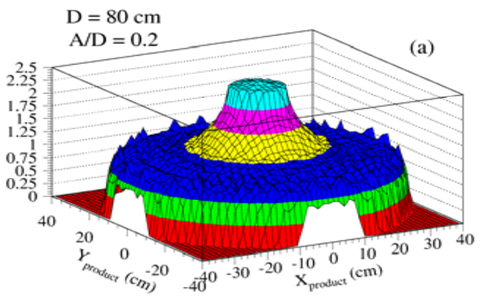


DUR versus A/D



A/D = 1





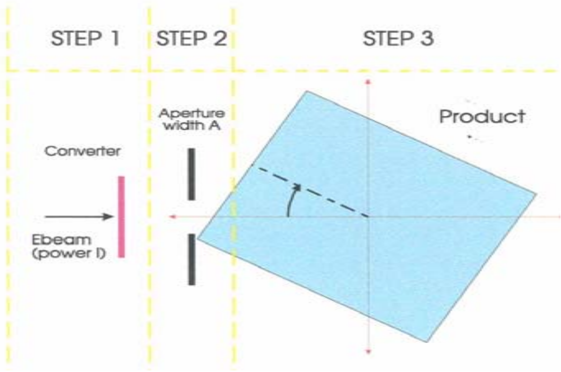
A/D << 1

⇒ Optimal A/D = 0.55

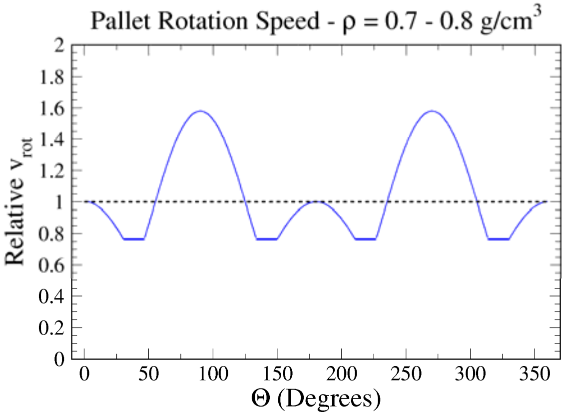
Irradiation Parameters

- Industrial pallets:
  100 x 120 x 180 cm^3
- Product density:
  0.1 - 0.8 g/cm^3
- Irradiation parameters:
  - Pallet rotation
    - Speed profile
    - Rotation time
  - Collimator aperture
  - E-beam scanning on target

Irradiation of rectangular footprint

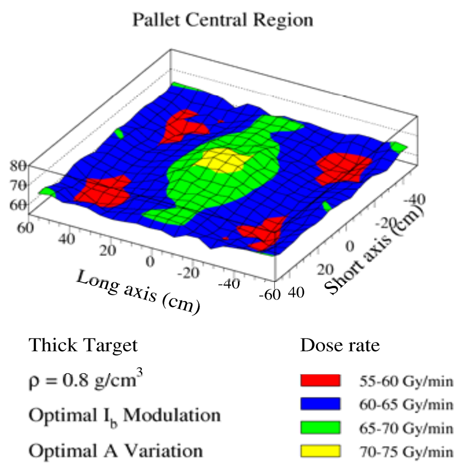


⇒ Non-uniform rotation speed



Monte Carlo Simulations

- **Palletron™ development based on Monte Carlo simulation tools:**
  - MCNP4 for Nordion
  - GEANT3 and MCNPX for IBA
- **Generation of X-rays by 5 to 7 MeV electrons impinging on a Ta target.**
- **Simulate absorption of these photons in the collimators and the product.**
- **Pallet movement approximated by 2° rotation steps with different weights.**
- **Checked that GEANT and MCNP give similar results.**



GEANT

DUR = 1.30
D_{min} = 56 Gy/min

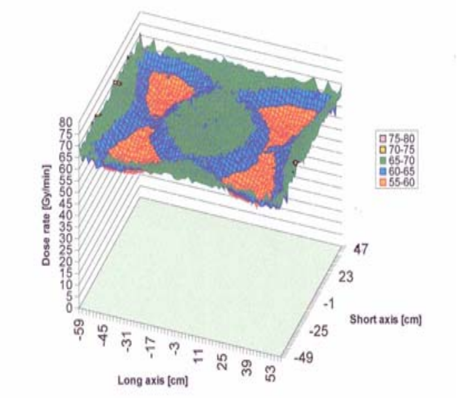
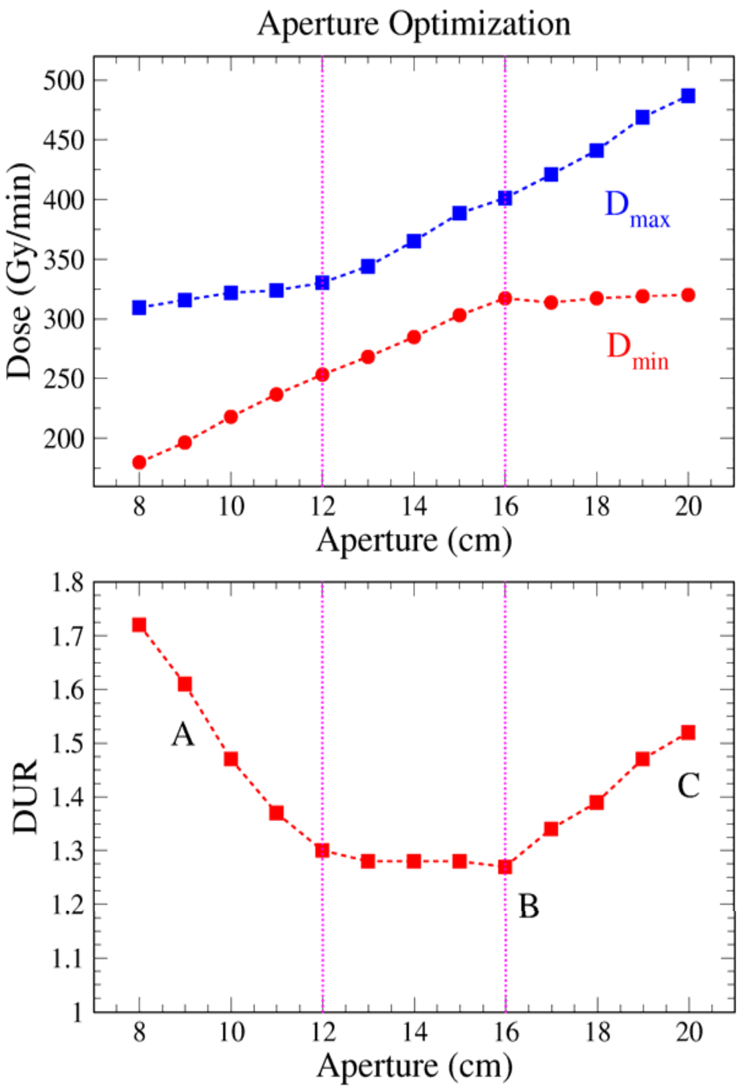


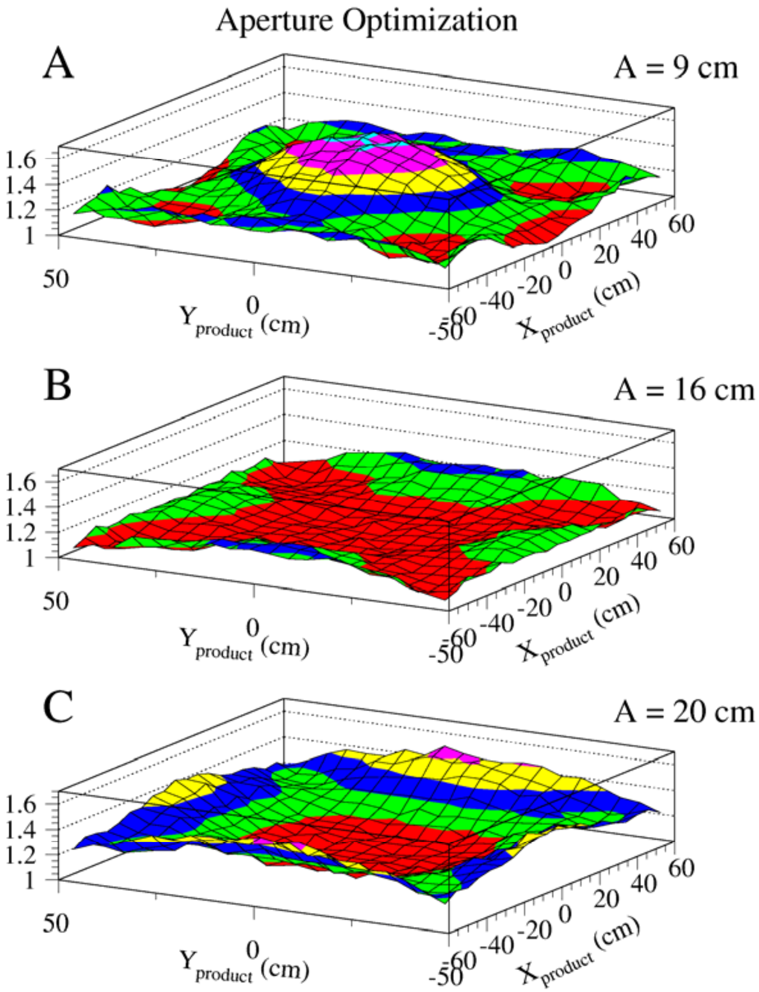
Figure 11 *Result for the centre slice of 0.8 g cm^{-3} WE product (Max/Min of 1.29). Obtained with full control of the aperture and beam power*

MCNP

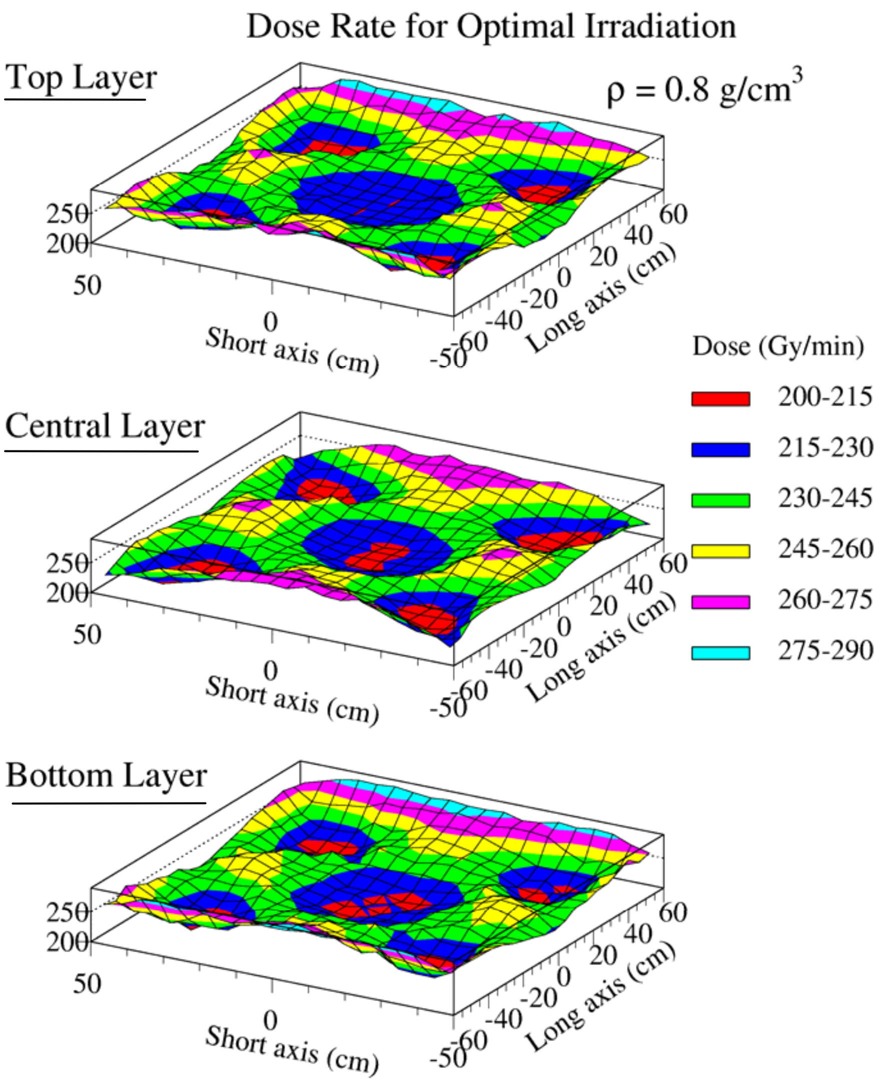
DUR=1.29
Dmin = 55 Gy/min

Aperture Optimization





Dose Distributions in Horizontal planes



2D dose distributions in top, central and bottom layers of a pallet

Central DUR = 1.3

Global DUR = 1.4

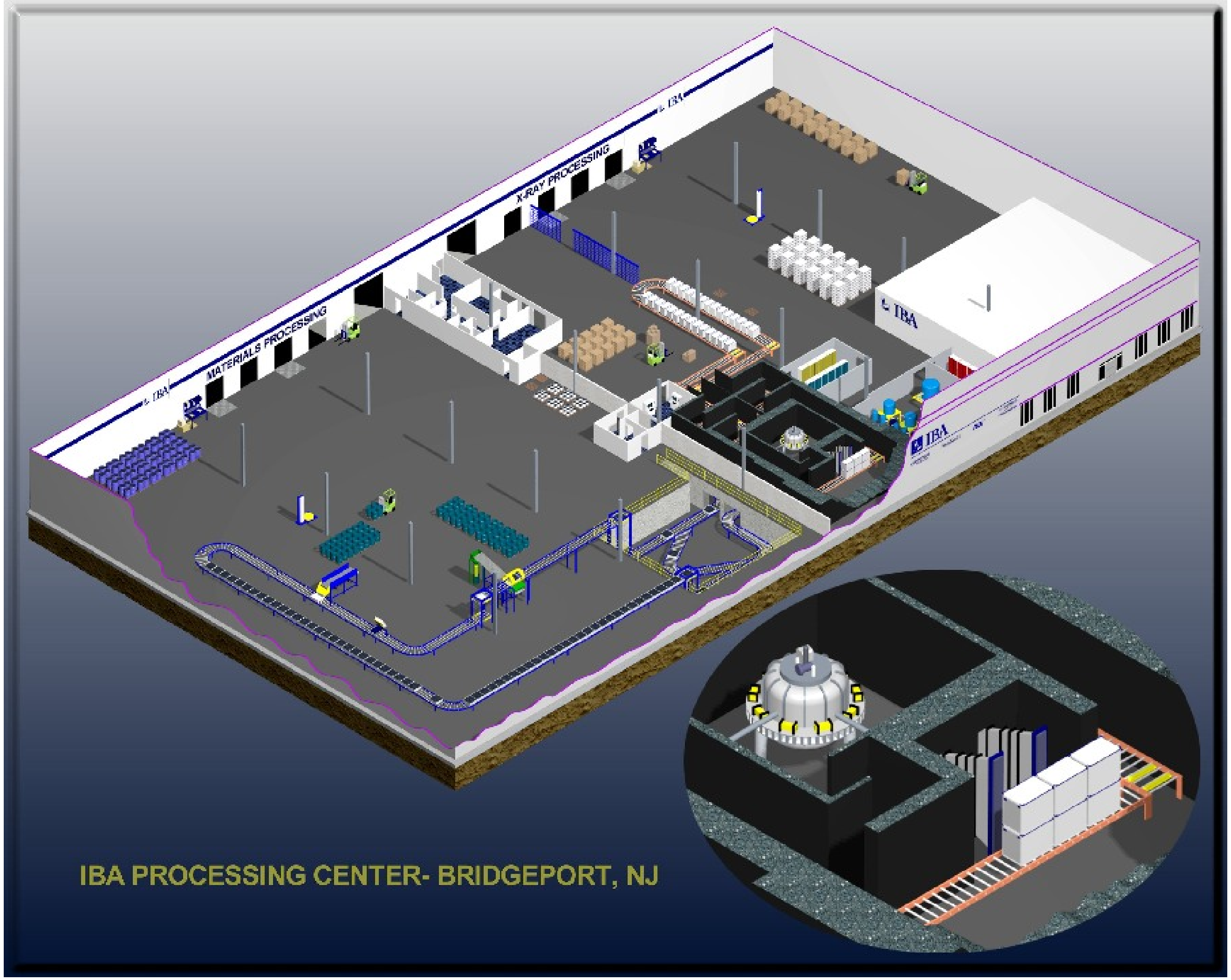
Palletron^{TM} Validation Tests

- **Irradiation at Bridgeport (New Jersey) of 40” x 48” x 60” pallets loaded with various materials:**
  - Medium-density fiberboard (MDF): density = 0.76 g/cm^3
  - Plywood plates: density = 0.57 g/cm^3
  - Cardboard + paper: density = 0.18 g/cm^3
- **Turntable with various speed profiles.**
- **Collimators made of 200 cm x 40 cm x 2 cm steel plates stacked together to obtain a total thickness of 10 cm. Manually moved to define the required aperture.**
- **CTA dosimeter grids + Far West (FWT) dosimeters located at various heights inside the pallet.**
- **Optimal run parameters determined by MC.**

Bridgeport Irradiation Center

E-beam Side

X-Ray Side

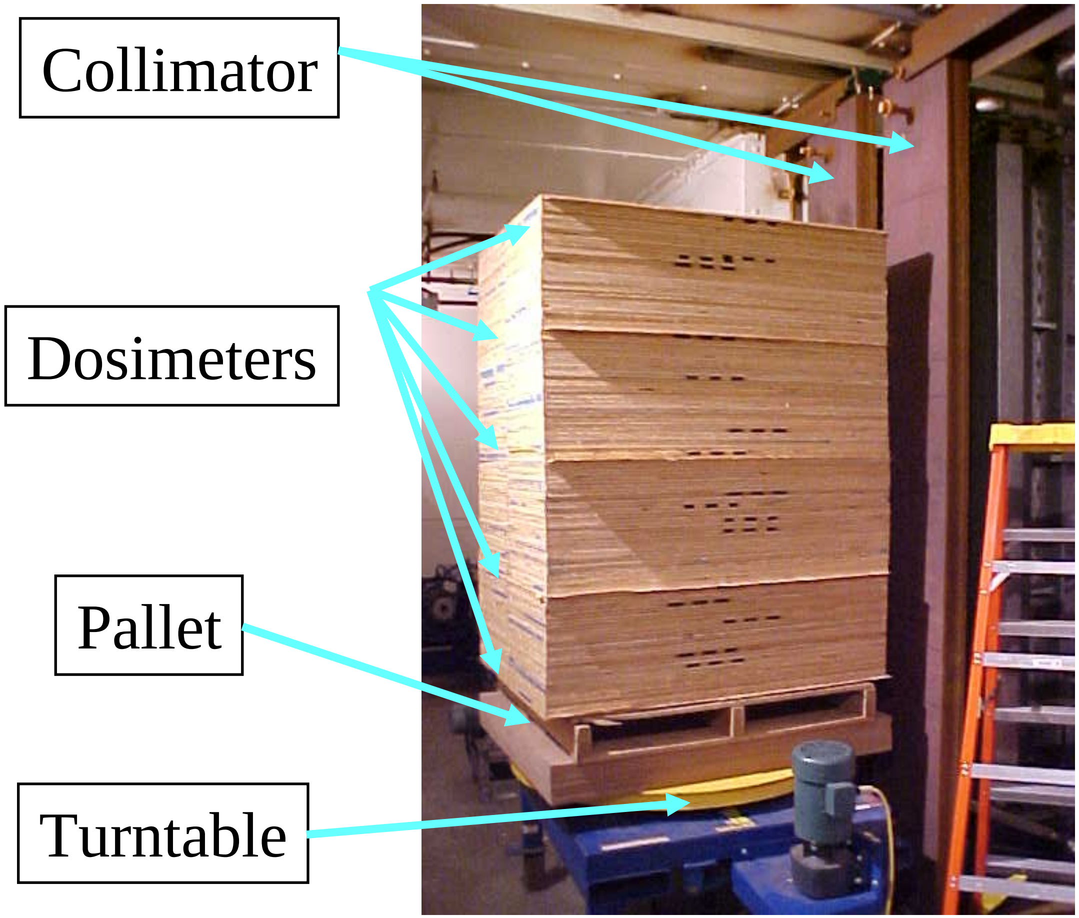


Bridgeport X-ray Irradiation Cell

5 MeV and 7 MeV X-ray targets / up to 25 mA beam current / 2 meter scanning width

Palletron™ Validation Tests (2)

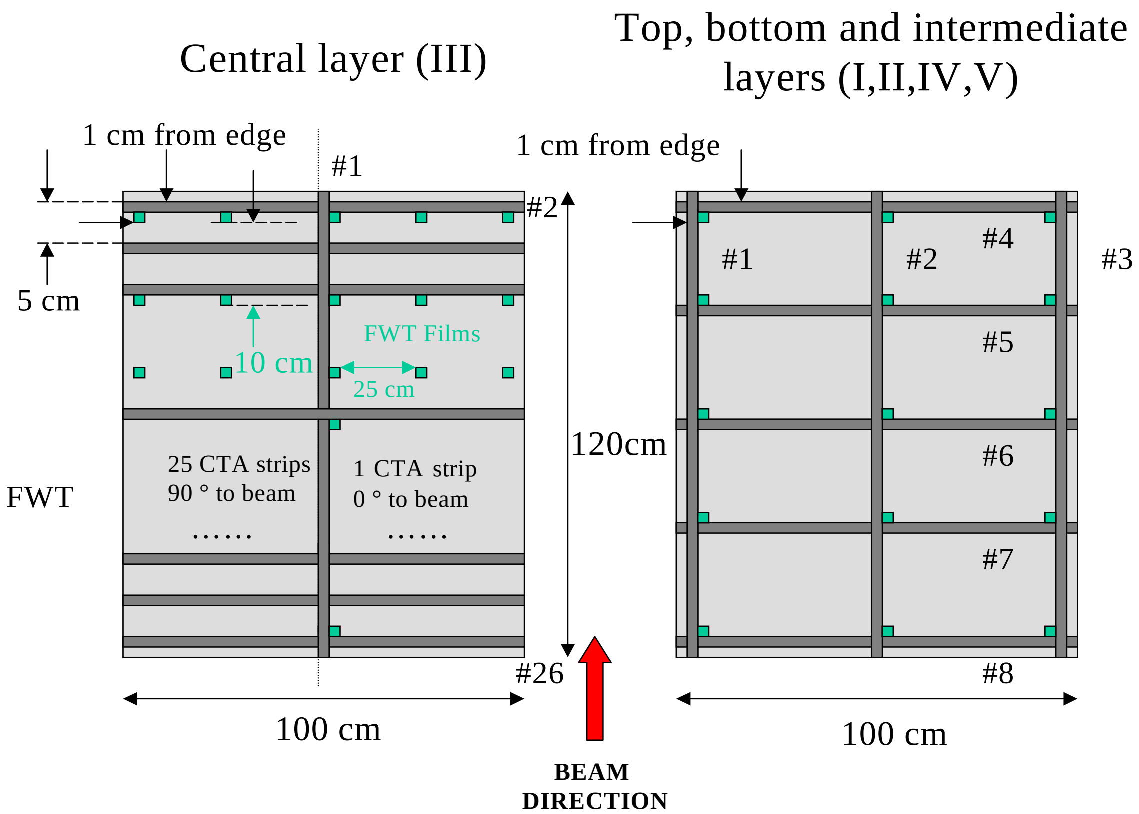
$\rho = 0.57\ g/cm^3$ – 5 MeV



$\rho = 0.76\ g/cm^3$ – 7 MeV

Palletron™ Validation Tests (3)

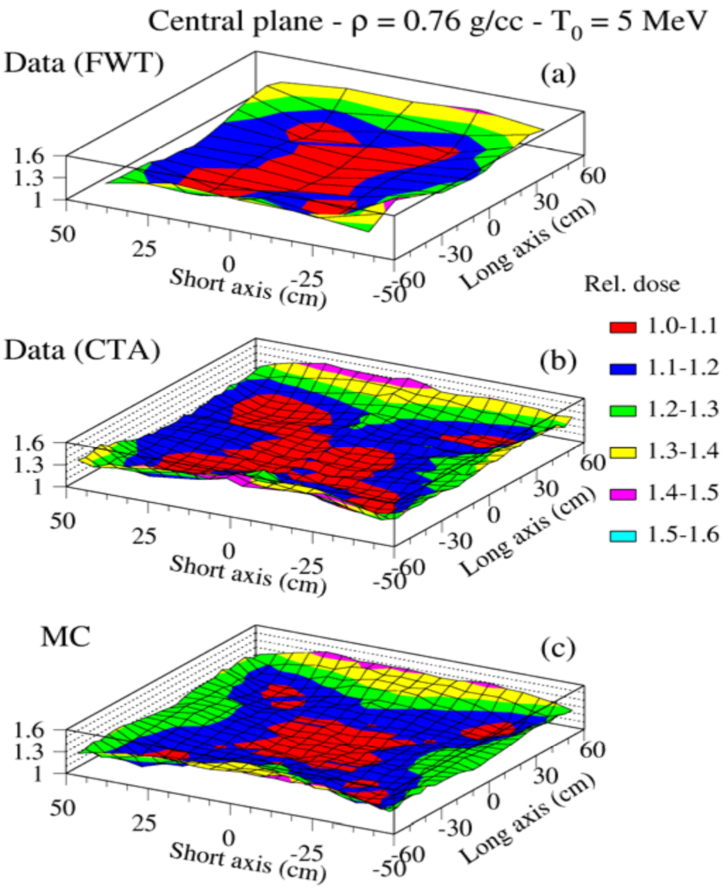
- **To perform precise 2D dose mapping in horizontal plane, use a fine grid of CTA strips and FWT dosimeters, especially in central layer.**



Study & Validation of Dose Uniformity (1)

$\rho = 0.76\ g/cm^3 - T_0 = 5\ MeV$

Layer	FWT	CTA	MC
I (Bott.)	1.18± 0.08	1.37± 0.10	1.41± 0.04
II	1.39± 0.10	1.56± 0.11	1.43± 0.03
III(Center)	1.50± 0.11	1.51± 0.11	1.45± 0.03
IV	1.34± 0.09	1.56± 0.11	1.45± 0.03
V (Top)	1.21± 0.09	1.42± 0.10	1.37± 0.04

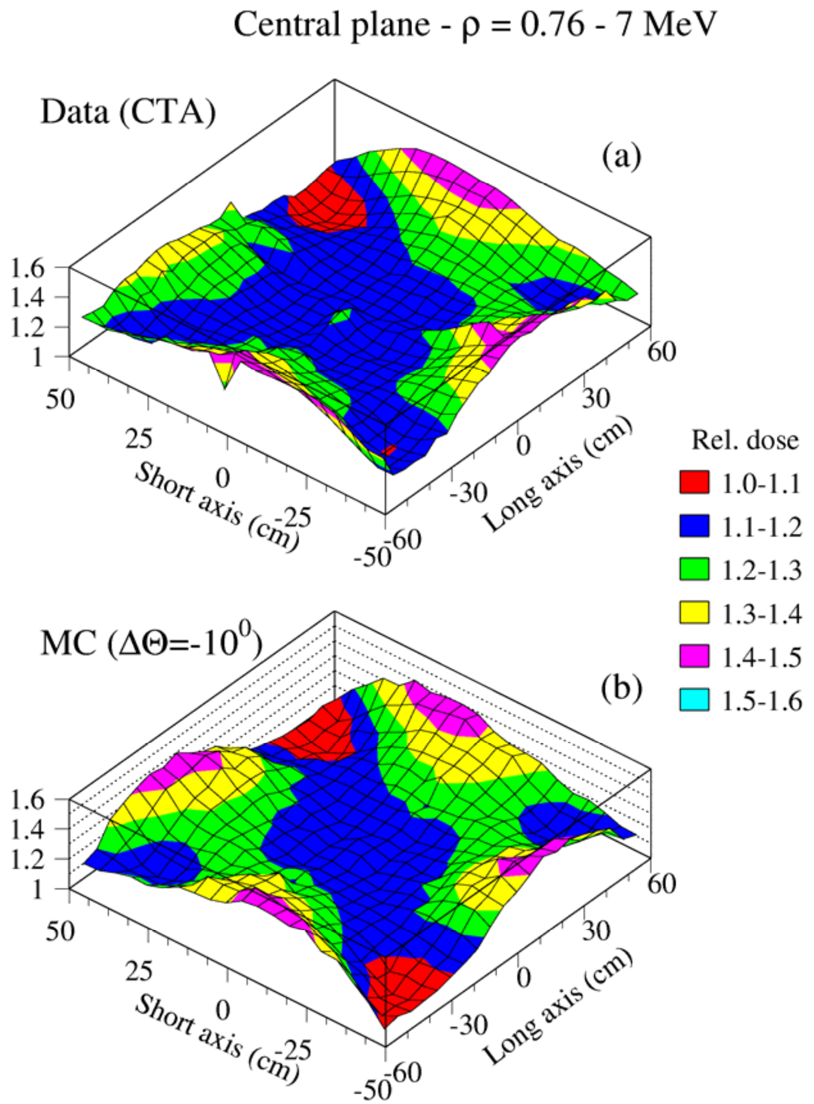


Study & Validation of Dose Uniformity (2)

0.76 g/cm^3 – 7 MeV

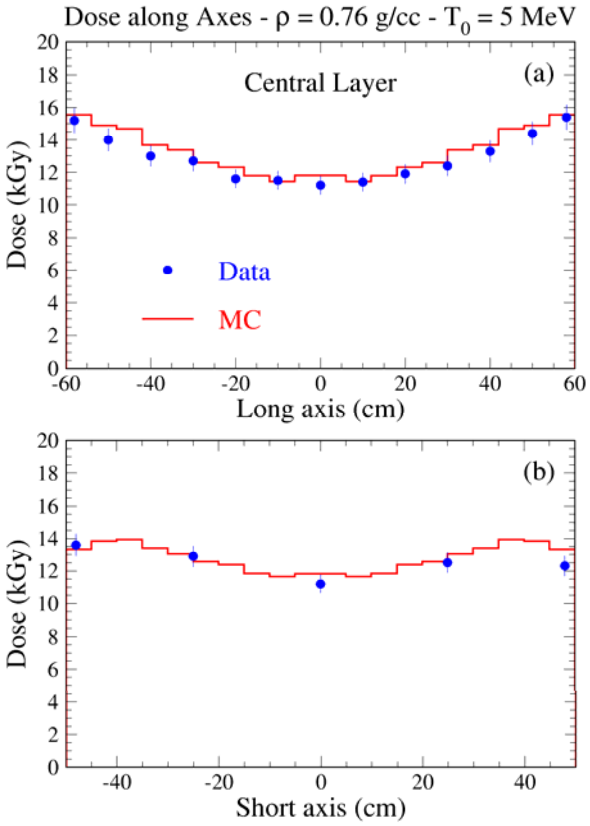
- The data show a clear asymmetry in the dose distribution.
- This asymmetry can be accurately reproduced by the MC when introducing a shift of 10° between the true position and the expected one.

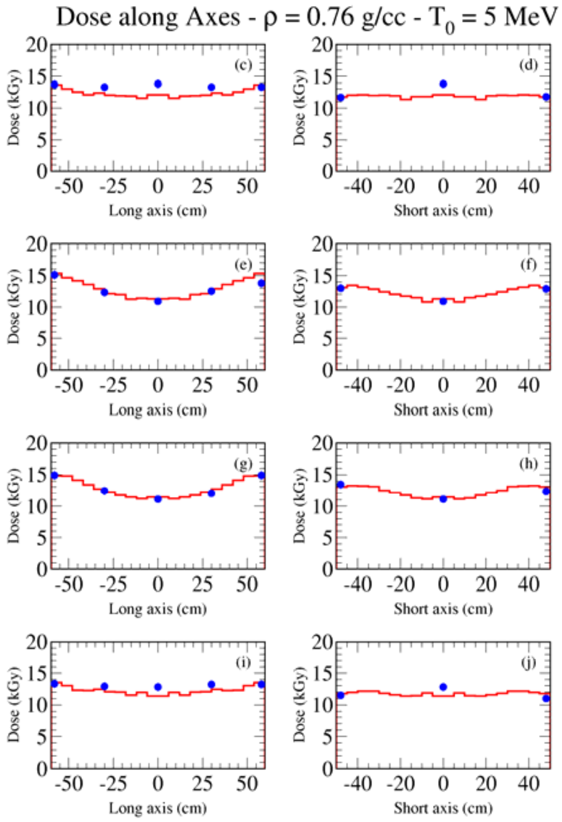
Data: DUR = 1.50 ⊕ 0.11
MC : DUR = 1.47 ⊕ 0.02

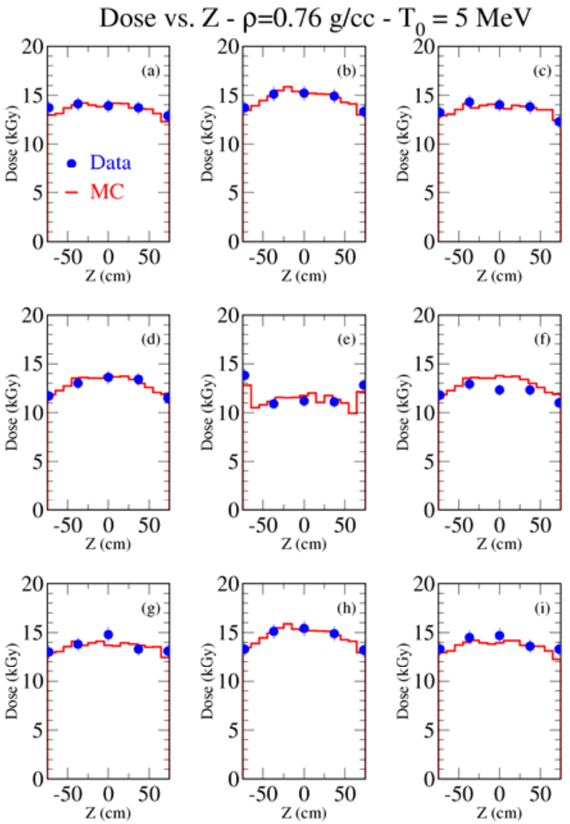


Dose Variation Along Axes

$\rho = 0.76\ g/cm^3 – T_0 = 5\ MeV$







E-Beam Benchmarking

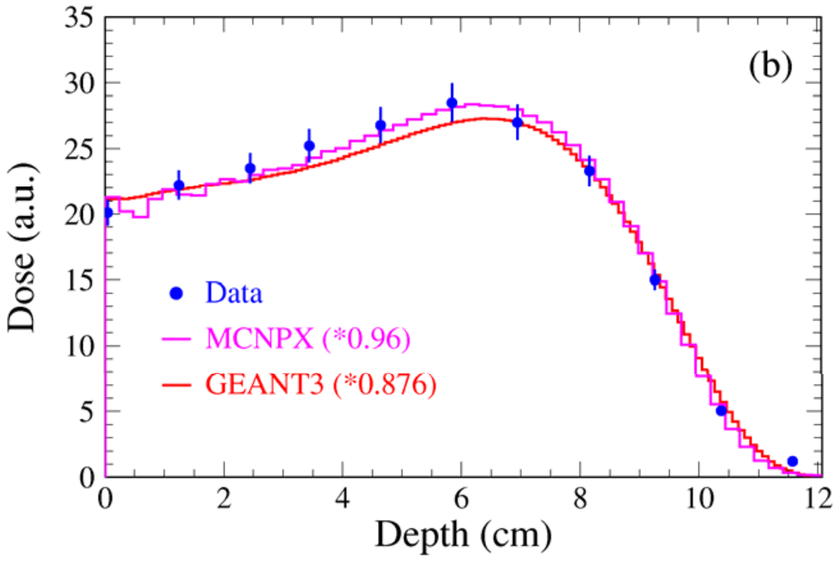
- Irradiation of various materials in the Sterigenics facility at Moerdrup during the IQ/OQ validation phase.
- 10 MeV E-beam with w=100 cm
- Phantoms of 60 x 80 x 50 cm³ made of:
  - Polystyrene foam ➔ = 0.0125 g/cc
  - Cardboard ➔ = 0.1 g/cc
  - Plywood ➔ 0.46 g/cc
- FWT and CTA dosimeters at various depths to measure:
  - Dose-depth curve
  - 2D dose maps at different depths

- Use these measurements to benchmark MCNPX and GEANT3 codes.

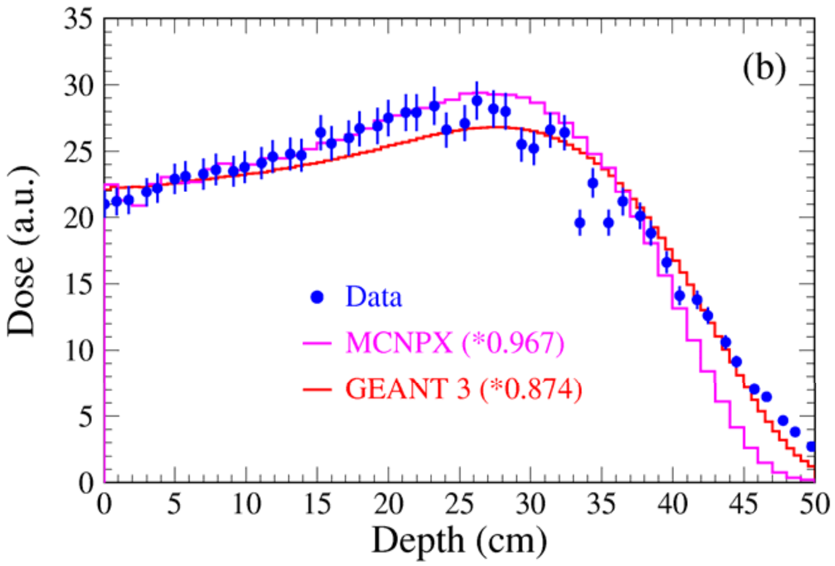
Dose-Depth Curves

Study of dose vs. depth profile in the center of boxes

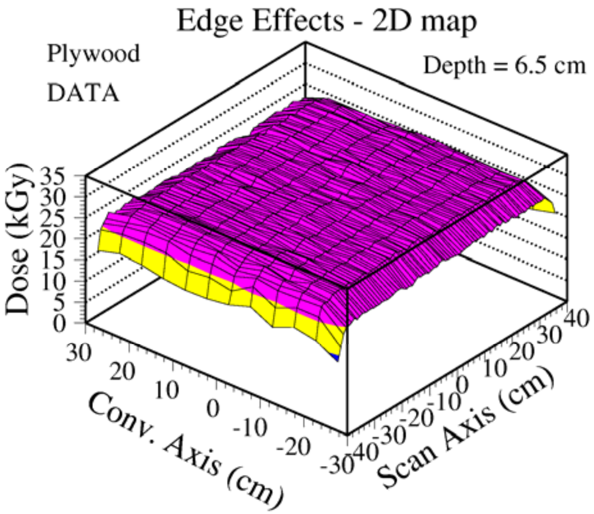
Plywood (ρ=0.46 g/cc)



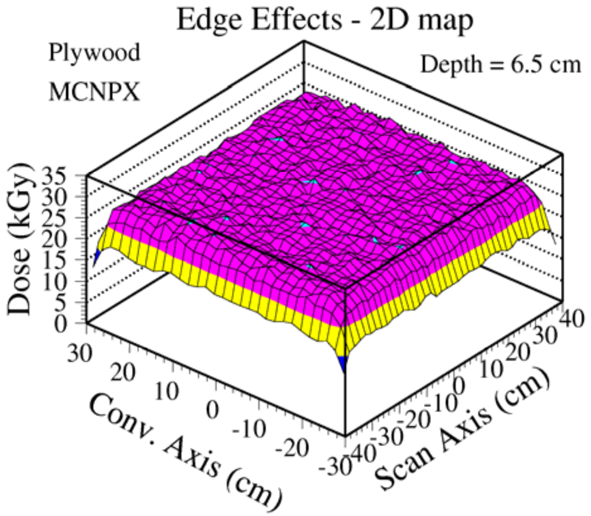
Cardboard (ρ=0.1 g/cc)



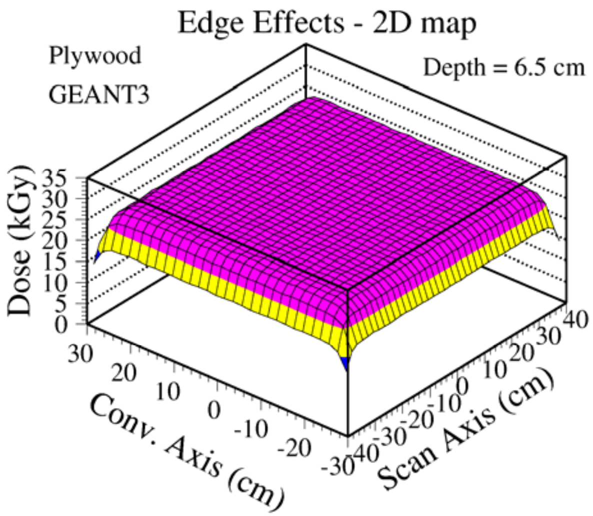
2D Dose Mapping in Plywood



Data

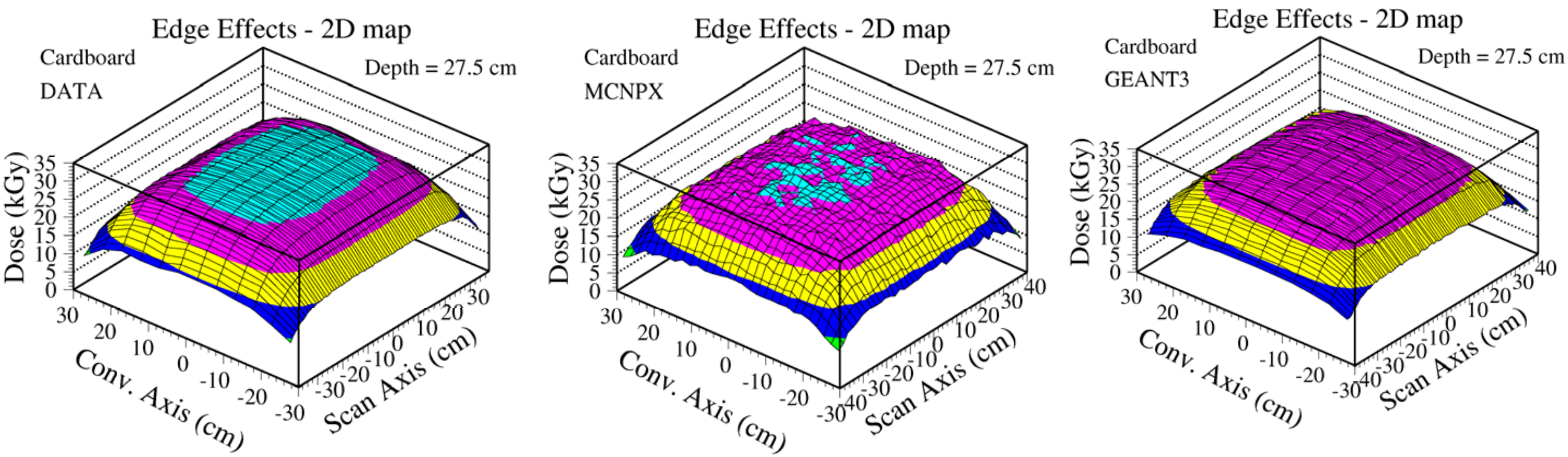


MCNPX



GEANT3

2D Dose Mapping in Cardboard



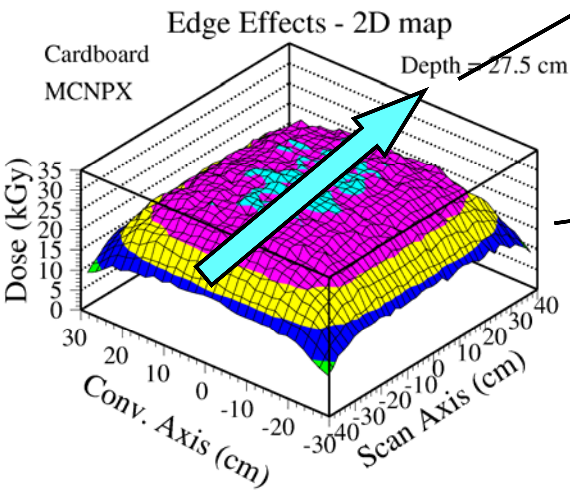
Data

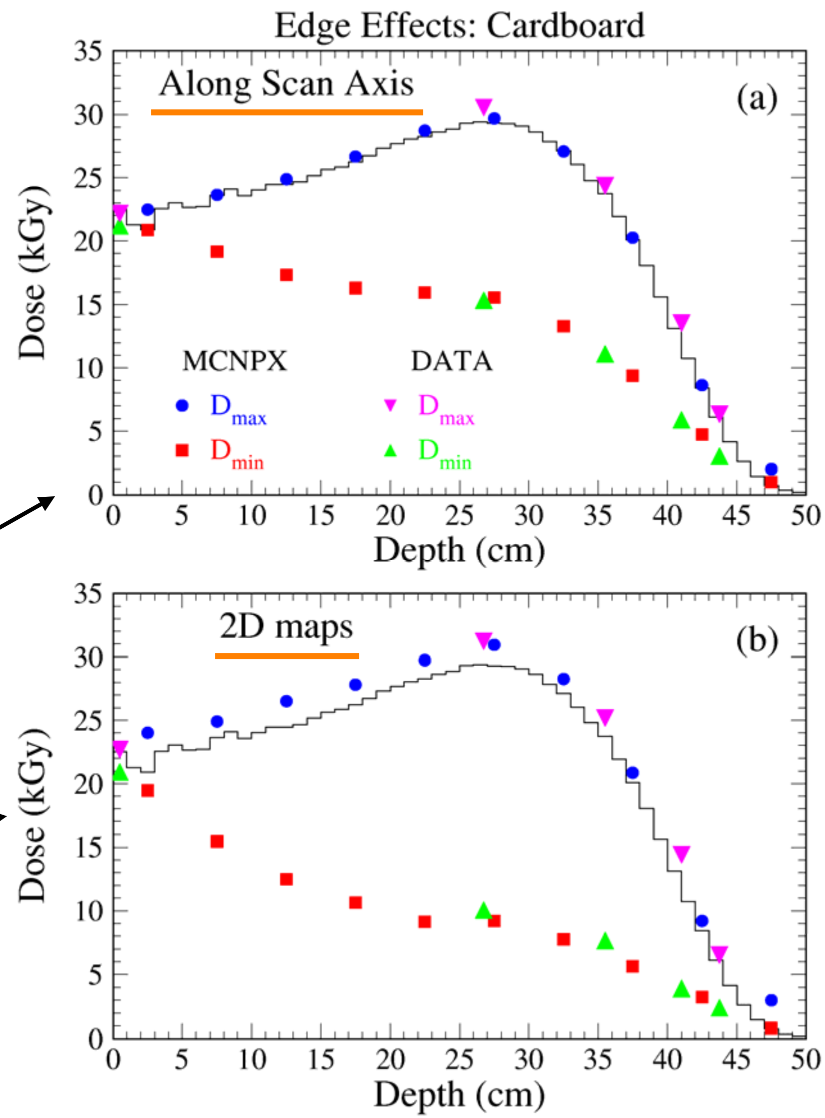
MCNPX

GEANT3

Edge Effects in Cardboard

- Study evolution of D_{max}, D_{min} values obtained in horizontal planes as a function of depth inside product.
- The evolution of D_{max} is driven by the dose-depth curve while the evolution of D_{min} is dominated by edge effects.





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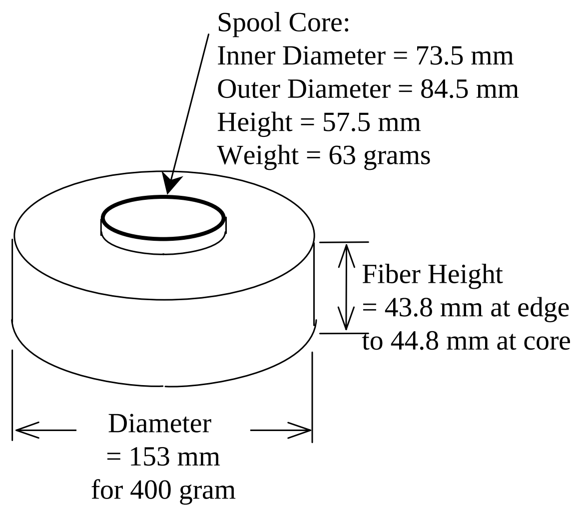
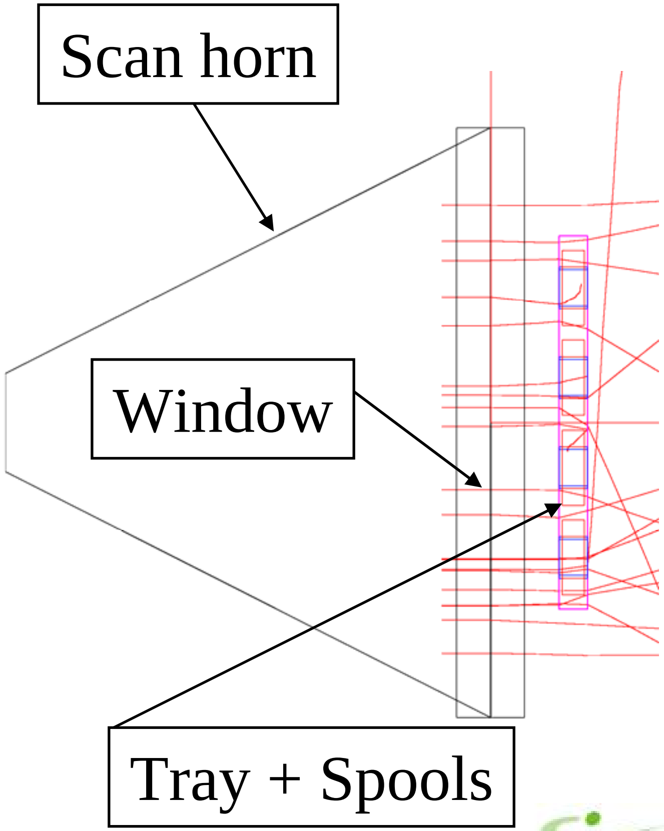
Study of Spool Irradiation with E-beam

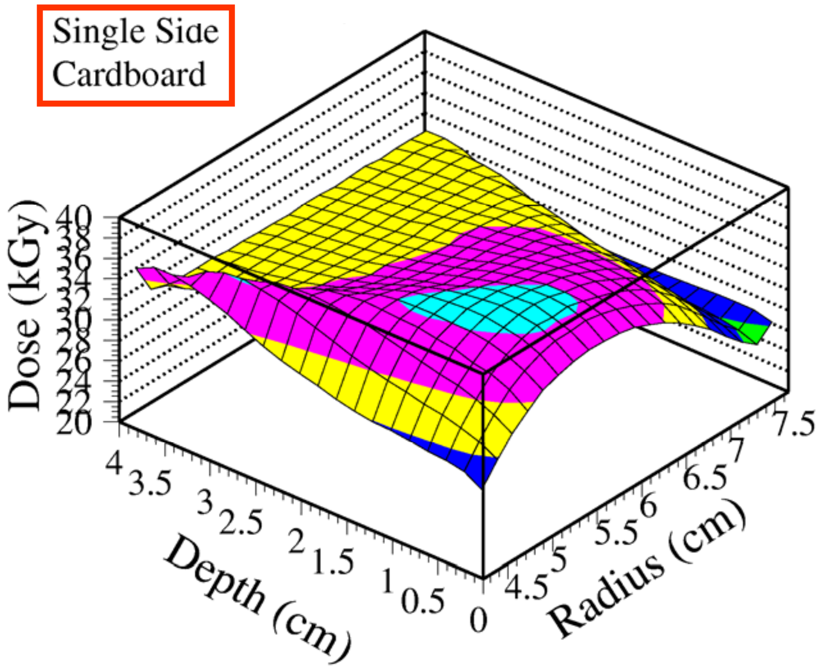
- **Study of spool irradiation using 10 MeV E-beam.**
- **Goals:**
  - Understand dose distribution inside product
  - Study the possibility to improve the dose uniformity thanks to a scattering plate above the spools
- **MC study based on GEANT3 validated by experimental measurements**

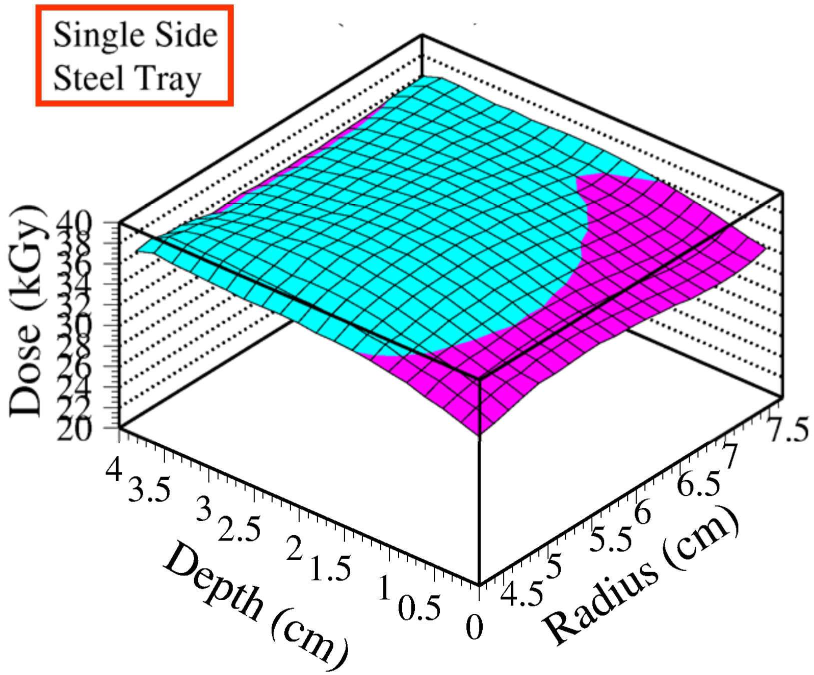




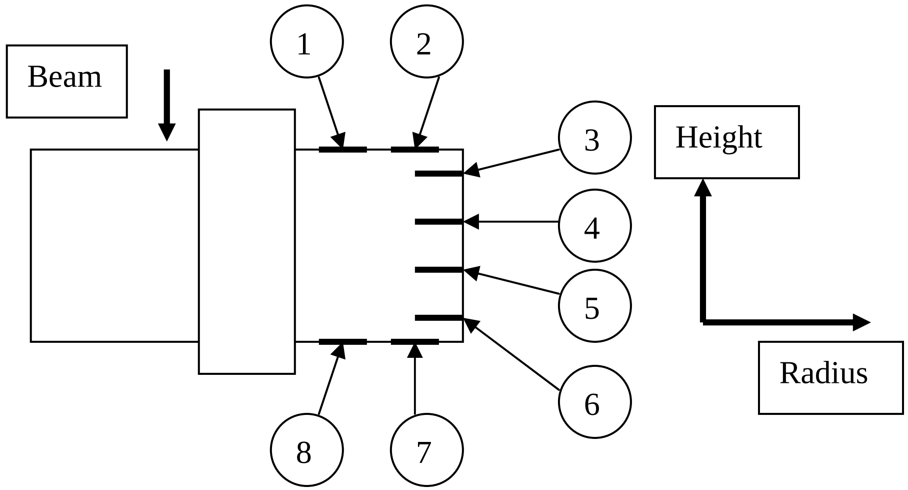
Monte Carlo Study

- Study dose distribution in (Radius,Depth) plane.
- Poor dose uniformity (DUR~1.7) due to edge effects at large radius.
- The presence of a scattering plate leads to a clear improvement of the dose uniformity (DUR ~ 1.2)

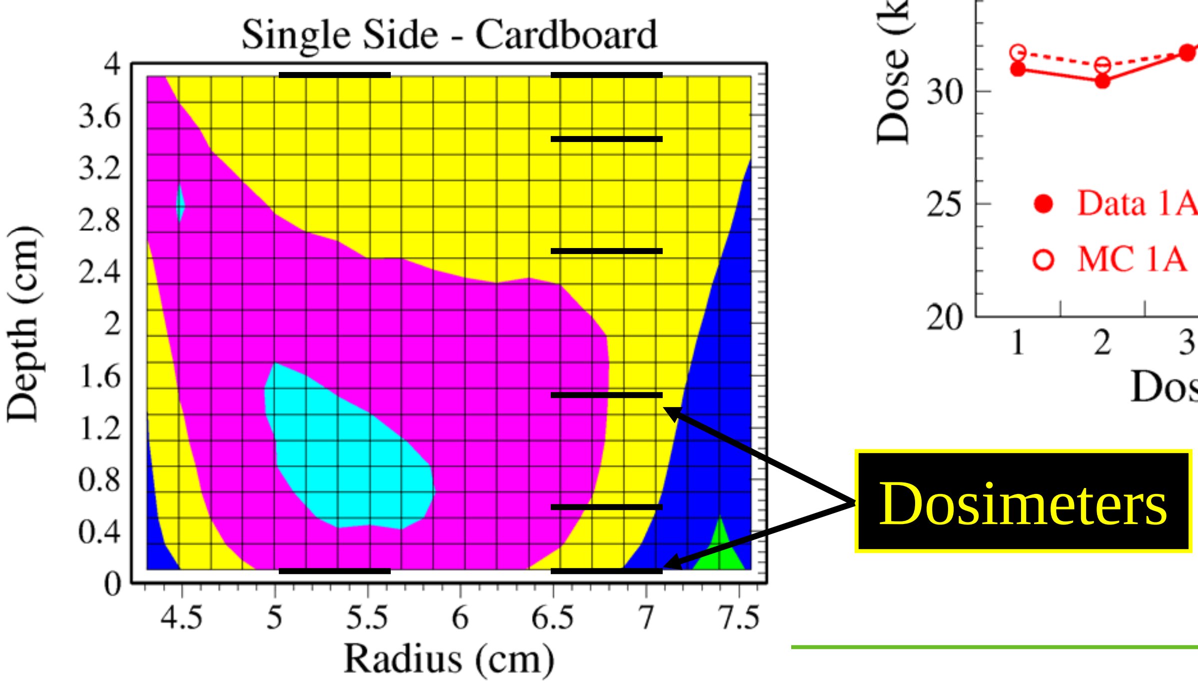


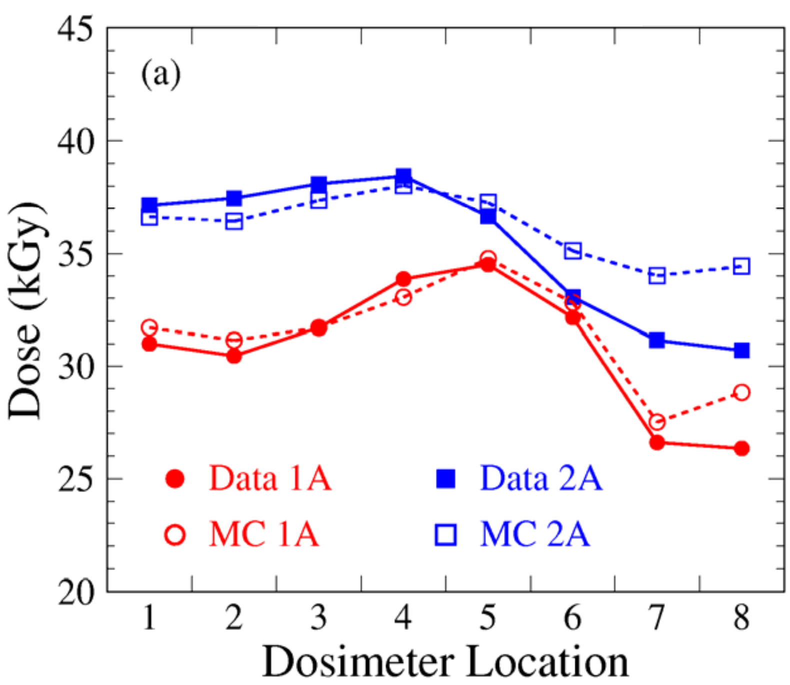


Experimental Validation



Test 1A: Cardboard tray
Test 2A: Steel tray





Conclusions

- Monte Carlo radiation transport codes are very useful tools to understand the physical distribution of doses inside product, both for simple (boxes) or complex (spool) geometries and complex systems.
- The possibility to display 2D dose maps is especially useful and easy to obtain with MC simulation codes.
- Measuring such 2D dose maps in real life is not so easy but is usually worth the effort to validate new designs in E-beam and X-ray irradiation systems.


Thank you…