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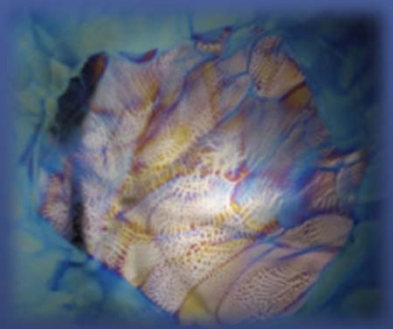
Engineering, Design and Manufacturing



A New High Dose Rate Research Irradiator

Robert Rushton, Michael Shannon, Ryan Howell,
Spencer Mickum, Zach Hope

APR 2016

Outline

- Focus
- Gammacell 220 Information
- New Design
  - System Concept
    - Inventor Photos
    - Horizontal Loading and Rotation
  - System Size
  - Shielding Material
- Dose Comparison
  - MCNP6 Simulation models
  - External Dose Rate
    - Irradiation and Transition Dose Profiles
  - Reduction in Transition Dose to Operator/Sample
  - Internal Dose Profiles with DUR
- Trade Space Table Overview
- Conclusions

Focus

- Develop a Self-contained Irradiation System
  - Replacement for Gammacell 220
  - Maximize Chamber size
  - Minimize External Dose
- Use Monte-Carlo simulations
  - Analyze radiation uniformity, potential streaming pathways, and external dose

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Gammacell 220 Information

- Developed in the 1950/60s by AECL
- Nordion took over business in 1980s
- Chamber size:

  6” diameter, 8” high
- Central dose rate with 24 kCi of Co-60:

  ~18 kGy/hr

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Gammacell 220 Information

Center Exposure Rate	Reference:
288 Gy/min	http://www.tandfonline.com/doi/abs/10.1080/00223131.2000.10874915
300 Gy/min	http://www.tandfonline.com/doi/pdf/10.1080/00223131.2000.10874915
5.0 Gy/min	https://www.researchgate.net/profile/Torbjoern_Reitberger/publication/12318153_Is_cellobiose_dehydrogenase_from_Phanerochaete_chrysosporium_a_lignin_degrading_enzyme_Biochim_Biophys_Acta_(BBA)_Protein_Struct_Mol_Enzymol_1480(1-2)83-91/links/00b495270386df41f0000000.pdf
90.17 Gy/min	https://www.ipen.br/biblioteca/2004/09927.pdf
110.0 Gy/min	http://onlinelibrary.wiley.com/doi/10.1002/pol.1972.150100221/full
26.4 Gy/min	http://www.genetics.org/content/171/4/1561.long
230 Gy/min	http://www1.bipm.org/cc/CCRI(I)/Allowed/21/NPL_Report_to_CCRI(I)_13.pdf
52.6 Gy/min	https://www.researchgate.net/profile/Mustafa_Sohrabpour/publication/238946243_Preparation_of_a_new_chemical_radiochromic_film_dosimeter/links/00b7d52e3782052331000000.pdf
600 Gy/min	http://www.farm.ucl.ac.be/Full-texts-FARM/Crucq-2000.pdf

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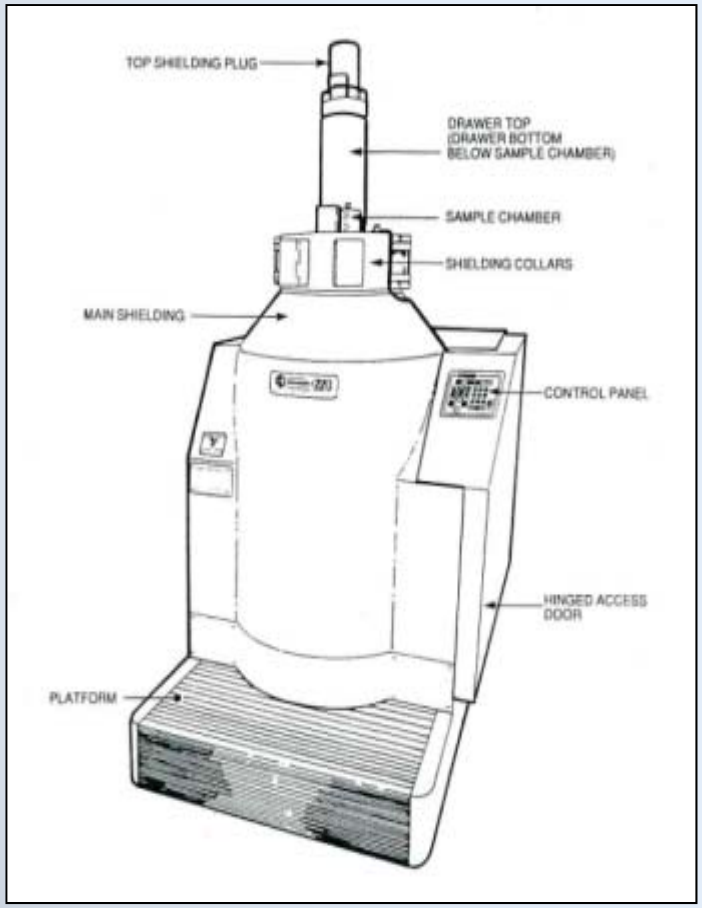
Gammacell 220 Information



- Premier stand-alone research irradiator
- Simple design, high dose rate, well characterized DUR
- Nordion business decision to discontinue in 2007
- Radiation protection needs improvement

New Integrated Shielding Design

- Primary Improvements
  - Increase chamber size
  - Optimize external dose
  - Reduce transition dose
- Primary Needs
  - Improved DUR for like chamber sizes
- Future Goals
  - Enhanced temperature control

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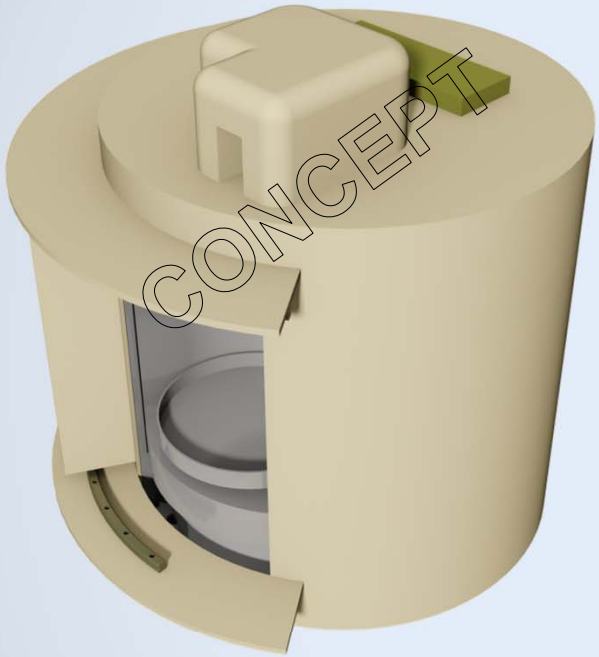
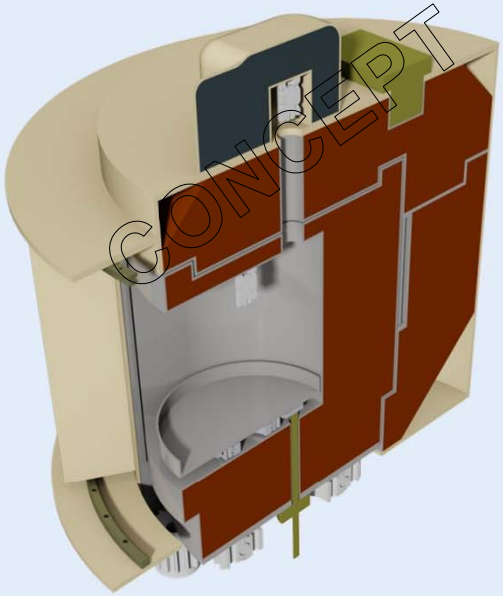
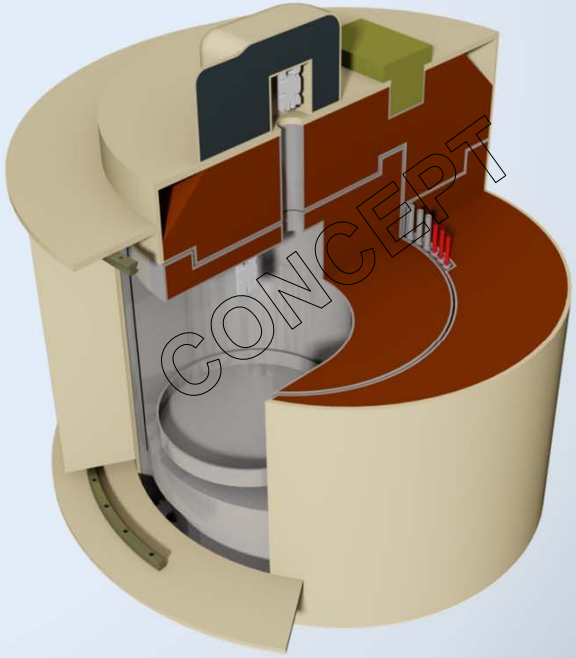
Design – System Concept

GR 440

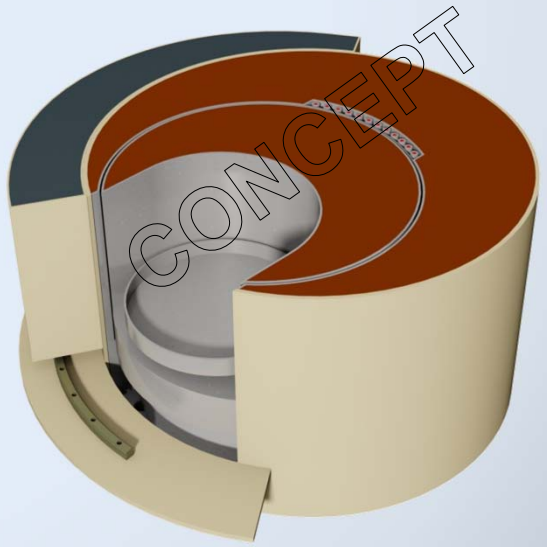






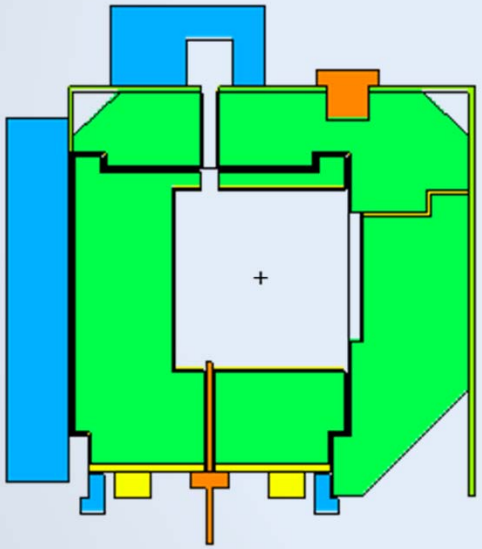
Design – System Concept

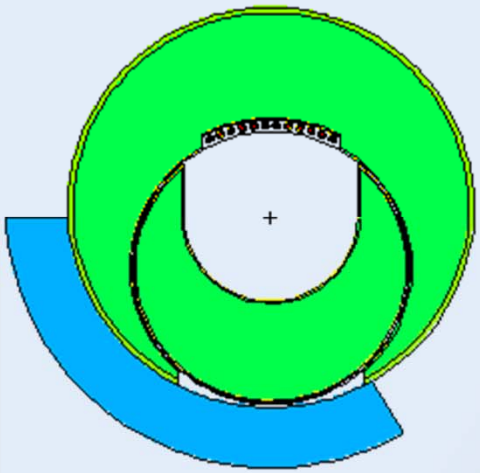
- Horizontal Loading Technique
  - Rotation from Loading to Irradiation Position
  - Chamber rotation in place for dose uniformity
- Movable Lead Door
  - Only opens with chamber in loading position
- Source and Activity
  - Up to One Dozen Co-60 Source rods
  - Up to 24 kCi



Design – System Concept

- GR 440





Design – System Size

	Weight [lbs.]	Chamber Size [inch]	System Height [ft.]	System Width [ft.]
GR 440	8361*	10.0 Diameter x 10.0 Height	2.6	2.5
Gammacell 220	8300‡	6.0 Diameter x 8.0 Height‡	4.8‡	2.5‡

* Not Including associated motors, steel enclosure, or electronics.
‡ Information about the Gammacell 220 can be found in the Gammacell 220-232 Operator's Manual. IN/OM 0194 GC220. Rev A. 1992 September.

Design – Shielding Material

- Depleted Uranium (DU)
  - DU is ~ 1.7 times more dense than Lead
  - DU has ~ 2 times smaller Half Value Layer than Lead
- Using DU
  - Can be cast and machined for precision shield designs
  - Fully enclosed in welded steel structure

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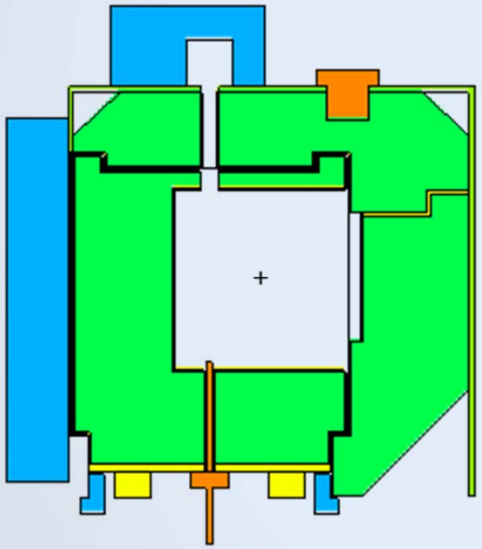
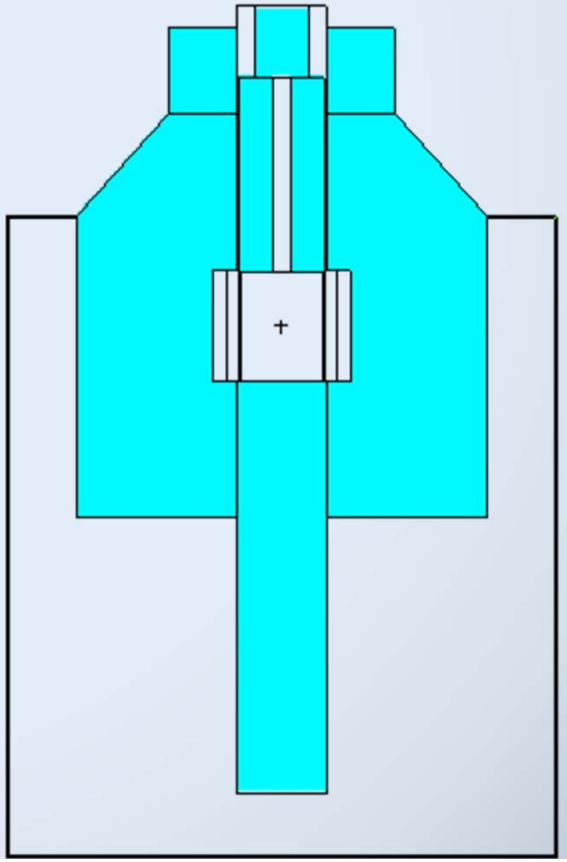
Design – System Comparison

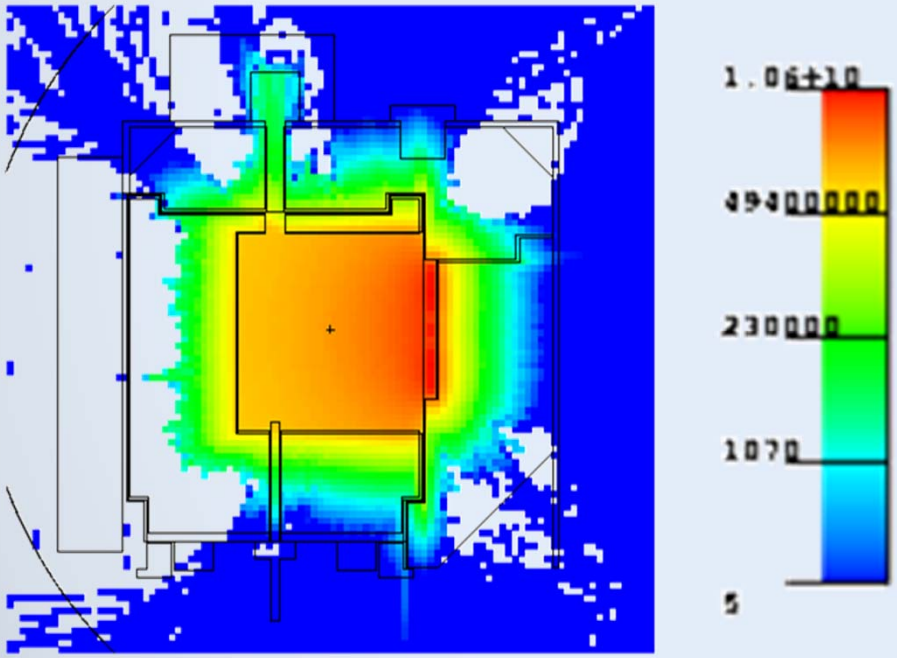
- **Gammacell 220**

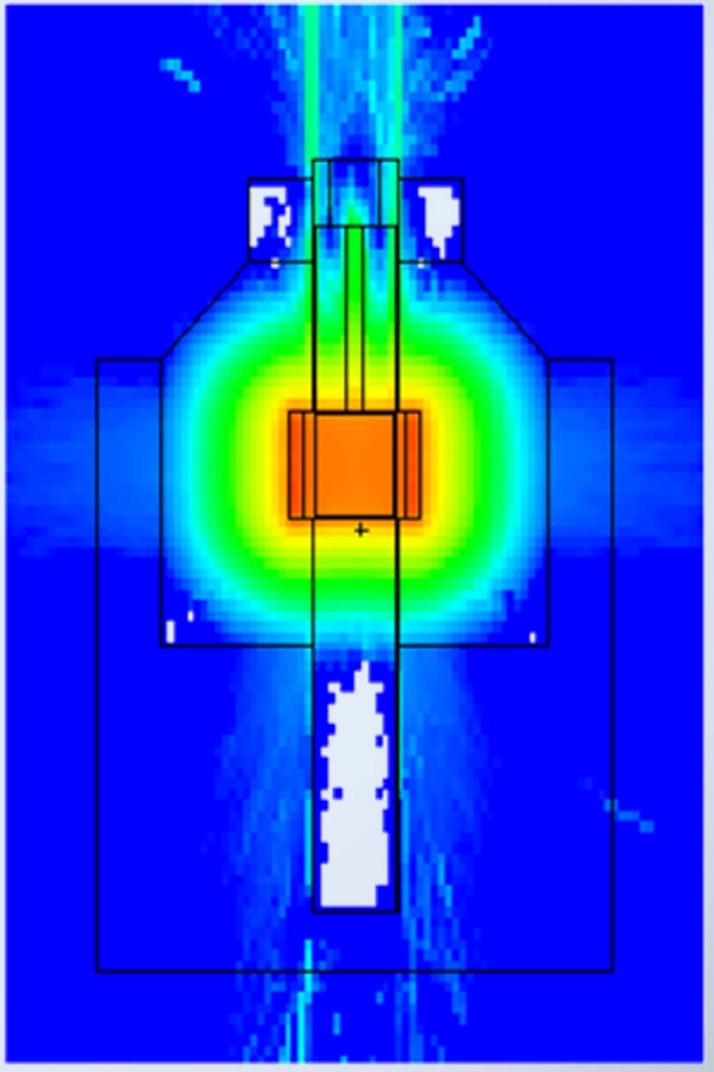




Dose Comparison – MCNP 6 Models

- Simulation





Dose Comparison – MCNP 6 Models

- **Simulation**
  - **Using Weight Windows[1] and Density Reduction Method[2]**
  - **Tally mesh inside irradiation chamber for Center Dose, Dose Uniformity and over entire geometry for External Dose**
  - **Mesh results in BLUE designate areas with dose rate below 5 mrem/hr**

1. T. Goorley, et al., "Initial MCNP6 Release Overview", Nuclear Technology, 180, pp 298-315 (Dec 2012).
2. Sato, S. & Nishitani, T. A study on variance reduction of Monte Carlo calculation with weight window generated by density reduction method. 2007. 5 p.

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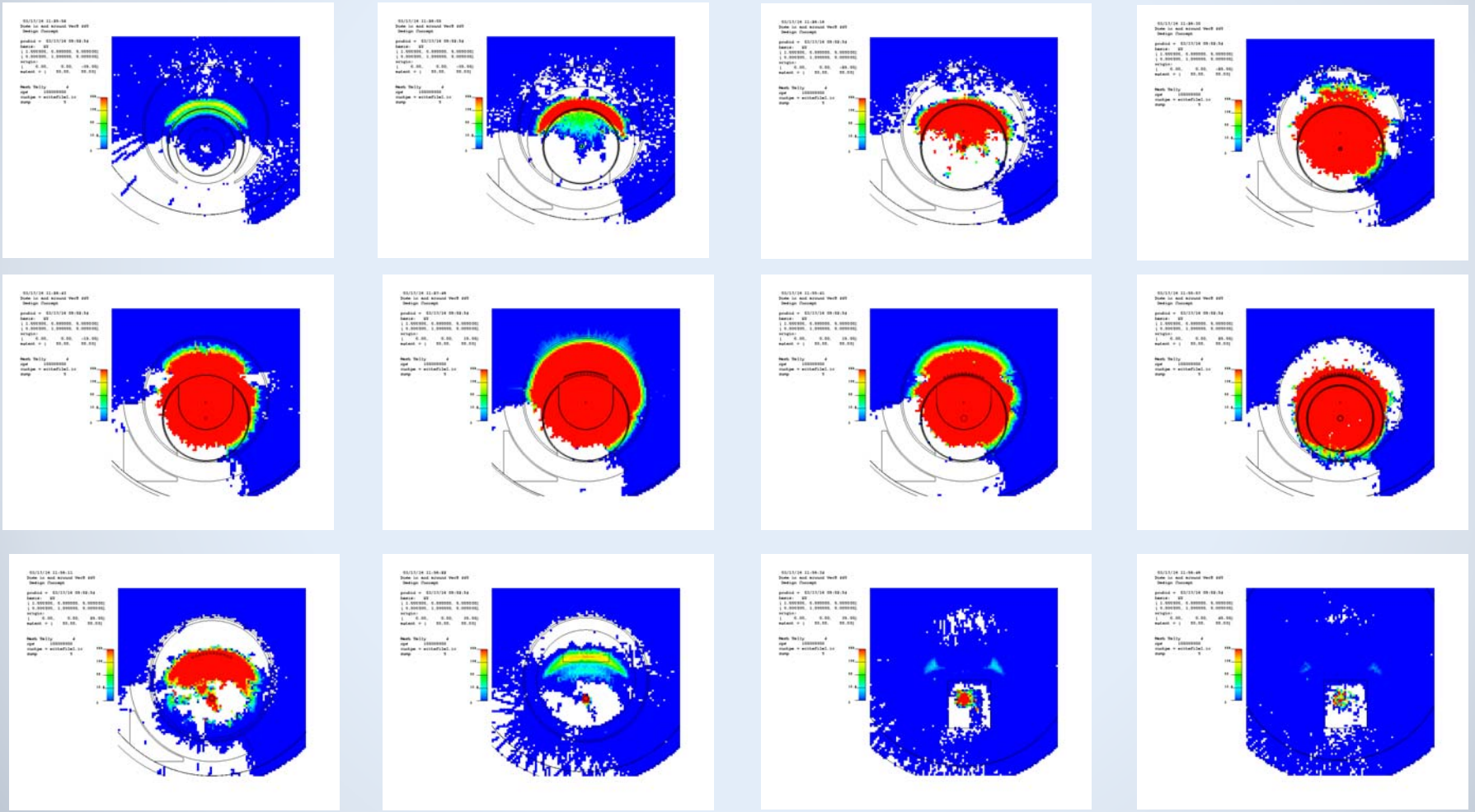
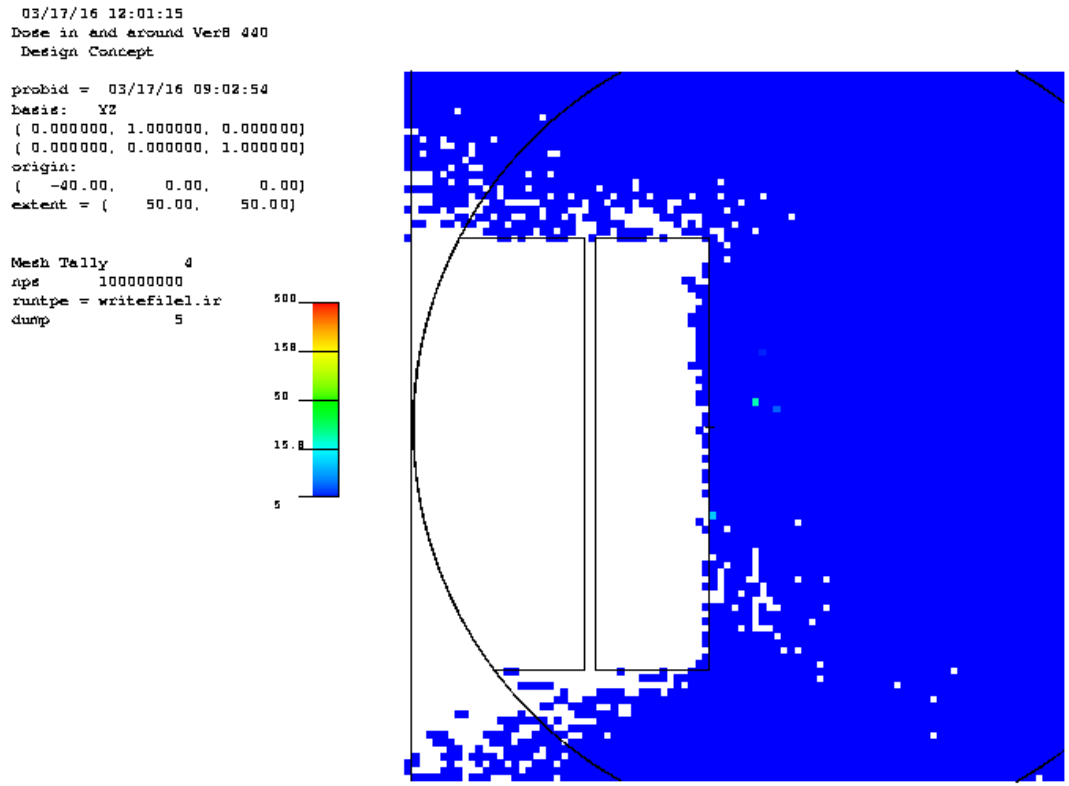
Dose Comparison – External Dose Rate

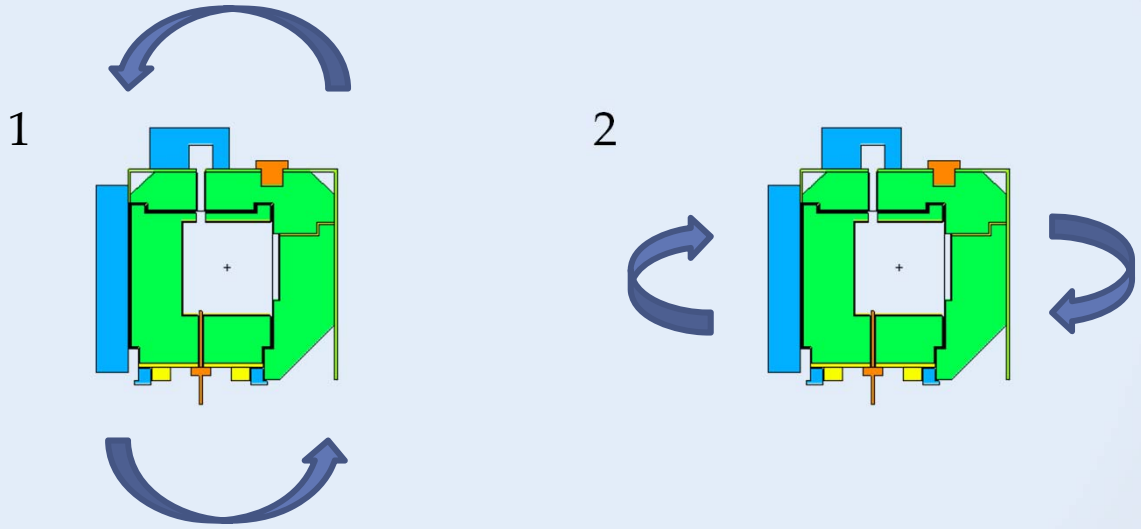


Dose Comparison – External Dose Rate



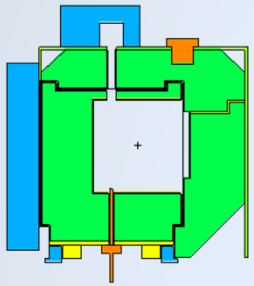
Dose Comparison – External Dose Rate

- **Measurement Format:**



Dose Comparison – External Dose Rate

Measurements:



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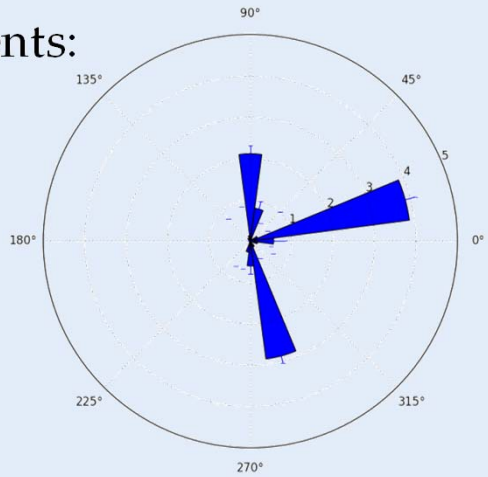

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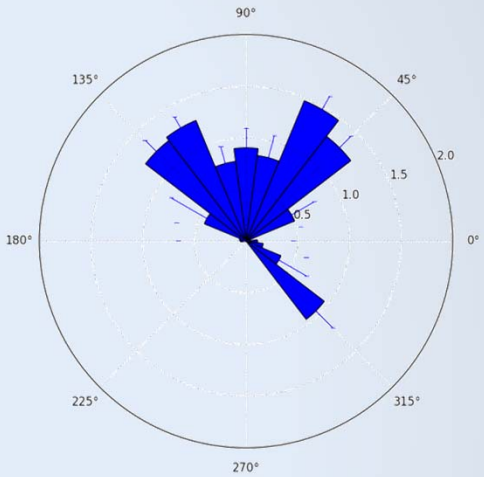

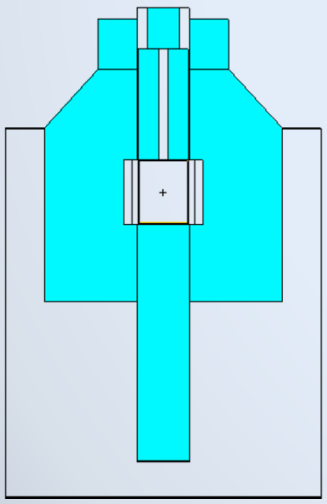

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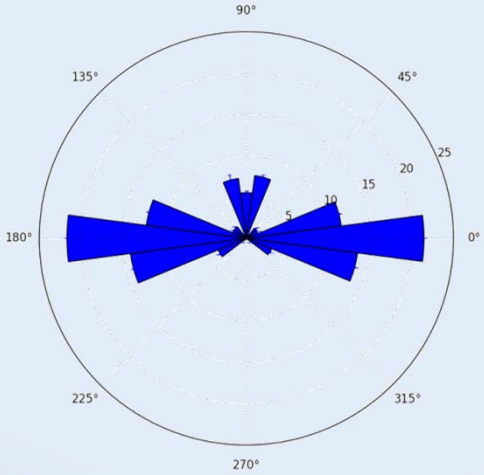

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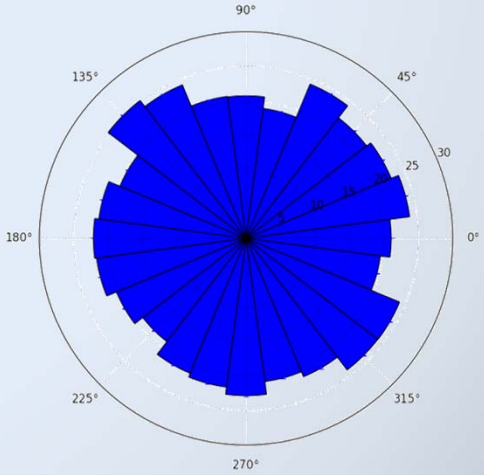
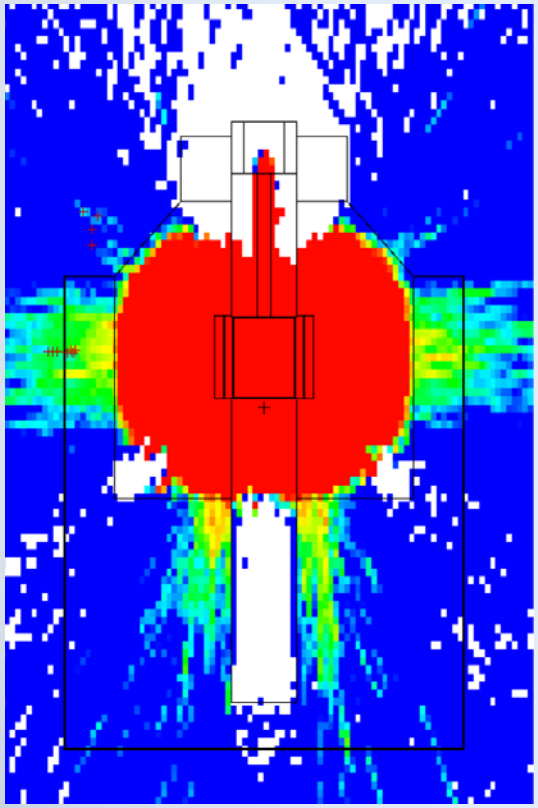
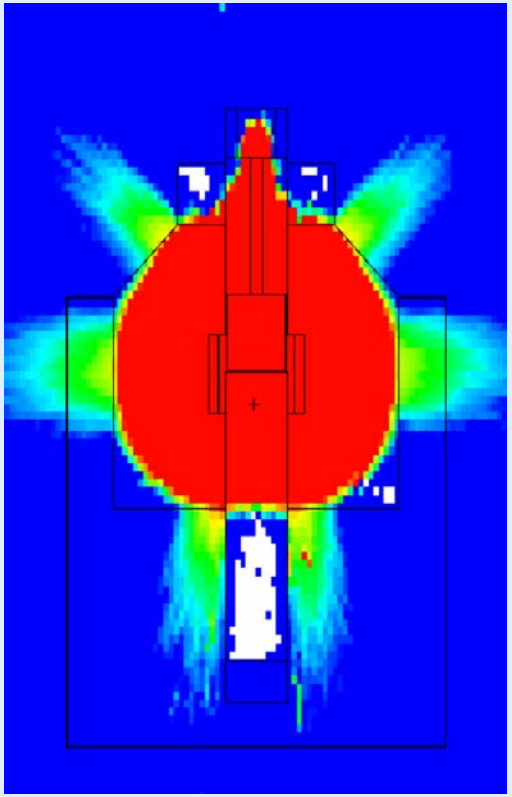
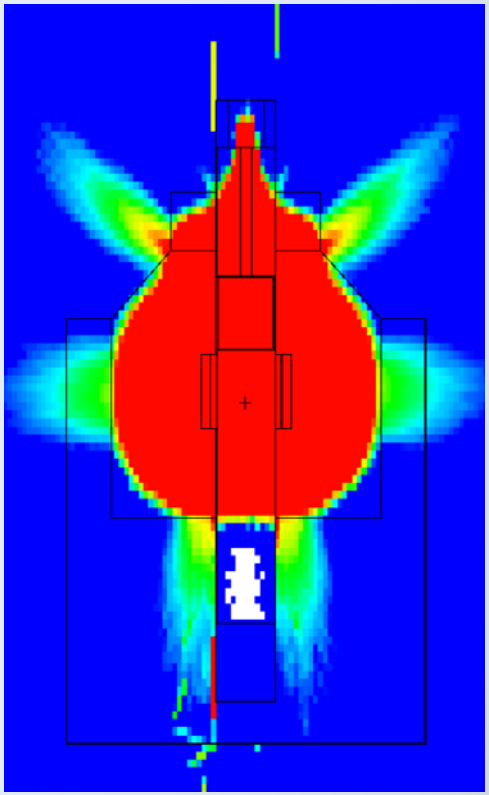


Dose Comparison – Transition Dose Rate







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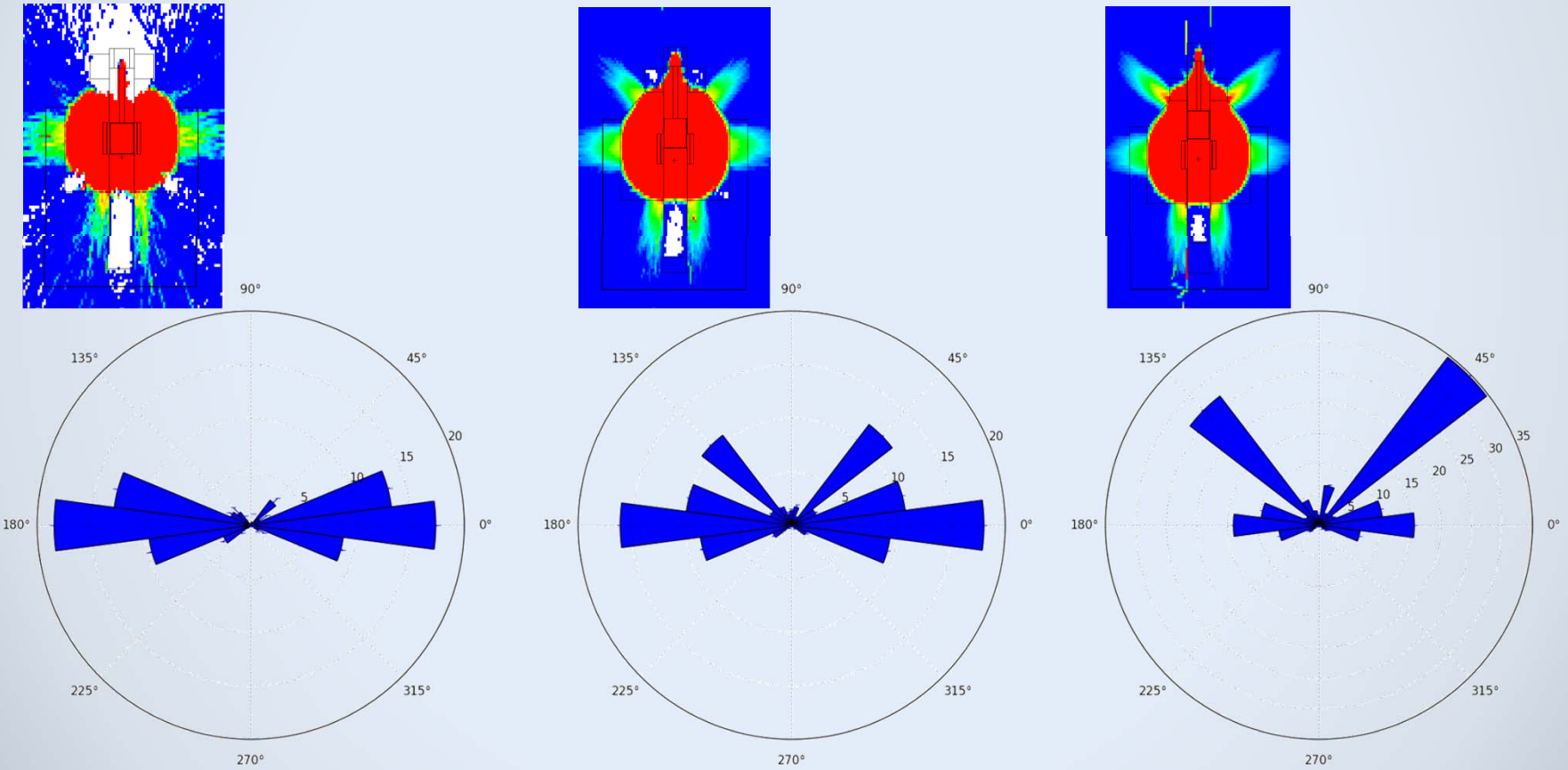
Dose Comparison – Transition Dose Rate



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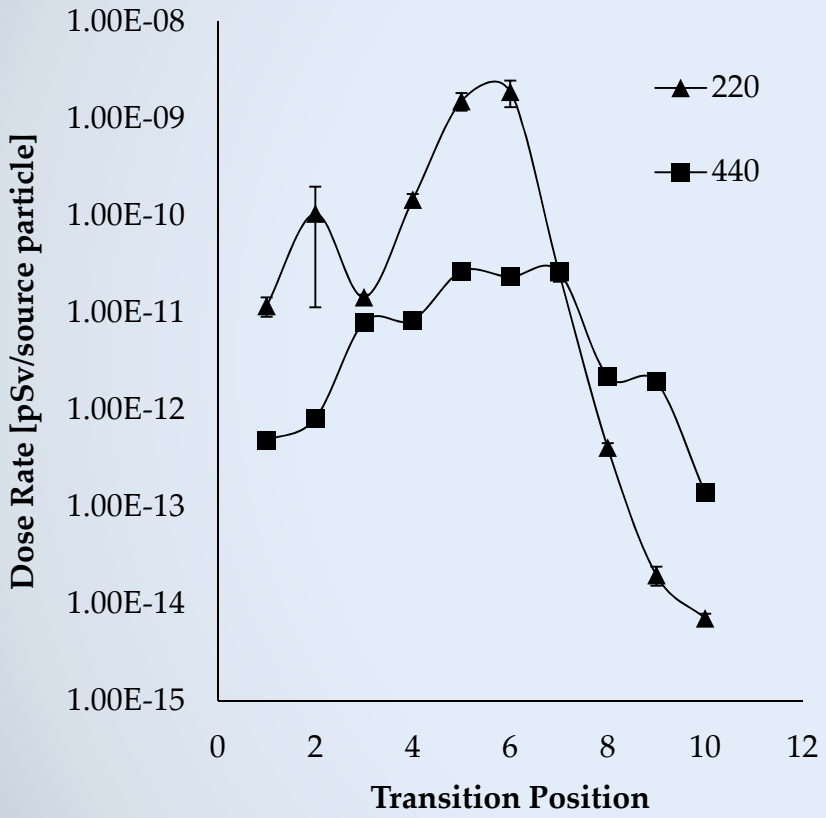
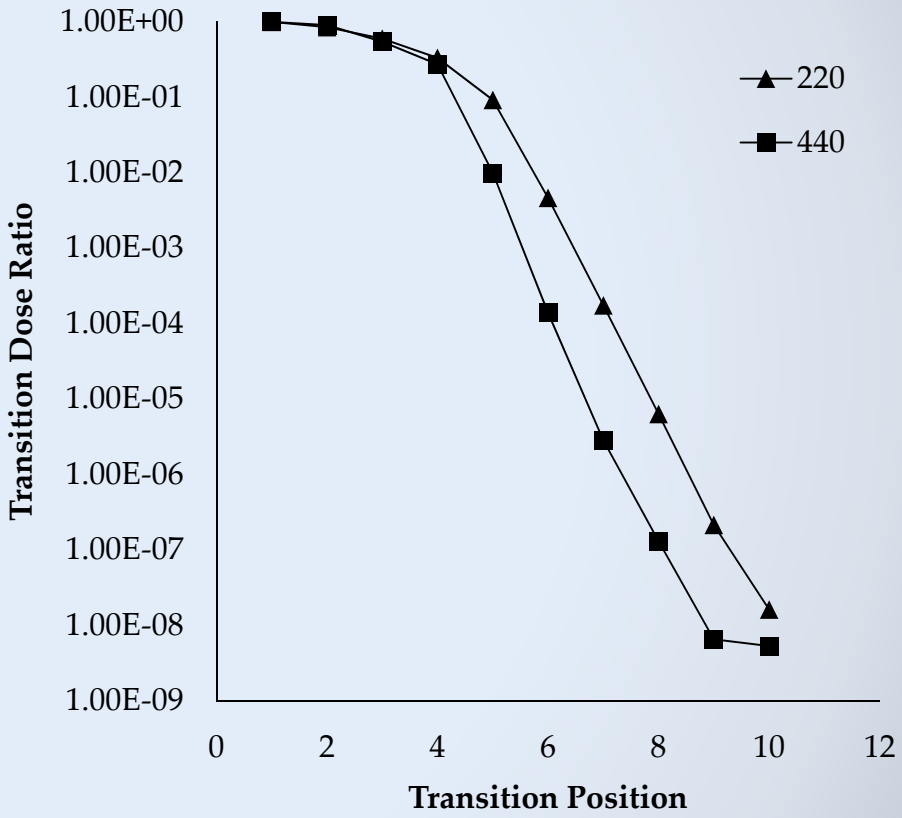
Dose Comparison – Transition Dose Rate



1. External Transition Dose



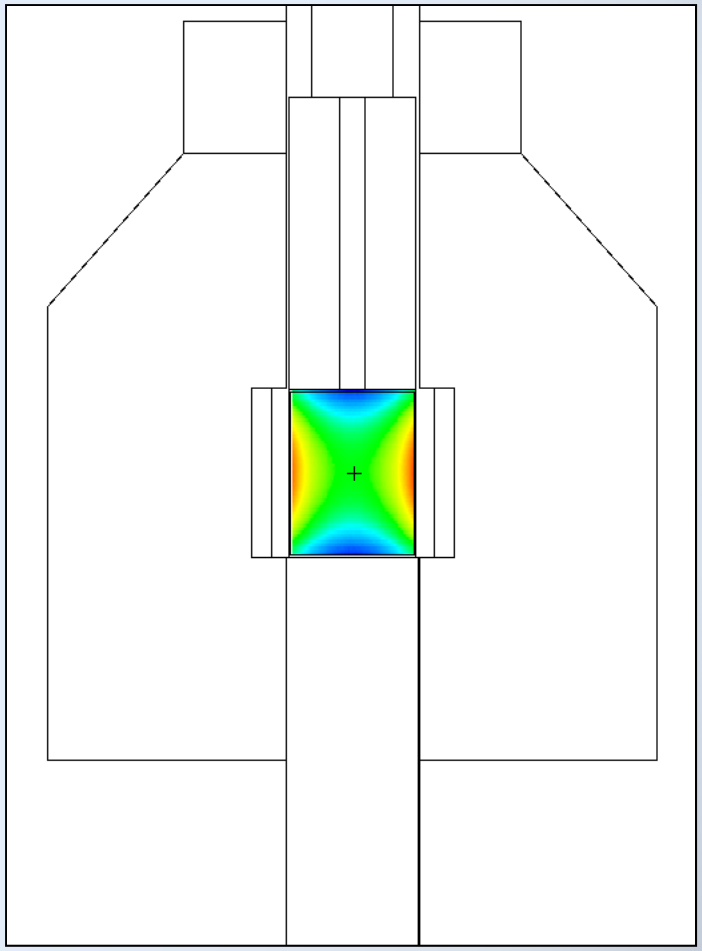
2. Internal Chamber Dose

Dose Uniformity Ratio Comparison

- **Dose Uniformity Ratio**

$$DUR = \frac{Highest\ Dose\ in\ Volume}{Lowest\ Dose\ in\ Voume}$$

- **FOM to determine uniformity of dose throughout irradiation chamber**



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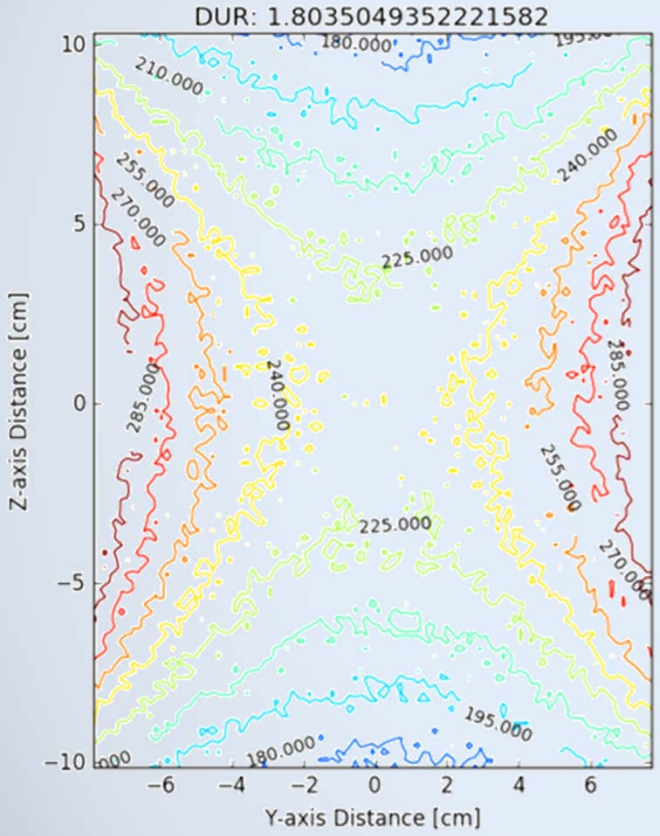
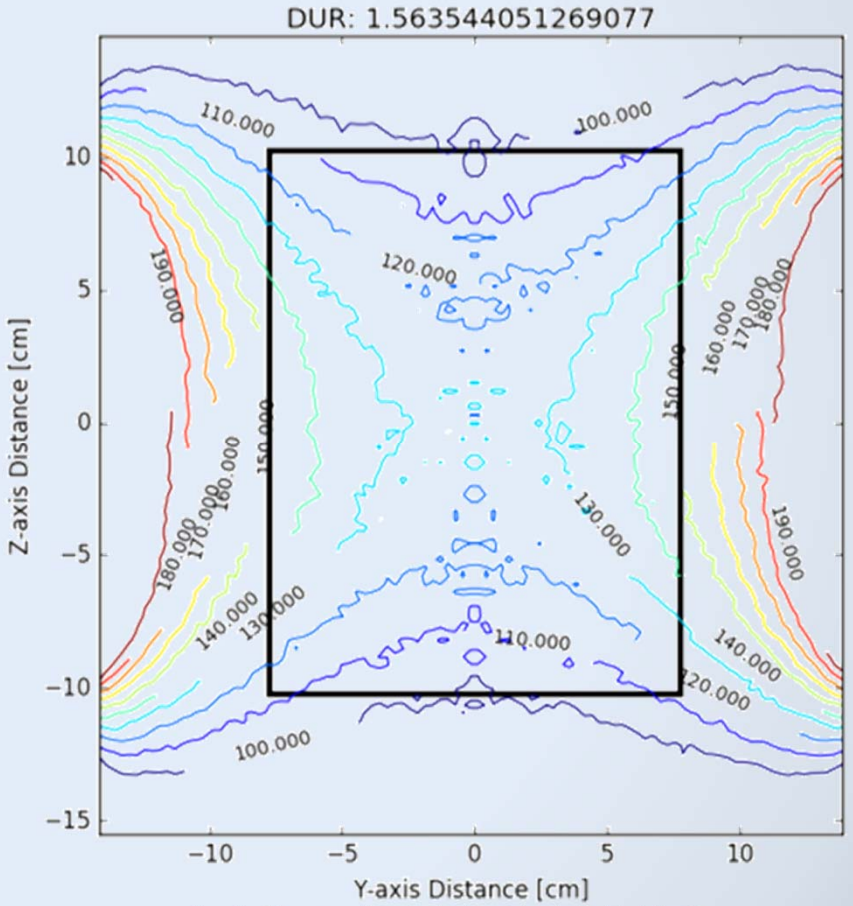
Dose Uniformity Ratio Comparison





220: 1.804 DUR

440: 1.564 DUR

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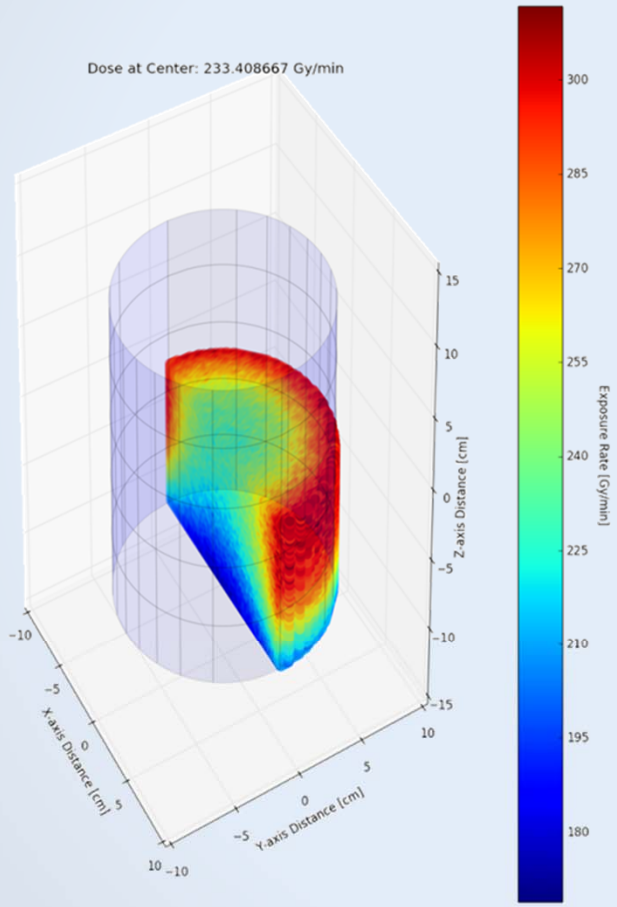
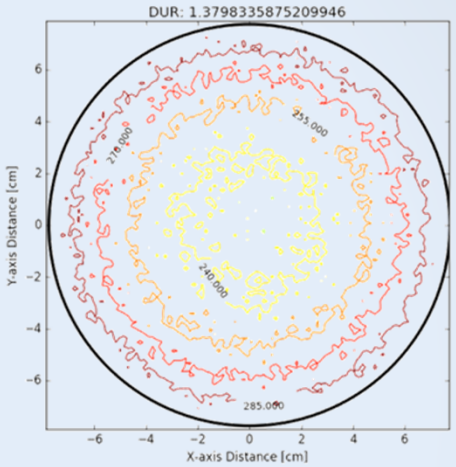
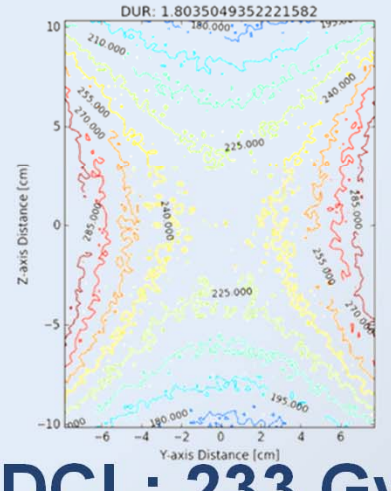
Internal Dose Rates and DUR comparison







- **220 DUR XY: 1.380 YZ: 1.804, DCL: 233 Gy/min**

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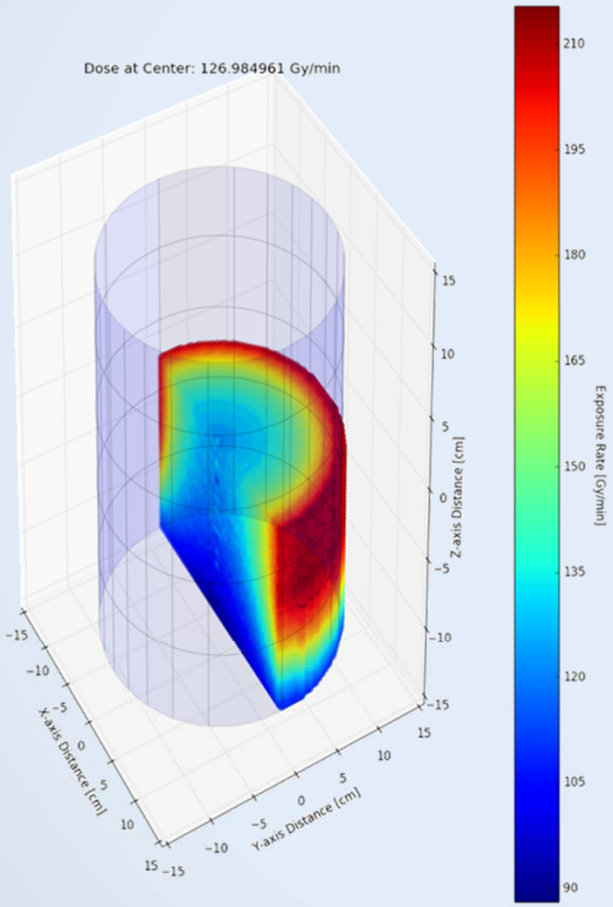
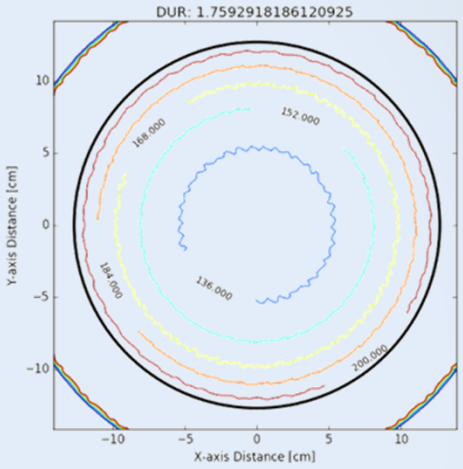
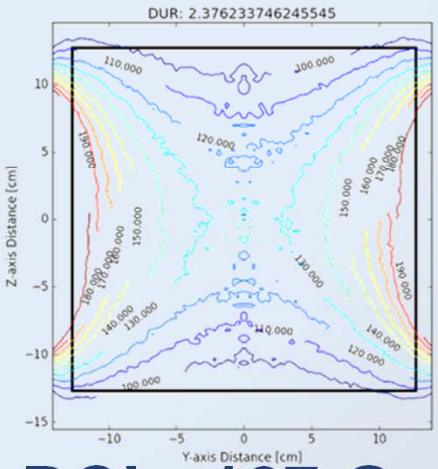
Internal Dose Rates and DUR comparison







- **440 DUR XY: 1.759 YZ: 2.376, DCL: 127 Gy/min**

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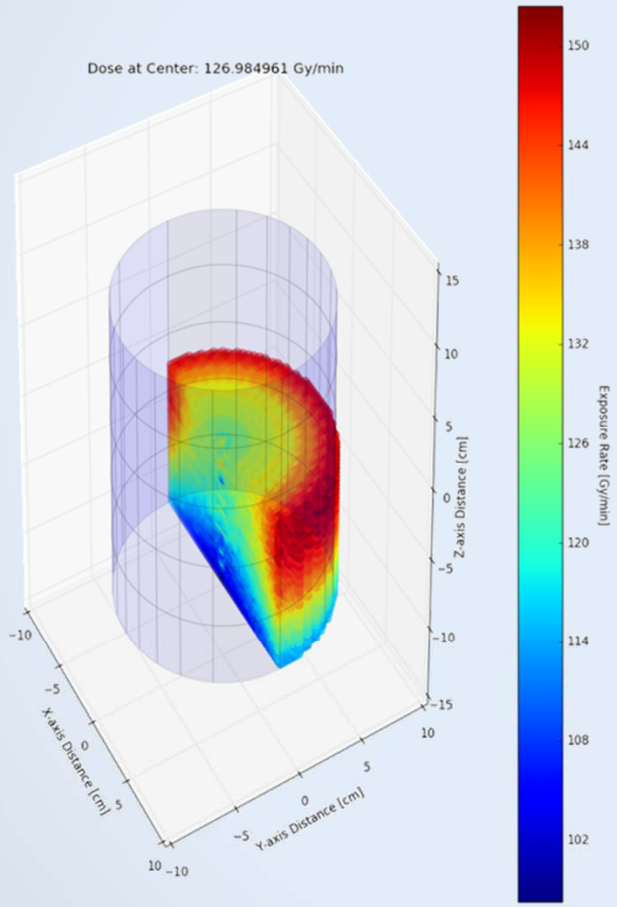
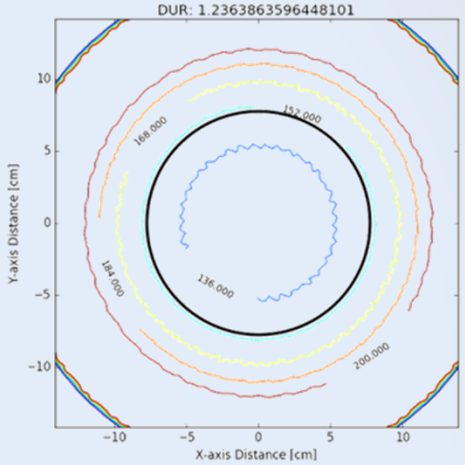
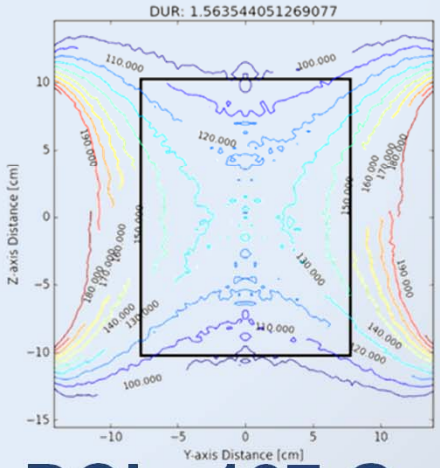
Internal Dose Rates and DUR comparison







- **440 DUR XY: 1.236 YZ: 1.563, DCL: 127 Gy/min**

Conclusion

- Parametric study completed using high-fidelity Monte-Carlo models.
- GR 440 Design Concept has increased chamber size and reduced operator external dose and transition dose.
- Irradiation chamber dose estimates maximize performance for new rotating design.
- Future work to couple temperature control.

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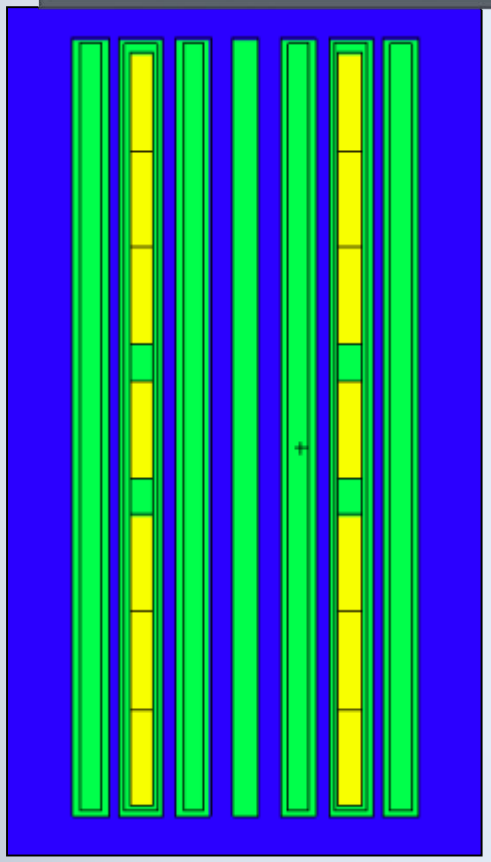
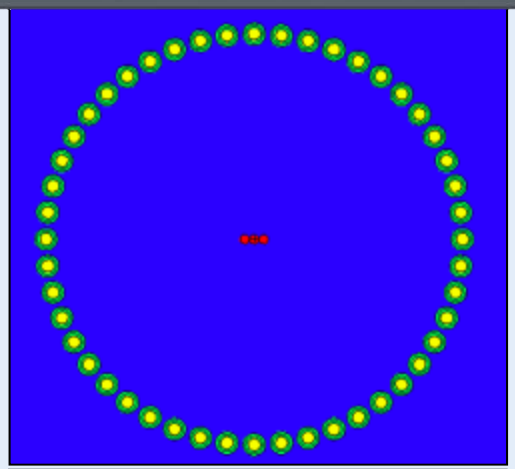
Questions?

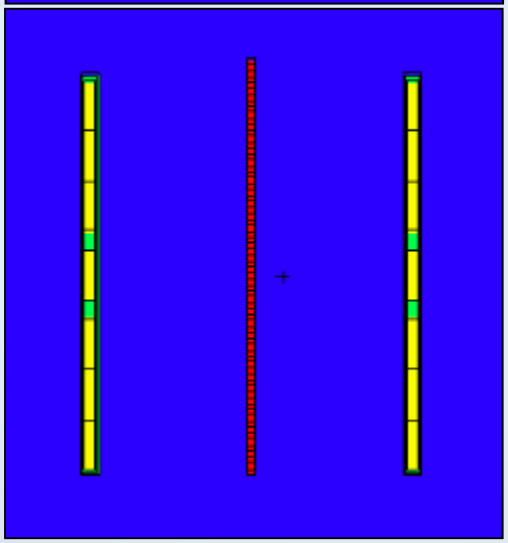
GR440 Design Baseline

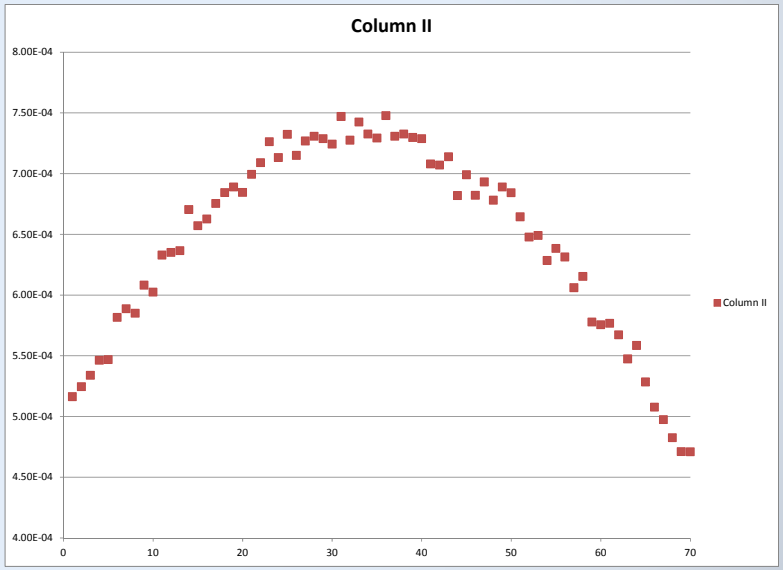
Improved Dose Uniformity (2 of 2)

Gamma Cell 220 Monte Carlo Model









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Tradespace Table

	220	440	440	440	440
Chamber Size (D x H):	6″ x 8″	6″ x 9″	8″ x 9″	10″ x 9″	12″ x 9″
Dose Center Line [Gy/min]:	234	239.8	179.3	122.15	97.79
DUR XY axis:	1.375	1.424	1.557	1.843	1.969
DUR XZ axis:	1.804	2.009	2.087	2.233	2.343
External Dose Ratio:	1	0.117	0.083	0.073	0.067

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GIF: Rotation of Center Shield