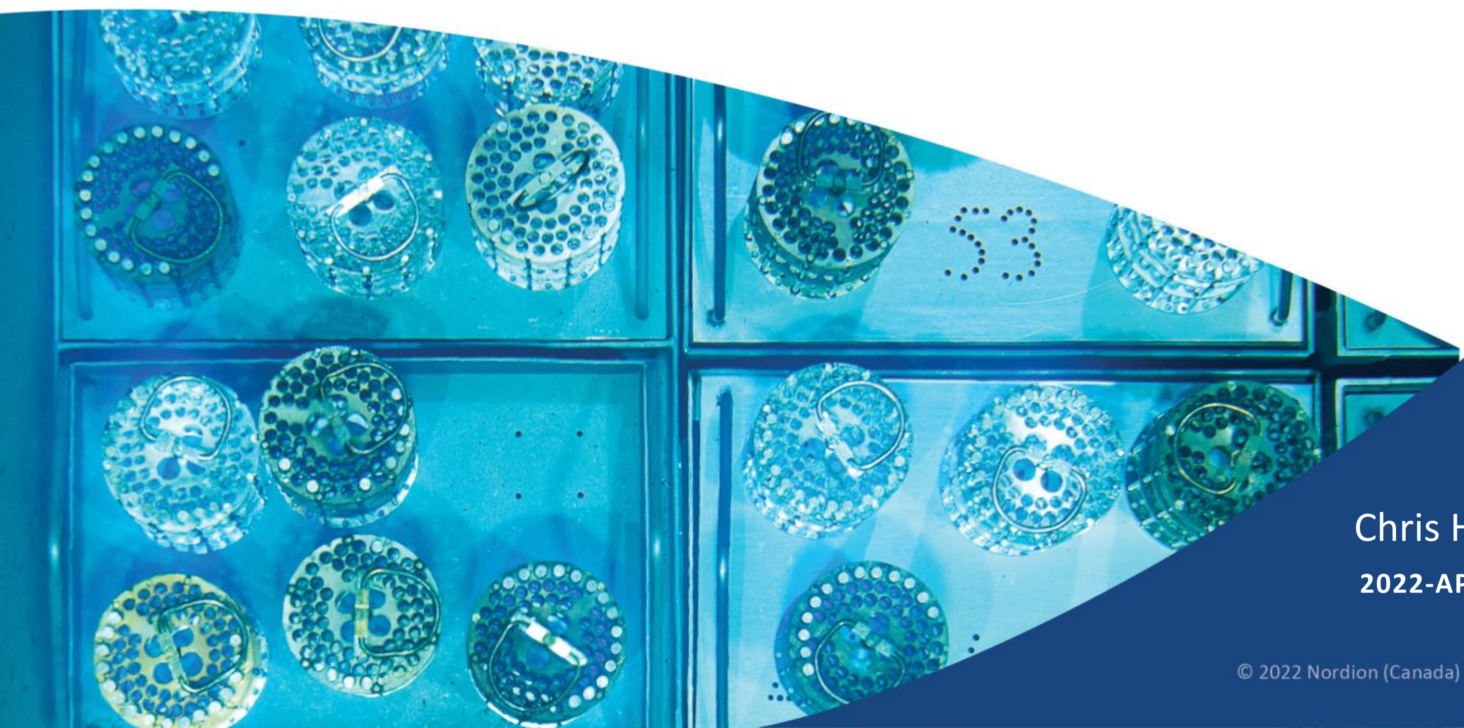
Using Mathematical Modeling to Improve Scheduling at Gamma Irradiator Facilities

CIRMS 2022



Chris Howard, PhD

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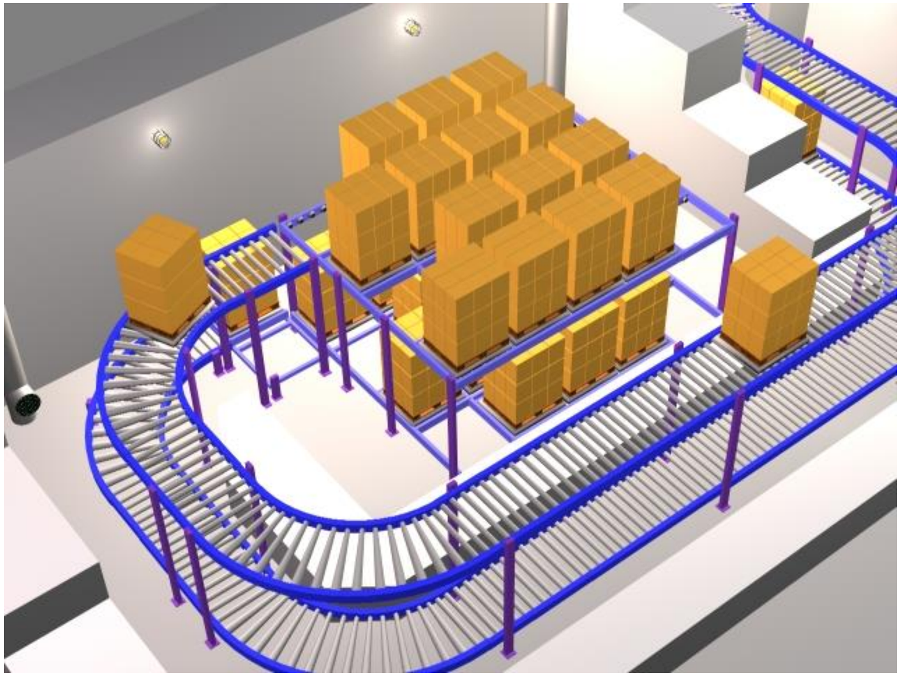
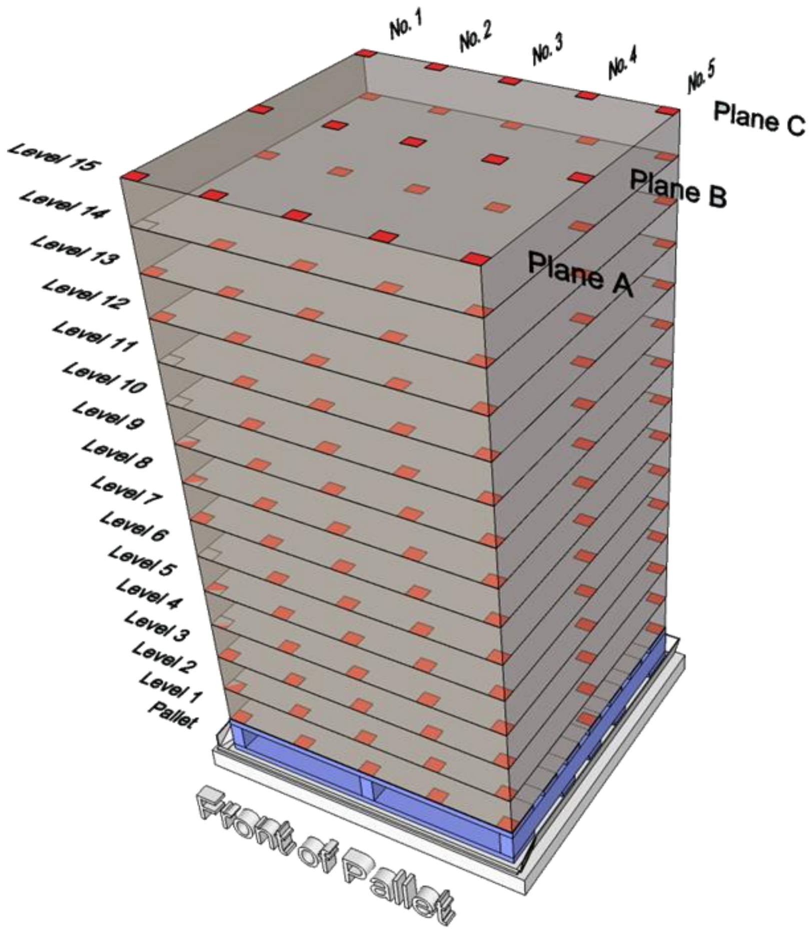
Gamma Irradiator Scheduling

- The order which products enter a Gamma Irradiator matter
- The radiation from the source can be attenuate and scatter by neighboring products
- The process can cause non-conformities in the product (i.e., under- or over-dosing)
- This is mitigated by using transition product or empties
  - Transition product: Product with large dose range that can be used to step from low to high timer settings or can be affected by attenuation and still meeting dose requirement specification
- This leads to inefficiencies
- The uncertainty around how attenuation/scattering will affect products leads to conservating product timer setting and scheduling

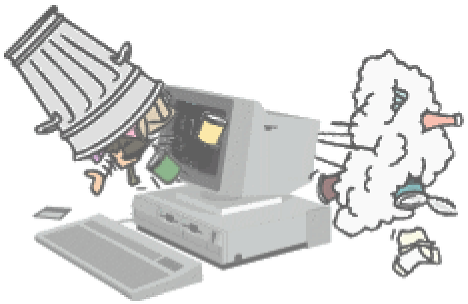


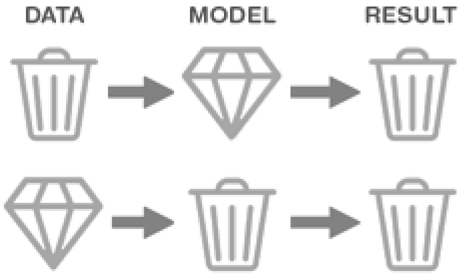
- Can we do better?
  - learning curve
  - institutional memory
- Data driven
  - Experiment
  - Expensive
  - Time consuming
  - Hard to interpret
- Mathematical Modelling
  - Better control
  - Heavy computational load for complex geometries or high densities



Modelling Notes of Caution

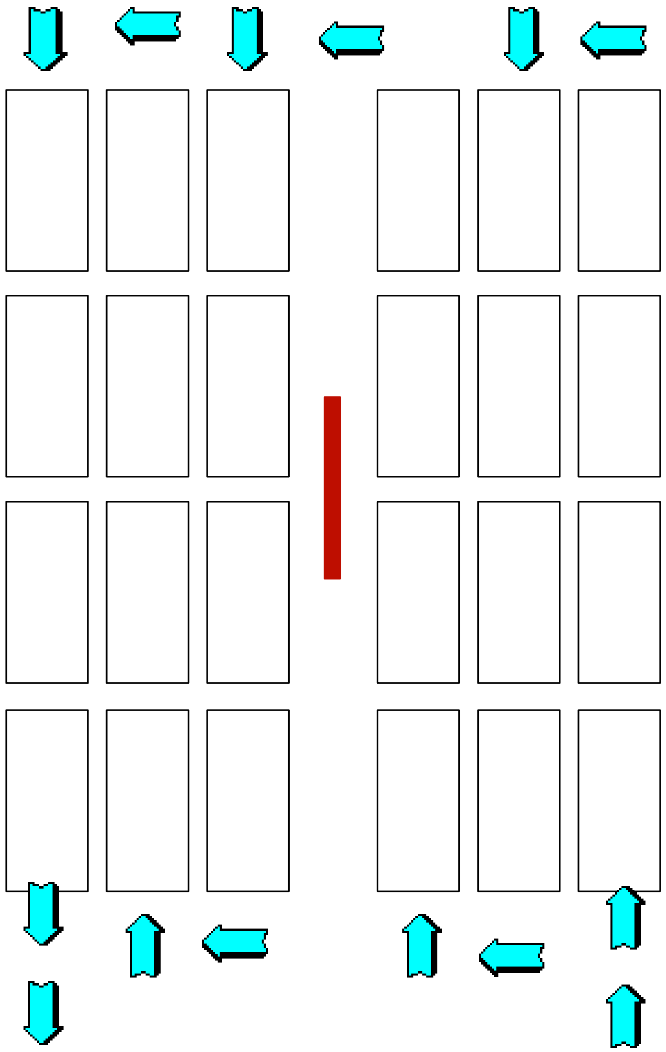
- Need to understand input
- Validation!
  - Operational Qualification
  - Performance (Product) Qualification
  - Density transition
  - Partial totes
- Data interpretation
  - Scoring Mesh
  - Dosimetry
- Understand approximation
  - Positional uncertainties
    - Dosimeters
    - Product Containers
    - Product (within container)
  - Material
  - Shapes
  - Dwell time
    - Model is made up of results per dwell position
    - Dwell >> shuffle time





How to Schedule in a Mathematical Model

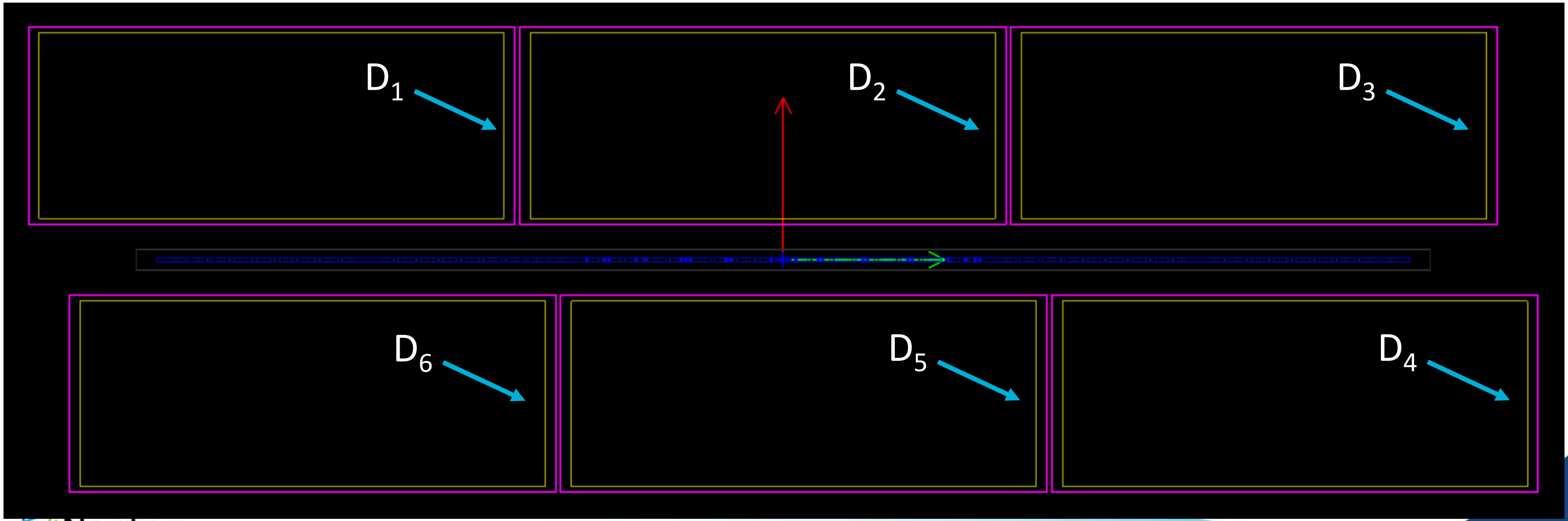
- Define product flow



How to Schedule in a Mathematical Model

- Define product flow
- Each dwell position is its own model
- Run simulation for each model
- Add the results of each model

$$D_{Total} = \sum_{i=1}^{N} D_N$$



Point Kernel vs Monte Carlo - Refresher

POINT KERNEL	MONTE CARLO

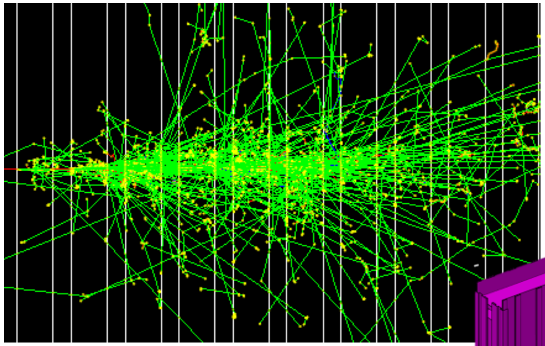
POINT KERNEL

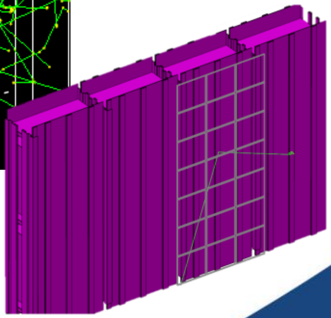
$$I = I_0 B \frac{e^{-\mu x}}{4\pi(r - r')^2}$$

- Includes all source information, I_0
- Uses linear attenuation coefficient, μ
  - From tote/carrier/pallet geometry
- Direct line from source to dosimeter, x
- Dose calculation at dosimeter, I
- Traveling from *r* to *r'*
- *B* is the build-up factor to correct for scattering
  - Good for low density materials

MONTE CARLO

- Includes all geometry
- Includes all physics
  - Scattering
  - Energy loss
- Tracks each particle
- Record deposited energy (*eg*. Dosimeter)





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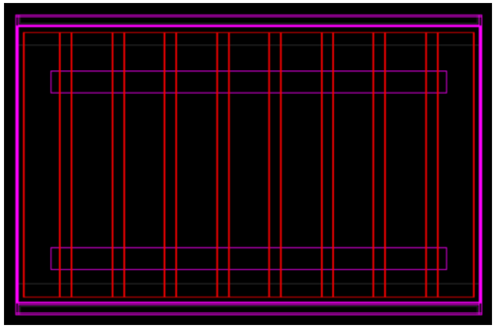
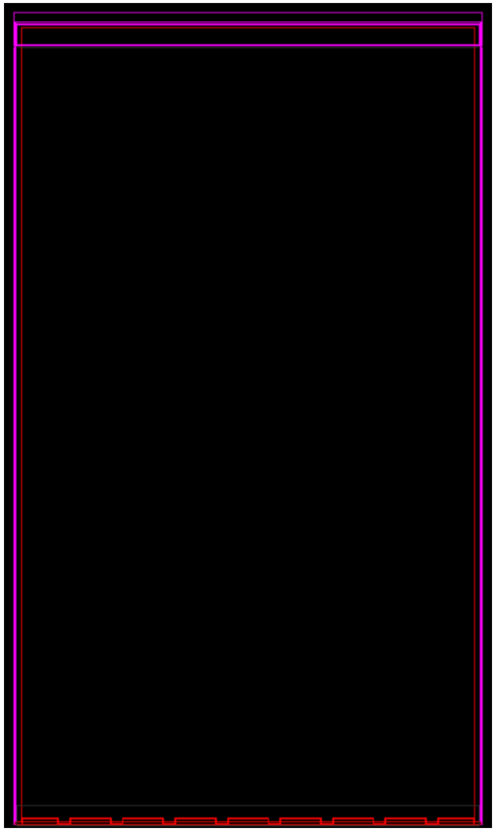
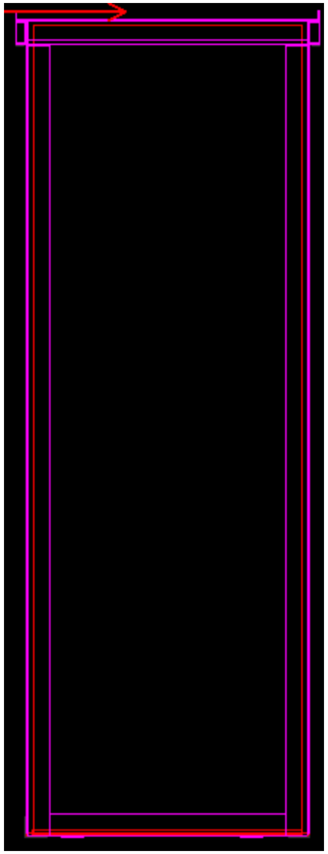
Scheduling in Point Kernel

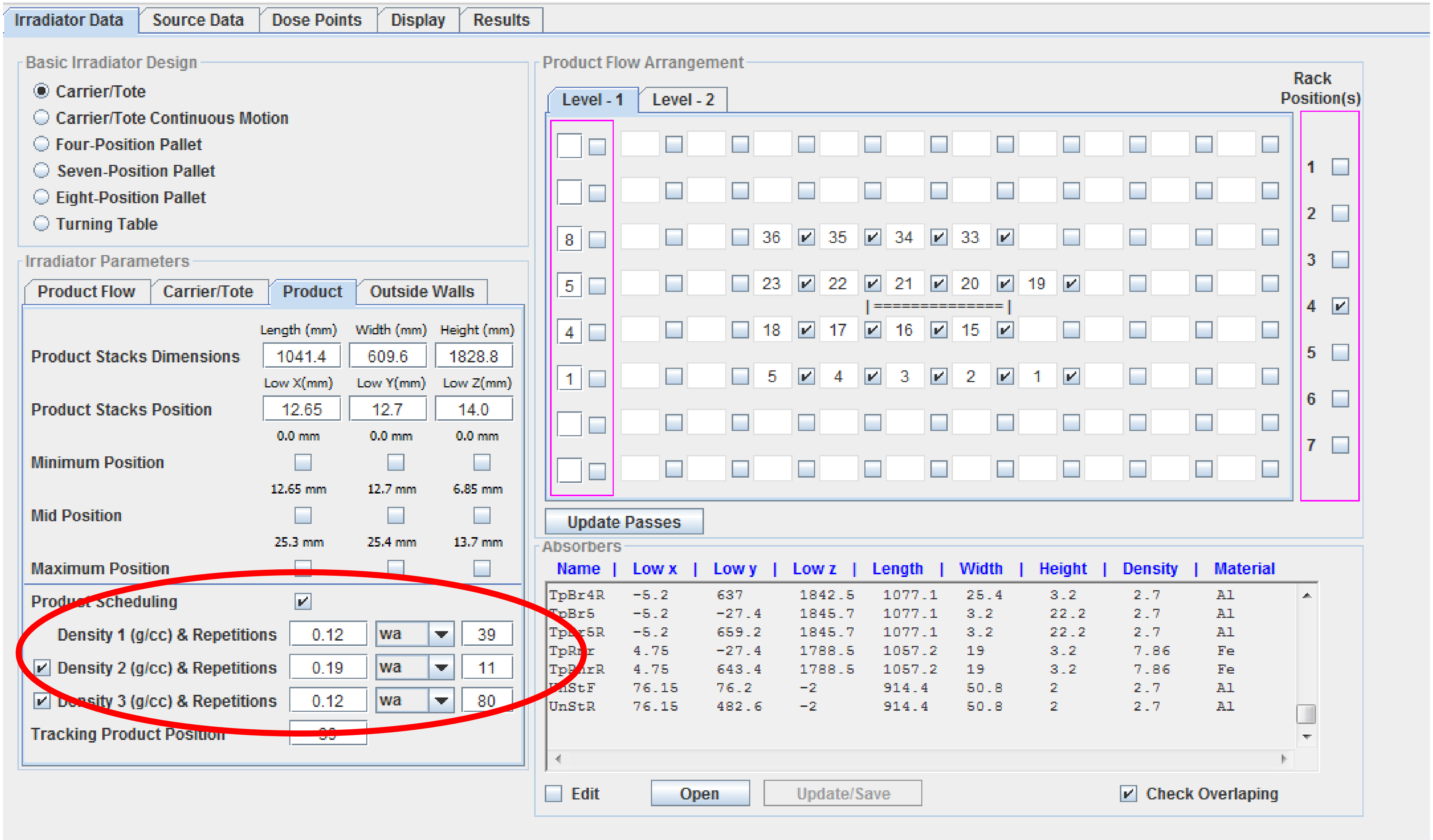
- Limited use cases
- Shapes assumed to be 3D boxes
- Homogenous material
- Water equivalent material
- No scattering from neighboring products







Scheduling with Point Kernel



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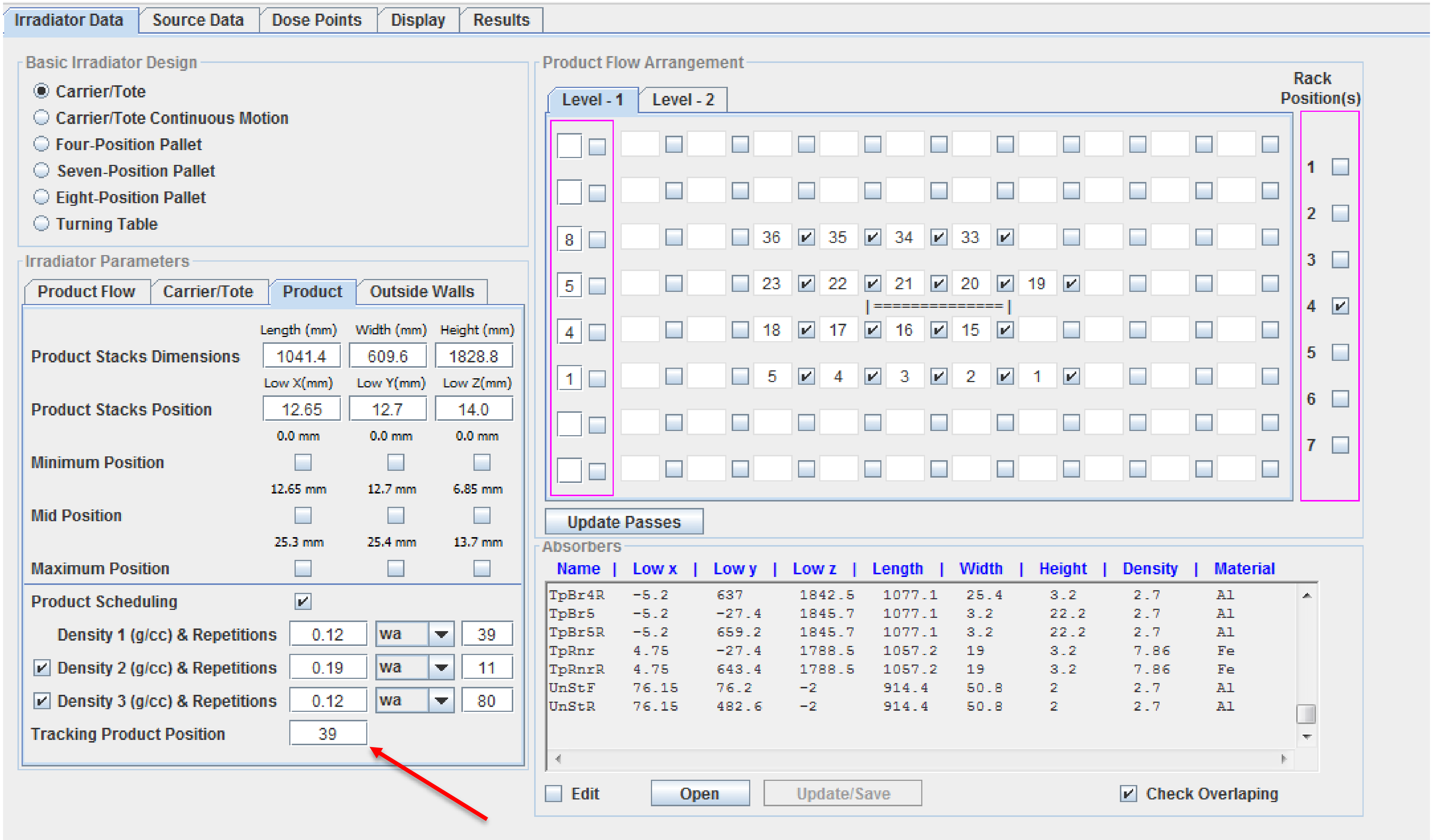

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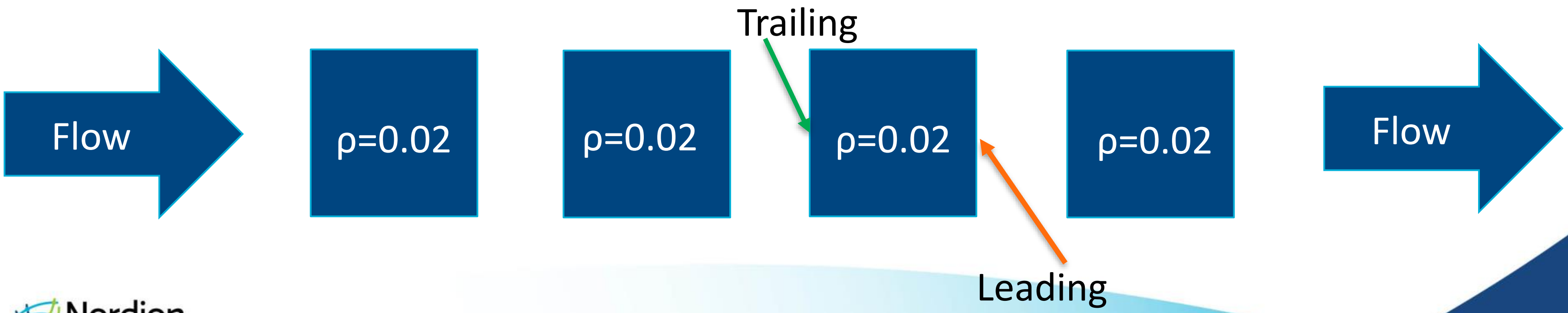
PK Scheduling Example – Transition Study

	Quiet Data (PI full of similar product)		
	Density [g/cc]	Dmin [kGy]	DUR
low	0.02	19.4	1.17
medium	0.14	20.2	1.26
intermediate	0.21	20.5	1.37



PK Scheduling Example – Transition Study

- Compare stepped density (data) to quiet data
- Density Flow:
  - Low
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  - Low
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  - (i.e. 1=same as quiet data).

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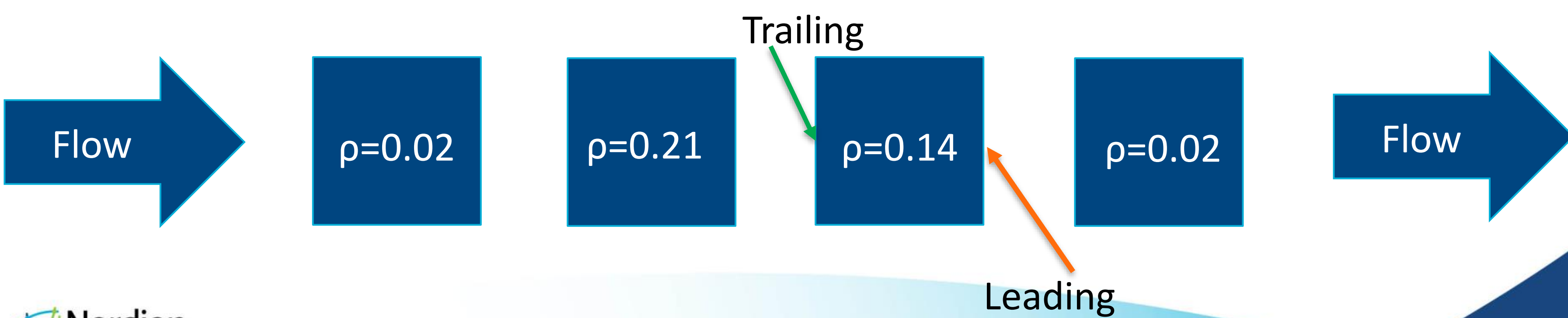
$$\frac{D_{Min}(Quiet)}{D_{Min}(Transition)}$$



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Data

Density	Leading Dmin	Trailing Dmin
Med	1.06	0.94
Intermediate	0.86	0.88

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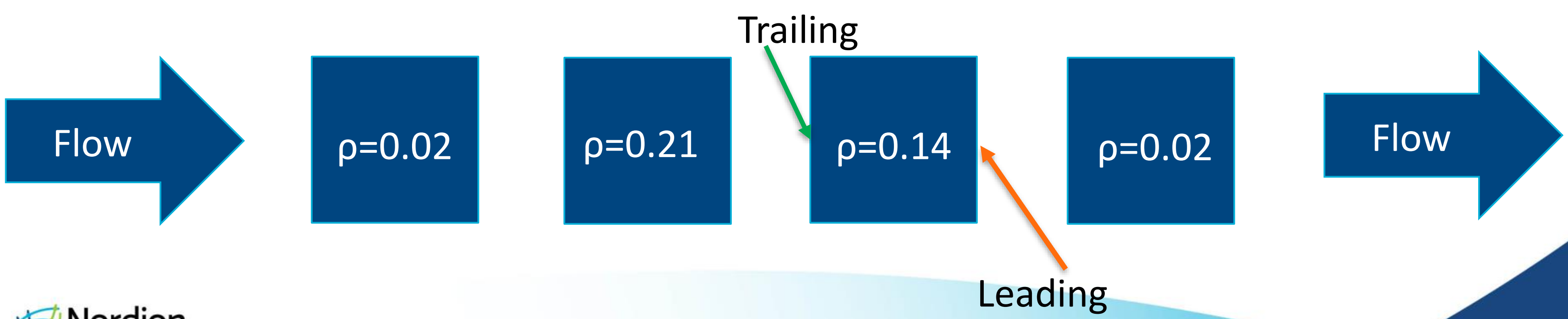

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Model

Density	Leading Dmin	Trailing Dmin
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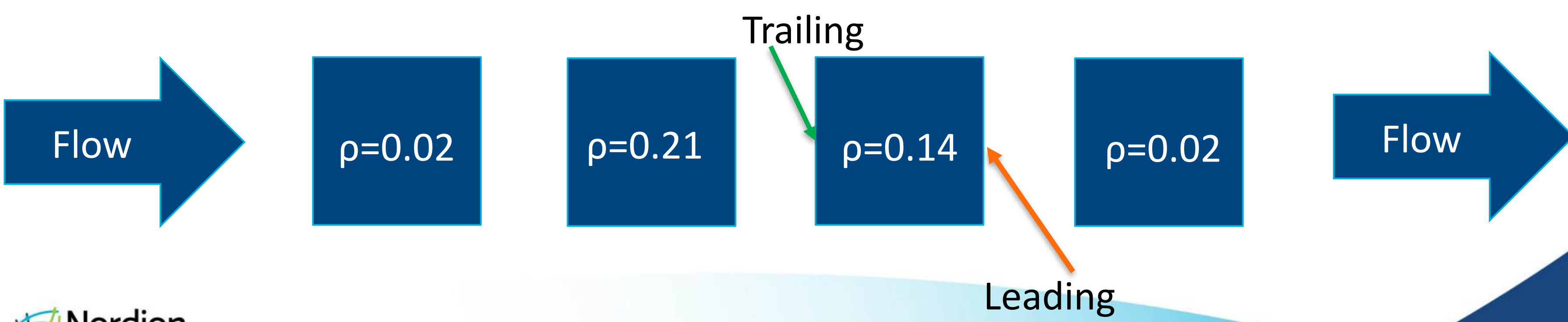

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Data

Density	Leading Dmin	Trailing Dmin
Med	1.06	0.94
Intermediate	0.86	0.88

Density	Leading Dmax	Trailing Dmax
Med	1.0	1.04
Intermediate	1.0	0.99

Model

Density	Leading Dmin	Trailing Dmin
Medium	1.06	0.93
Intermediate	0.86	0.90

Density	Leading Dmax	Trailing Dmax
Medium	1.01	1.02
Intermediate	1.04	0.99

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Scheduling Example -- Product

- On product results do not look as nice as OQ
  - Product size assumed to be full
  - Product assume homogenous
  - OQ used repeated totes
  - Work to be done to better predict data
- OQ results show it's possible
  - need to work to determine where it can be applied and where it shouldn't be

# totes	Density Group	Tote	Location	Data/Model [%]
39	1	leading	1C9	
	1	leading	16A5	
	1	End	1C9	0.00%
	1	End	16A5	-6.78%
11	2	leading	1C1	-2.28%
	2	leading	1C9	3.58%
	2	leading	TC1	5.83%
	2	leading	TA5	-1.12%
	2	leading	TC9	9.38%
	2	end	1C1	2.55%
	2	end	1C9	-3.94%
	2	end	TC1	11.97%
	2	end	TA5	-3.37%
	2	end	TC9	6.44%
80	3	leading	1C9	-18.25%
	3	leading	16A5	-3.00%
	3	end	1C9	-21.23%
	3	end	16A5	-14.04%
40				

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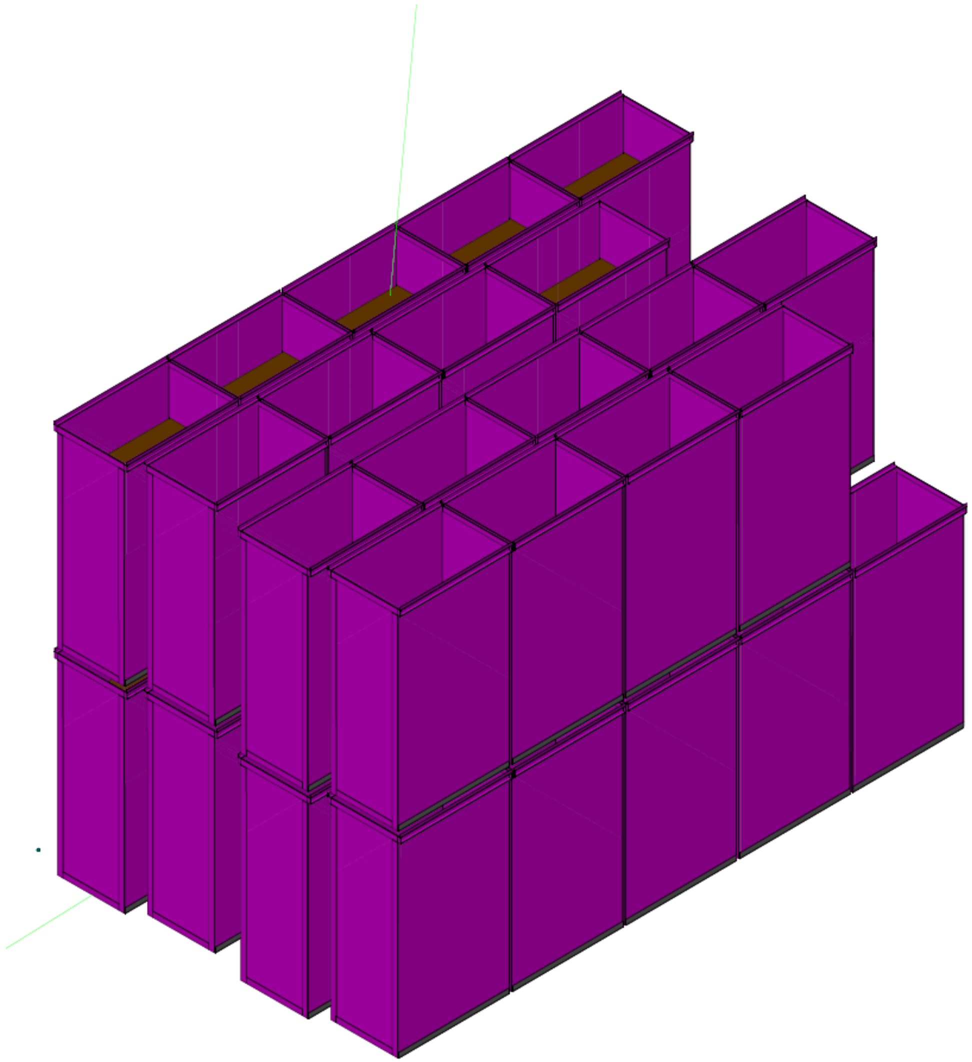
Scheduling in Monte Carlo

- Use the Geant4 to create the Model
- A quiet system takes about 12 hours for a JS10000 style irradiator
  - 32 CPUs



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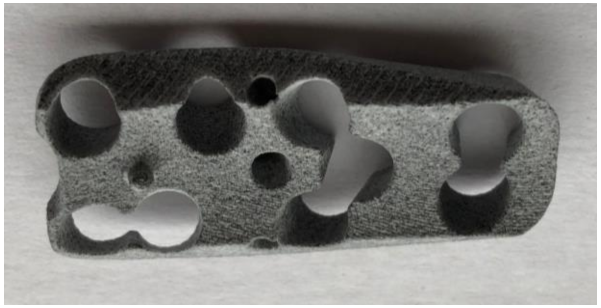
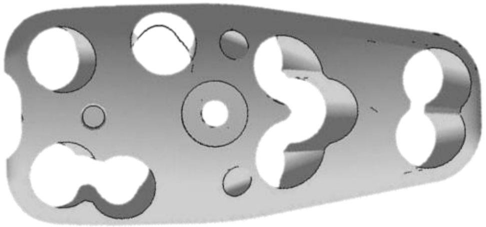
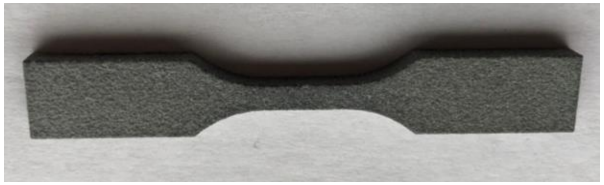
- CAD can be imported



Photo



Geant4

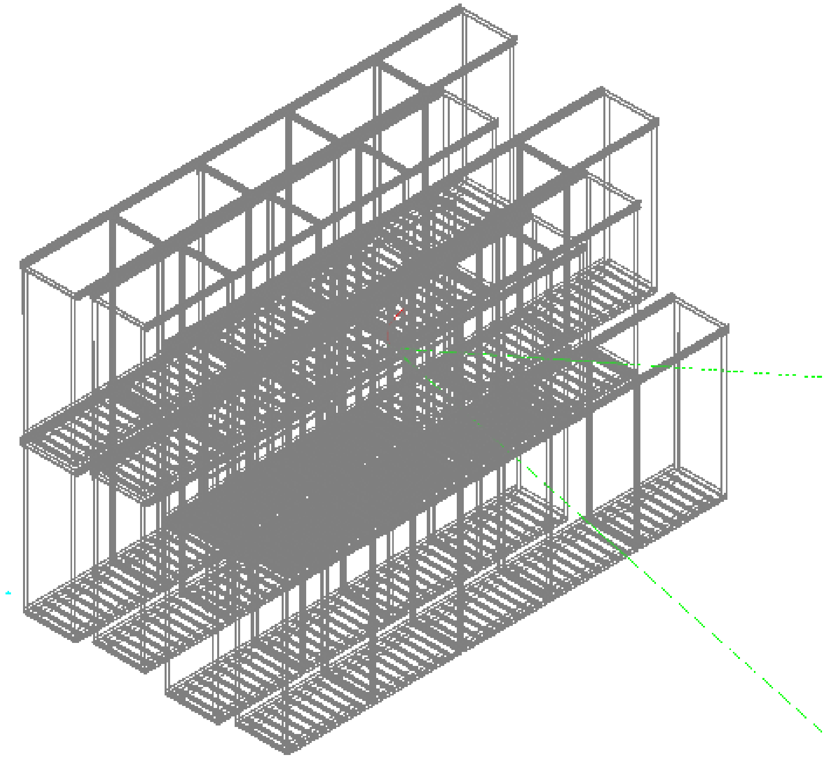


Photo

Geant4

Scheduling in Monte Carlo

- Use the Geant4 to create the Model
- A quiet system takes about 12 hours for a JS10000 style irradiator
  - 32 CPUs
- CAD can be imported
- Validated using a JS8900 design
- I have created a working version
- Future:
  - Run full statistics
  - JS10000 = 36 positions
  - 36 x 0.5 days = 18 days
  - Need cloud computing
  - Can be run on Azure/AWS in ~1 hours for few hundred USD



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Summary

- Scheduling is expensive and time consuming
  - Experiments
  - Dosimetry
- P-K can be used in many situations
- MC + CAD can be in any situation
- MC Modelling can run a scenario in the cloud within hours
- DoE can be used to optimize scheduling
- Cloud computing is mature enough to handle Monte Carlo
  - Requires learning curve