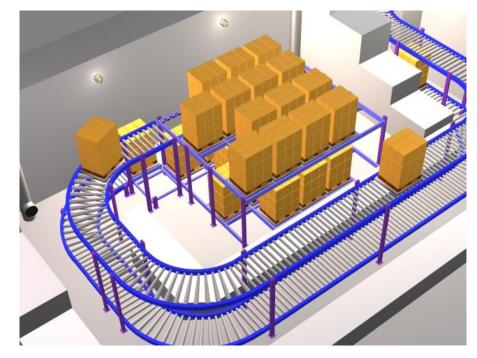


# Using Mathematical Modeling to Improve Scheduling at Gamma Irradiator Facilities

**CIRMS 2022** 

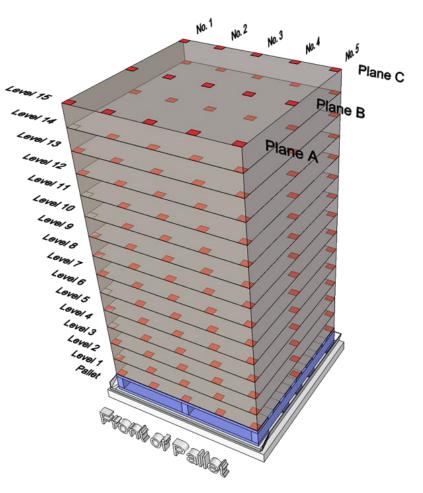


- The order which products enter a Gamma Irradiator matter
- The radiation from the source can be attenuate and scatter by neighboring products
- The process can cause nonconformities in the product (i.e., under- or over-dosing)
- This is mitigated by using transition product or empties
  - Transition 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





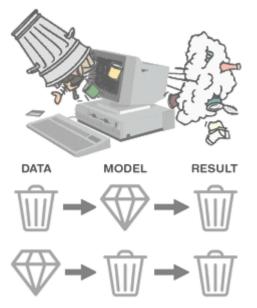
- Can we do better?
   learning curve
   institutional memory
- Data driven
  - Experiment
  - Expensive
  - Time consuming
  - Hard to interpret
- Mathematical Modelling
  - Better control
  - Heavy computational load for complex geometries or high densities





### **Modelling Notes of Caution**

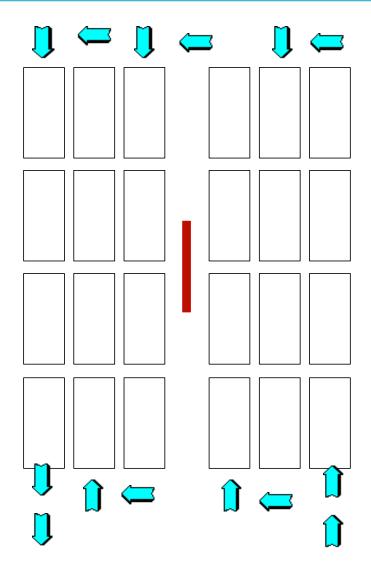
- Need to understand input
- Validation!
  - Operational Qualification
  - Performance (Product) Qualification
  - Density transition
  - Partial totes
- Data interpretation
  - Scoring Mesh
  - Dosimetry
- Understand approximation
  - Positional uncertainties
    - Dosimeters
    - Product Containers
    - 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

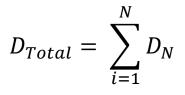
• Define product flow

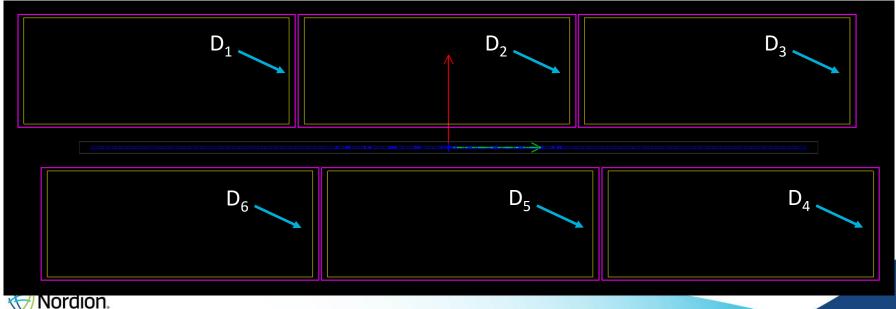




- Define product flow
- Each dwell position is its own model
- Run simulation for each model
- Add the results of each model

A Sotera Health company





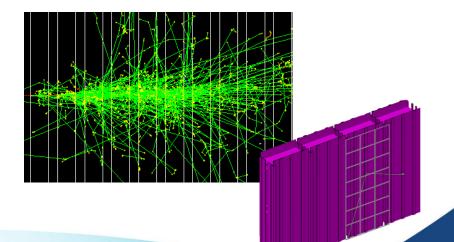
#### POINT KERNEL

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

- Includes all source information,  $I_0$
- Uses linear attenuation coefficient,  $\mu$ 
  - 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

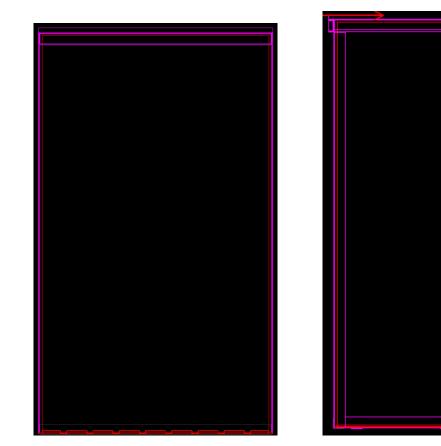
- Includes all geometry
- Includes all physics
  - Scattering
  - Energy loss
- Tracks each particle
- Record deposited energy (*eg*. Dosimeter)

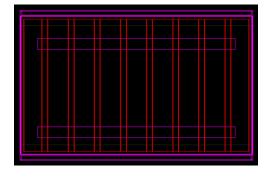




#### **Scheduling in Point Kernel**

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







# **Scheduling with Point Kernel**

Basic Irradiator Design Carrier/Tote Carrier/Tote Continuous Motion Four-Position Pallet	Rack Position
Carrier/Tote Continuous Motion	Position
Four-Position Pallet     Seven-Position Pallet	1
Eight-Position Pallet	
○ Turning Table     8     36     235     24     233     □     □	2
Irradiator Parameters	3
Product Flow     Carrier/Tote     Product     Outside Walls	4
Length (mm) Width (mm) Height (mm)	4
Product Stacks Dimensions 1041.4 609.6 1828.8 6	5
Low X(mm) Low Y(mm) Low Z(mm)	6
Product Stacks Position 12.65 12.7 14.0	
	7
12.65 mm 12.7 mm 6.85 mm	
Mid Position	
25.3 mm 25.4 mm 13.7 mm Absorbers	
	aterial
Product scheduling         TpBr4R         -5.2         637         1842.5         1077.1         25.4         3.2         2.7         A           SpBr5         -5.2         -27.4         1845.7         1077.1         3.2         22.2         2.7         A	
Density 1 (g/cc) & Repetitions 0.12 wa v 39 Tpx 5R -5.2 659.2 1845.7 1077.1 3.2 22.2 2.7 A	
TpRr 4.75 -27.4 1788.5 1057.2 19 3.2 7.86 F	
✓ Density 2 (g/cc) & Repetitions         0.19         Wa         ▼         11         TpFnrR         4.75         643.4         1788.5         1057.2         19         3.2         7.86         F           ✓ Density 2 (g/cc) & Repetitions         0.19         Wa         ▼         11         TpFnrR         4.75         643.4         1788.5         1057.2         19         3.2         7.86         F           ✓ Distribution         ✓ Distributi	
✓ Density 3 (g/cc) & Repetitions 0.12 wa ▼ 80 UnStR 76.15 482.6 -2 914.4 50.8 2 2.7 A	
Tracking Product Position	-
	•
Edit Open Update/Save Check Ove	rlaping



## **Scheduling with Point Kernel**

Irradiator Data Source	ce Data	Dose Points	s Displ	ay Results															
Basic Irradiator Desigr	n				P	roduct Flo	ow Arrange	ment											Rack
Carrier/Tote					ſ	Level - 1	Level -	2											osition(s)
<ul> <li>Carrier/Tote Contir</li> <li>Four-Position Palle</li> </ul>		on																	
<ul> <li>Seven-Position Pale</li> </ul>																			1 🔲
Eight-Position Pall	et																		
O Turning Table						8			36	☑ 35	☑ 3	4 🖌	33	~					2
Irradiator Parameters														_					3 🗌
Product Flow Carr	rier/Tote	Product	Outside	Walls		5			23	≥ 22	2	1 🗹		✓ 19					4 🖌
	Le	ength (mm)	Width (mm)	Height (mm)		4			18	☑ 17	1								4 💌
Product Stacks Dime	nsions	1041.4	609.6	1828.8					-							_			5 🗌
	-		Low Y(mm)			1			5	₩ 4		3	2	┏ 1					6 🔲
Product Stacks Positi	ion	12.65	12.7 0.0 mm	14.0															
Minimum Position																			7 🔲
		12.65 mm	12.7 mm	6.85 mm															
Mid Position						Update	Passes												
		25.3 mm	25.4 mm	13.7 mm	A	bsorbers													
Maximum Position					Ŀ	Name	Low x	Low	y I	Low z			Widt	<u> </u>	Height	Density		erial	
Product Scheduling		<b>V</b>				TpBr4R TpBr5	-5.2 -5.2	637 -27	4	1842.5 1845.7		77.1 77.1	25.	4	3.2	2.7	Al Al		^
Density 1 (g/cc) &	Repetition	s 0.12	wa	▼ 39	1	TpBr5R	-5.2	659		1845.7		77.1	3.2		22.2	2.7	Al		
Density 2 (g/cc) &	Repetition	s 0.19	wa	▼ 11		TpRnr TpRnrR	4.75 4.75	-27. 643.		1788.5 1788.5		57.2 57.2	19 19		3.2 3.2	7.86 7.86	Fe Fe		
Density 3 (g/cc) &	Repetition	s 0.12	wa	▼ 80		UnStF UnStR	76.15 76.15	76.2		-2 -2		4.4 4.4	50. 50.		2	2.7	Al Al		_
Tracking Product Pos	ition	39	-						-	-				-	-				
						•												Þ	
						Edit	Ope	en		Update/	Save					🖌 Che	ck Overla	aping	



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



•	Compare stepped density (data) to quiet data Density Flow:			Quiet Data of similar p	
	<ul> <li>Med</li> <li>Intermediate</li> </ul>		Density [g/cc]	Dmin [kGy]	DUR
	• Low	low	0.02	19.4	1.17
	o Intermediate	medium	0.14	20.2	1.26
•	Results are dose relative to quiet data	intermediate	0.21	20.5	1.37

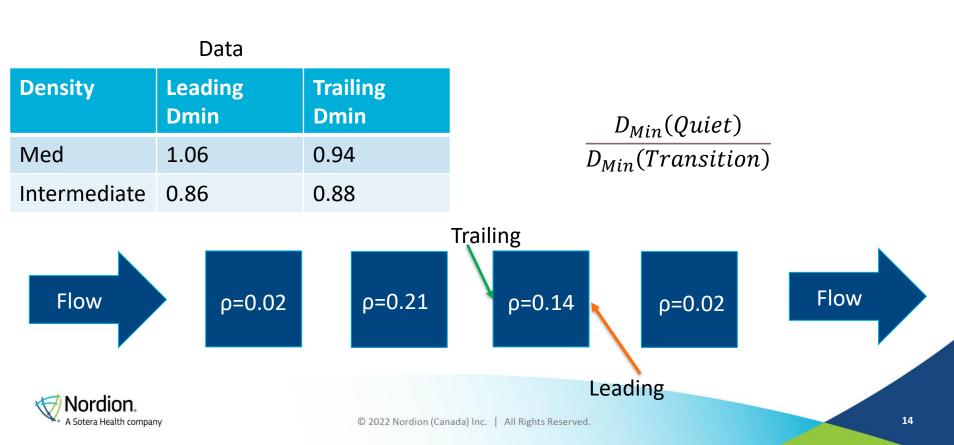
• (i.e. 1=same as quiet data).

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



<ul> <li>Compare stepped density (data) to quiet data</li> <li>Density Flow:         <ul> <li>Low</li> </ul> </li> </ul>		Quiet Data (PI full of similar product)		
• Med		,	Dmin [kGy]	DUR
<ul> <li>Intermediate</li> <li>Low</li> </ul>	low	0.02	- /-	1.17
<ul> <li>Intermediate</li> </ul>	medium	0.14	20.2	1.26
<ul> <li>Results are dose relative to quiet data</li> </ul>	intermediate	0.21	20.5	1.37

• (i.e. 1=same as quiet data).



<ul> <li>Compare stepped density (data) to qu</li> <li>Density Flow:         <ul> <li>Low</li> </ul> </li> </ul>	iet data		Quiet Data (PI full of similar product)		
<ul> <li>Med</li> <li>Intermediate</li> </ul>			,	Dmin [kGy]	DUR
<ul> <li>Intermediate</li> <li>Low</li> </ul>		low	0.02	19.4	1.17
<ul> <li>Intermediate</li> </ul>		medium	0.14	20.2	1.26
Results are dose relative to quiet data		intermediate	0.21	20.5	1.37

• (i.e. 1=same as quiet data).

	Data			Model		
Density	Leading Dmin	Trailing Dmin	Density	Leading Dmin	Trailing Dmin	
Med	1.06	0.94	Medium	1.06	0.93	
Intermediate	0.86	0.88	Intermediate	0.86	0.90	
Flow	ρ=0.02	Γr ρ=0.21	railing ρ=0.14	ρ=0.02	Flow	
Nordion. A Sotera Health compar	пу	© 2022 Nordion (Canada)		ding		15

<ul> <li>Compare stepped density (data) to quiet data</li> <li>Density Flow: <ul> <li>Low</li> </ul> </li> </ul>		Quiet Data (PI full of similar product)		
<ul> <li>Med</li> <li>Intermediate</li> </ul>		,	Dmin [kGy]	DUR
<ul> <li>Intermediate</li> <li>Low</li> </ul>	low	0.02	19.4	1.17
<ul> <li>Intermediate</li> </ul>	medium	0.14	20.2	1.26
<ul> <li>Results are dose relative to quiet data</li> </ul>	intermediate	0.21	20.5	1.37

• (i.e. 1=same as quiet data).

	Data		Model					
Density	Leading Dmin	Trailing Dmin	Density	Leading Dmin	Trailing Dmin			
Med	1.06	0.94	Medium	1.06	0.93			
Intermediate	0.86	0.88	Intermediate	0.86	0.90			
Density	Leading Dmax	Trailing Dmax	Density	Leading Dmax	Trailing Dmax			
Med	ρ= 1.0	1.04	Medium	1.01	1.02			
Intermediate	1.0	0.99	Intermediate	1.04	0.99			



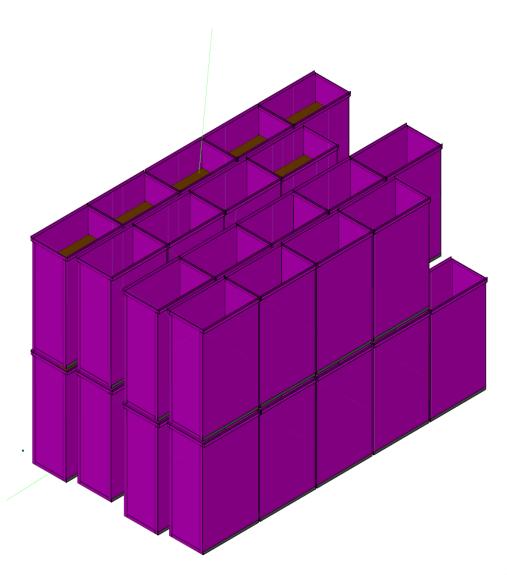
- On product results do not look as nice as OQ
  - Product size assumed to be full
  - Product assume homogenous
  - OQ used repeated totes
  - Work to be done to better predict data
- OQ results show it's possible
  - need to work to determine where it can be applied and where it shouldn't be

	Density	Taka		Data/Model
# totes	Group	Tote	Location	[%]
3	9	1 leading	1C9	
		1 leading	16A5	
		1 End	1C9	0.00%
		1 End	16A5	-6.78%
1	1	2 leading	1C1	-2.28%
		2 leading	1C9	3.58%
		2 leading	TC1	<mark>5.83</mark> %
		2 leading	TA5	-1.12%
		2 leading	тс9	9.38%
		2 end	1C1	2.55%
		2 end	1C9	-3.94%
		2 end	TC1	<mark>11.97</mark> %
		2 end	TA5	-3.37%
		2 end	тс9	<mark>6.44</mark> %
8	0	3 leading	1C9	- <mark>18.25</mark> %
		3 leading	16A5	-3.00%
		3 end	1C9	- <mark>21.23</mark> %
		3 end	16A5	- <mark>14.04</mark> %
4	0			



### **Scheduling in Monte Carlo**

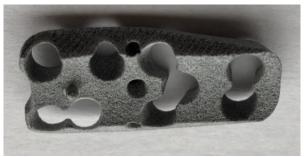
- Use the Geant4 to create the Model
- A quiet system takes about 12 hours for a JS10000 style irradiator
  - 32 CPUs





#### **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



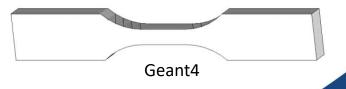
Photo



Geant4



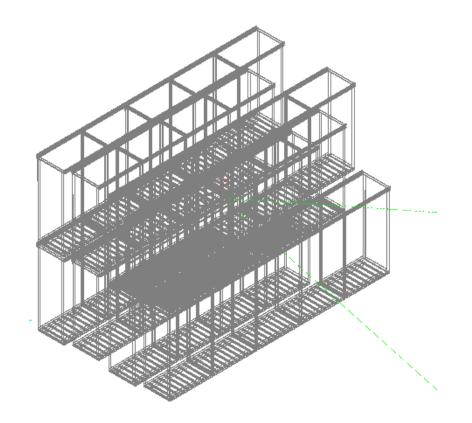
Photo





#### **Scheduling in Monte Carlo**

- Use the Geant4 to create the Model
- A quiet system takes about 12 hours for a JS10000 style irradiator
  - o 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
  - $\circ$  Need cloud computing
  - Can be run on Azure/AWS in ~1 hours for few hundred USD





- 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

