Radiation Levels Generated in the Hall and in the Environment during the HKS Experiment

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Radiation Physics Group

RadCon/ESH, November 2024

ERR Charge #6

- Are the radiation levels expected to be generated in the hall acceptable?
- Is any local shielding required to minimize the effects of radiation in the equipment?

Role of RadCon

- Our work is to make JLab compliant with CFR Title 10 Part 835 – Occupational Radiation Protection
- Includes radiation protection of Life and Environment
- Important part of the job is evaluation of new projects at Jlab, optimizing designs for ALARA purposes, making sure they would satisfy the design criteria and JLab policies
- Protection of Equipment is not a direct RadCon responsibility, but our tools can be used for that goal in collaboration with the Experiment’s Subject Matter Experts
- Synergy between the RadCon and other departments, ALARA process helps everyone

Law Requirements: Design and Control

- § 835.1001: maintain radiation exposure in controlled areas *ALARA* through *engineered* and *administrative* controls
- § 835.1002 sets objectives for facility design and modifications
  - use optimization methods to achieve ALARA goals in developing and modification of *facility design* and *physical controls*
  - design objective for controlling personnel exposure: keep the dose accumulation ALARA, below 10 mSv (1 rem) in a 2000-hour work year for radiological workers
  - avoid releases of *airborne radioactive material* to the workplace atmosphere under normal conditions
  - Include in the design, and in material selection, features that facilitate *operations*, *maintenance*, *decontamination*, and *decommissioning*
- § 835.1003: maintain *occupational dose* to general employees within limits and ALARA

Environmental Design Goals

- Practical *criteria* based on design goals in routine beam operations
  - Yearly accumulated dose to the public beyond the JLab Accelerator fence should be below 10 mrem
  - Extremely conservative, but it is a good neighbor policy: the dose increase is less than 10% of natural radiation background in our area
- Every upcoming experiment's contribution to the environmental dose is evaluated in the process of "Radiation Budgeting"
  - During the design stage, its contribution to the dose accumulation at the boundary is calculated and summed for all experiments to be run during a calendar year
  - If the sum exceeds 10 mrem (the "Budget") then the experiments contributing the most of the dose are recommended for detailed review

Overview of the Radiation Budgeting

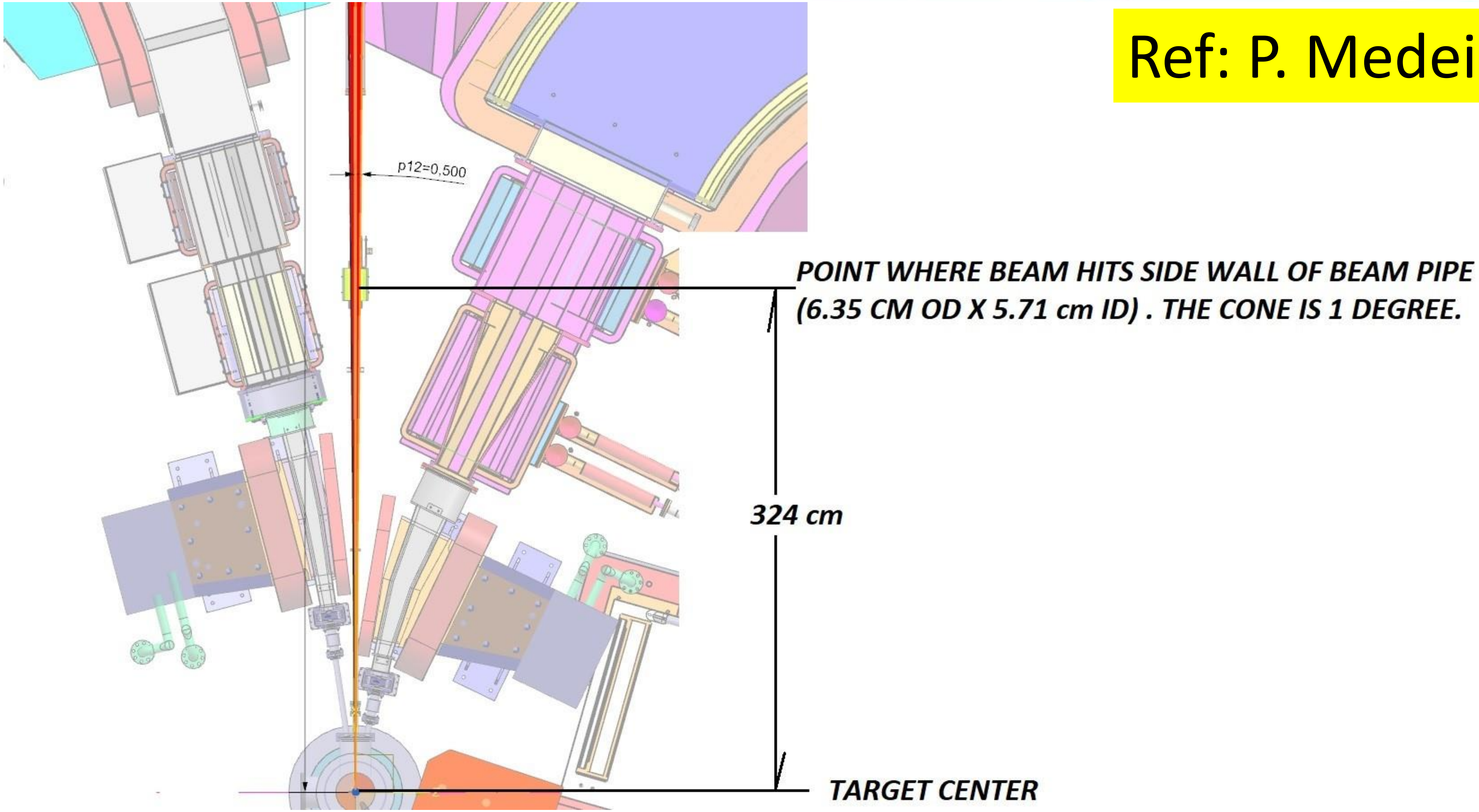
- Realistic shielding calculations – conservative design approach using ALARA Design Goals as defined in the RadCon Manual
- Overall confidence in shielding calculations for typical setups
  - In electromagnetic processes: as needed (typical accuracy 5 - 10%)
  - In photo- and electronuclear reactions: factor 1.5-2.0 due to lack of experimental data and difficulties in the model development
  - The situation is improving as we have the opportunity to use both FLUKA and GEANT Monte Carlo codes for independent verification.
- Optimizing shielding design by finding ALARA solutions for new experimental setups; minimizing dose accumulation in the environment; helping experimentalists to minimize the detector backgrounds and minimize material activation
- Monitoring radiation environment, verifying calculations and making adjustments if necessary. “Balancing yearly budget”

Radiation Budget Calculation Tools

- JLab standard analytical calculation tool ELEC5 was developed by Geoffrey Stapleton in late 1990s and then converted to the Excel Rad. Budget spreadsheet workbook
- Every experiment is split into “Setups”, each setup characterized by the unique combination of beam energy + current, target material + thickness, beamline parameters, and planned beam time
- Standard Hall A or Hall C geometries assumed, no magnetic fields in the beam line (a “typical” experiment)
- Excel Rad. Budget calculations typically give good “1st-Order ” values
- More complex experiments with non-standard beam lines and the presence of magnetic fields may require detailed MC simulations

Radiation Budget for HKS: Beam Line

Ref: P. Medeiros



ELEC5 Radiation Budget for HKS

Setup #9

Hall: C

RADIATION BUDGET FORM

page: 1 of 1

Exp. # HKS Group **rev:** **run dates:** 2026-2027 **name of liaison:** T. Gogami

setup number			1	2	3	4	5	6	7	8	9	
beam	energy	GeV	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	*totals:*
	current	uA(CW)	2.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	25.0	
exp't target	element		C	Li	Be	B	C	Al	Ca40	Ca48	Pb	
	thickness	mg/cm2	386	100	100	100	150	150	150	150	150	
	dist. to pivot	m	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Z		6	3	4	5	6	13	20	20	82	
	A		12	7	9	11	12	27	40	48	207	
add'l target 1	element		H									
	thickness	mg/cm2	64									
	dist. to pivot	m	0.0									
	Z		1	0	0	0	0	0	0	0	0	
	A		1	0	0	0	0	0	0	0	0	
critical window	radius	cm	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	
	dist. to pivot	m	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	3.24	
scattering weighting factor			0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	
time	run time	hours	144	120	384	72	168	672	456	552	1000	3568
	(100% eff.)	days	6.0	5.0	16.0	3.0	7.0	28.0	19.0	23.0	41.7	148.7
	installation	hours										0
	time	days	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
dose rate at	method 1	urem/hr	0.06	0.24	0.27	0.29	0.50	0.72	0.98	0.84	1.23	
the fence post	method 2	urem/hr										
(run time)	conservative	urem/hr	0.06	0.24	0.27	0.29	0.50	0.72	0.98	0.84	1.23	
dose per setup		urem	8	29	103	21	84	482	445	464	1231	2868
% of annual dose budget		%	0.1	0.3	1.0	0.2	0.8	4.8	4.5	4.6	12.3	28.68
% of allowed dose for the total time												70.41
% of allowed dose for the run time only												70.41

If > 200%, discuss result with Physics Research EH&S officer

date form issued: November 15, 2024 *authors:* P. Degtiarenko

2.2 GeV, 25 mA

Pb Target
150 mg/cm^2

BL Opening
R = 2.85 cm at
Z = 3.24 m

1000 PAC hours
(48 days)

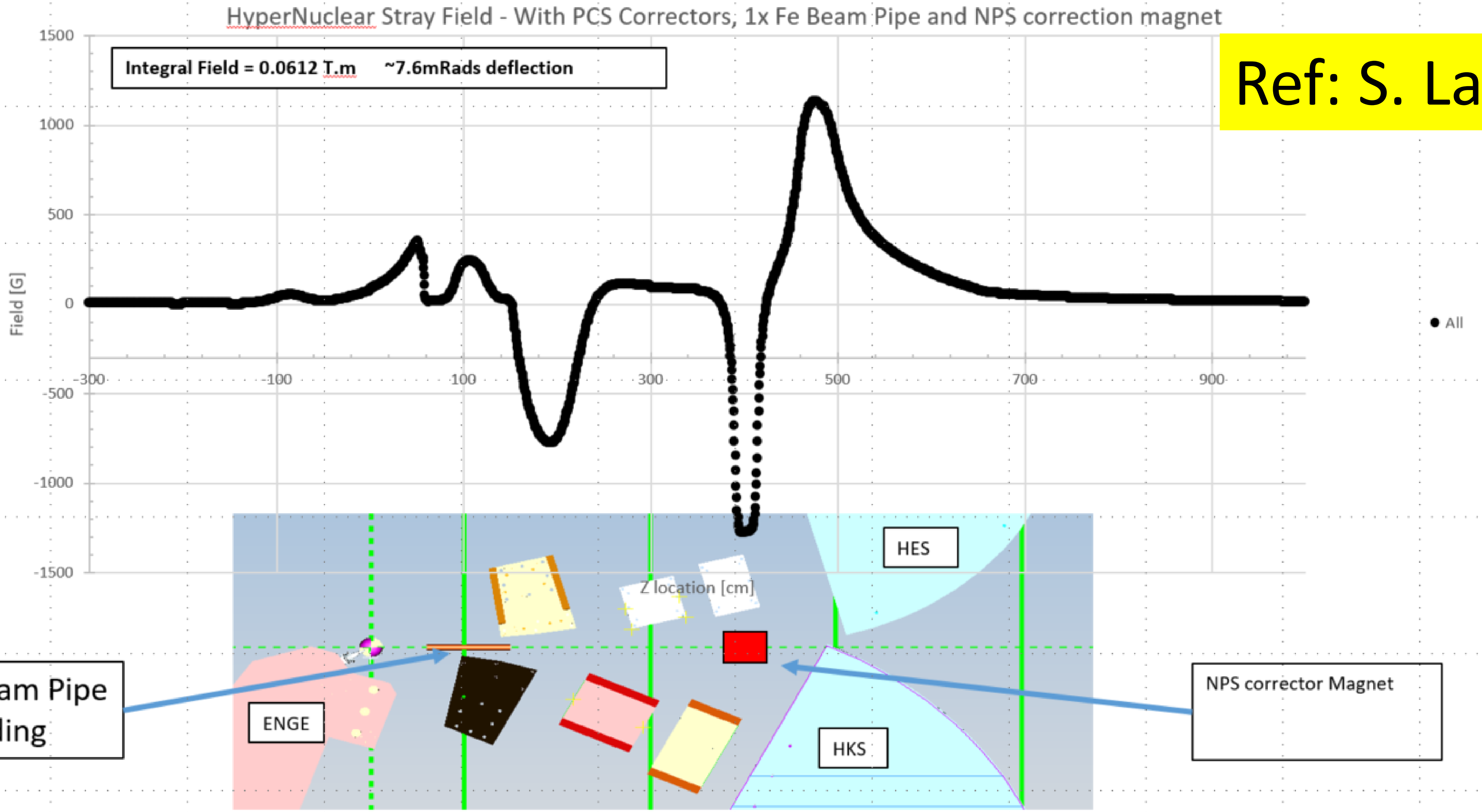
1.23 μrem/h at
RBM-4

12% of 10 mrem

Total 29%

Jefferson Lab

Sum of Stray Fields with Front Fe beam line shielding

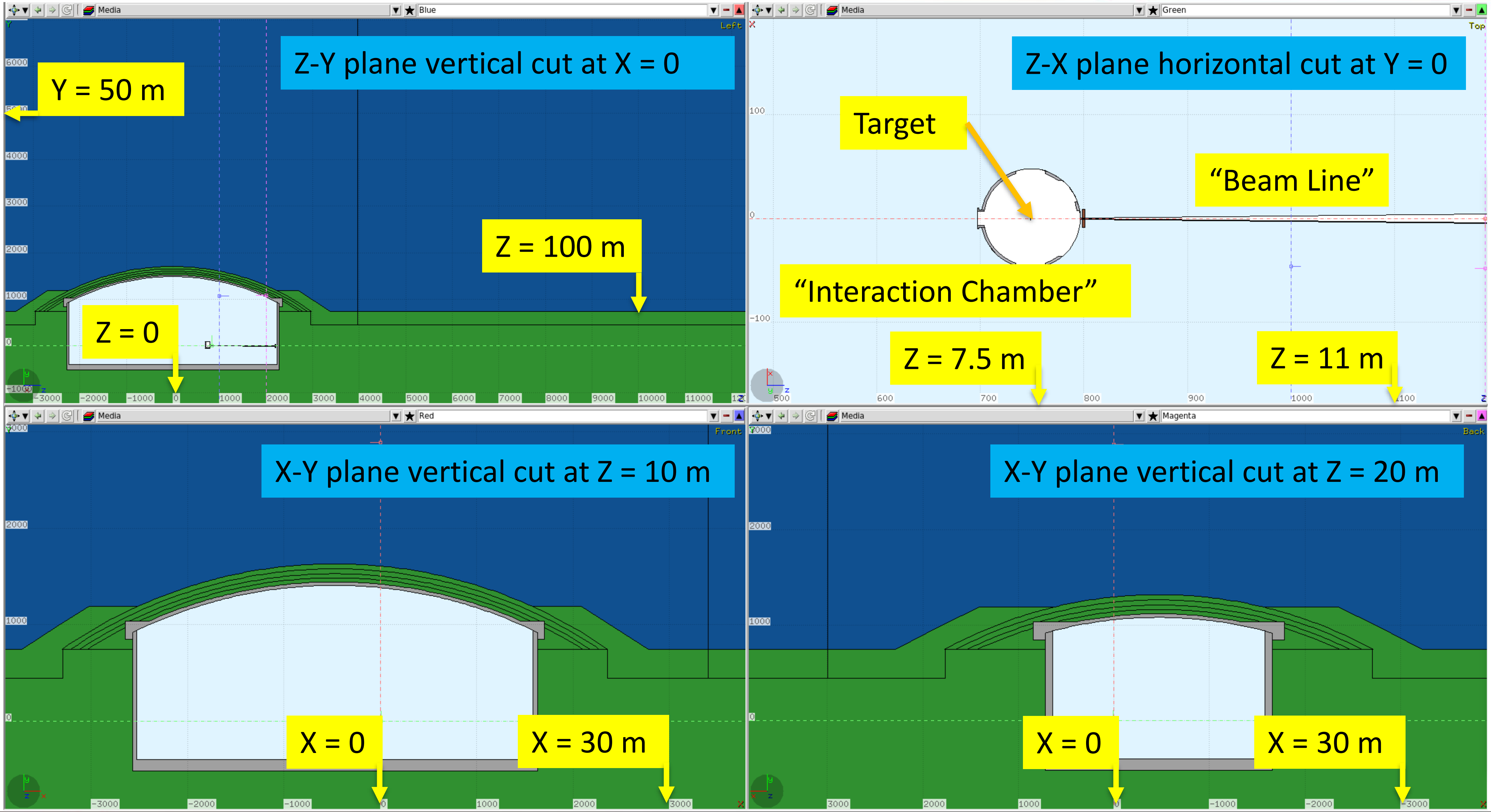


Ref: S. Lassiter

Fe Beam Pipe Shielding

NPS corrector Magnet

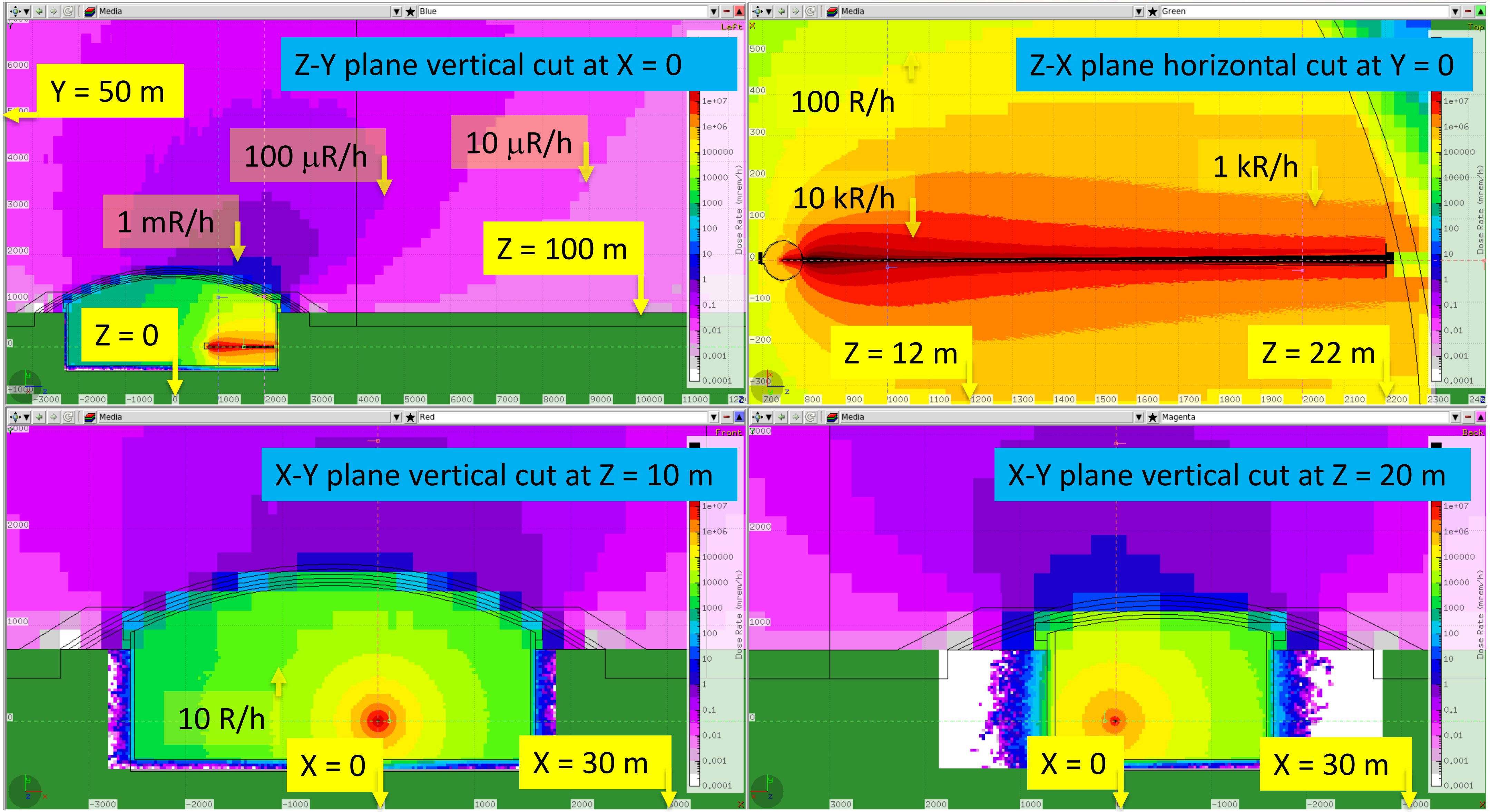
FLUKA Model for the HKS BL in Hall C



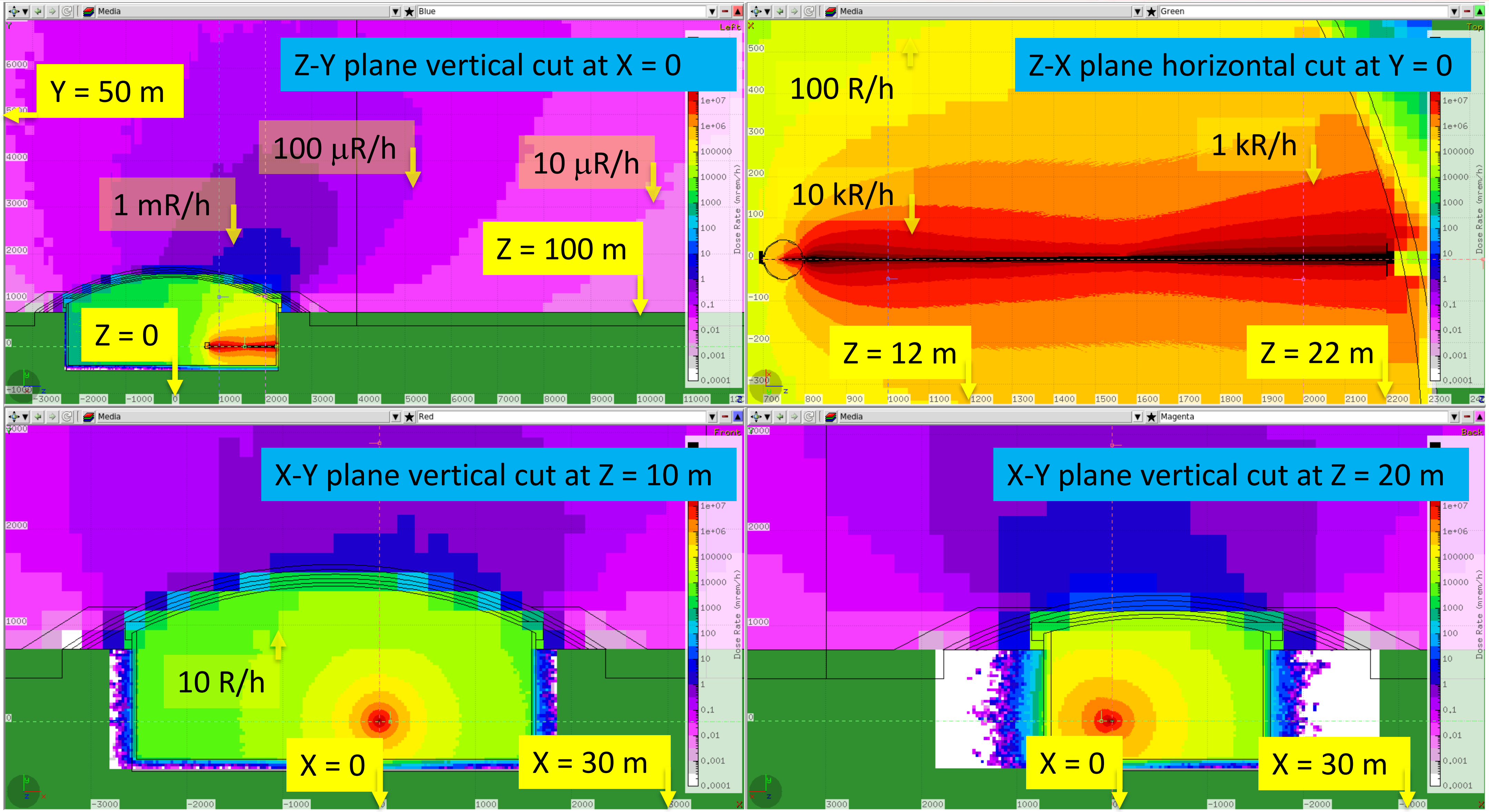
FLUKA Model for the HKS BL in Hall C

- Realistic Model of the Hall enclosure, including roof and the surrounding space
- Simple model for the Target and the Beam Line as a cone with the opening angle the same as in ELEC5 calculations
- Option to estimate effects of the stray magnetic fields in the beam line
- A first step to the full HKS beam line simulation that would need real geometry
- Allowed to compare with the ELEC5 results for the dose rates at the boundary, evaluate prompt radiation fields in the Hall at the 1st order, and evaluate beam line activation
- No model for the beam dump tunnel and beam dump body

Prompt Dose Rates During Setup #9



Prompt Dose Rates During Setup #9

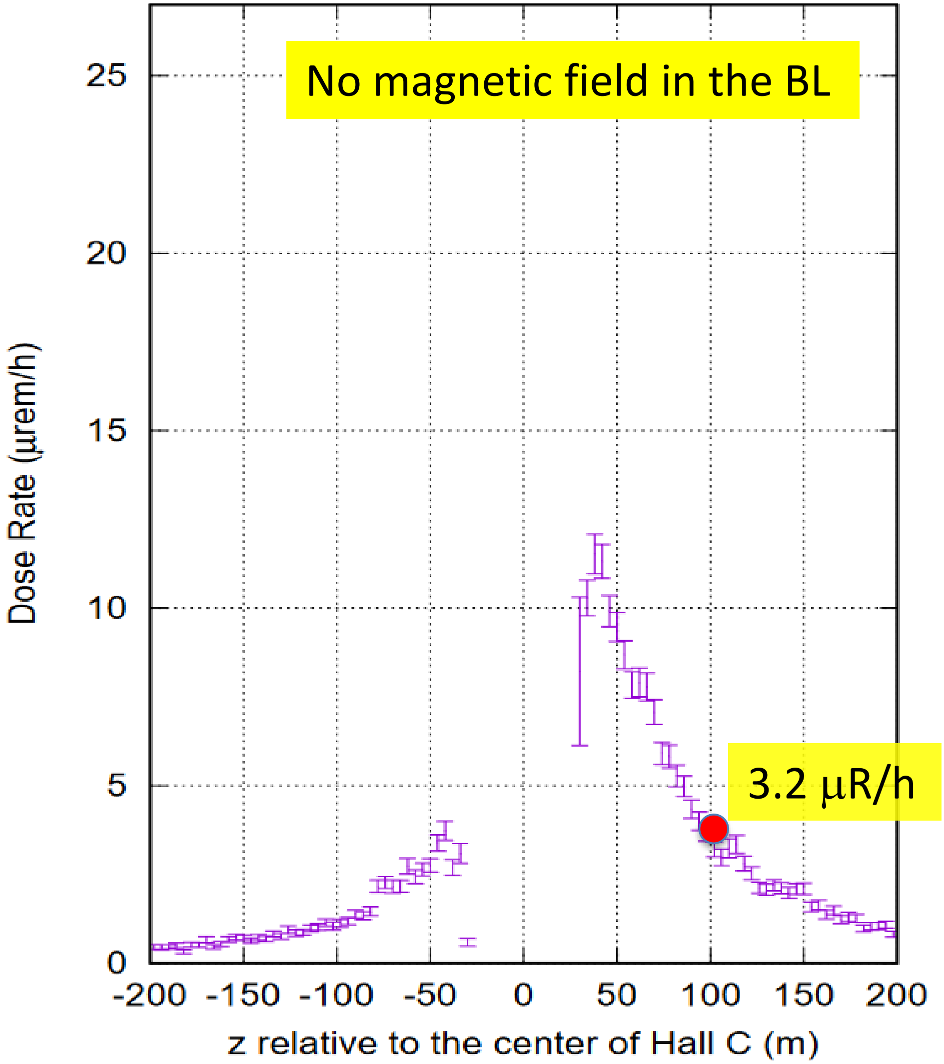


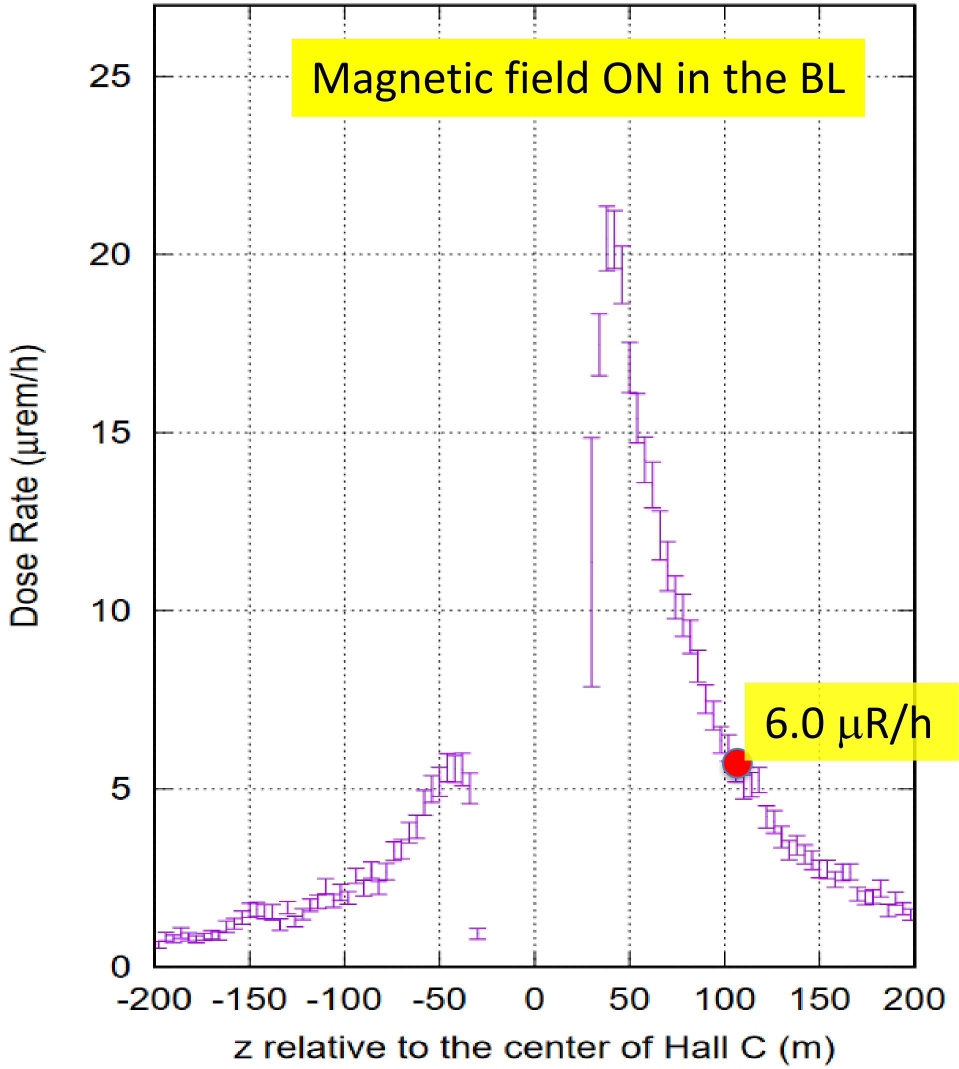
Jefferson Lab

Boundary Dose Rates During HKS Setup #9

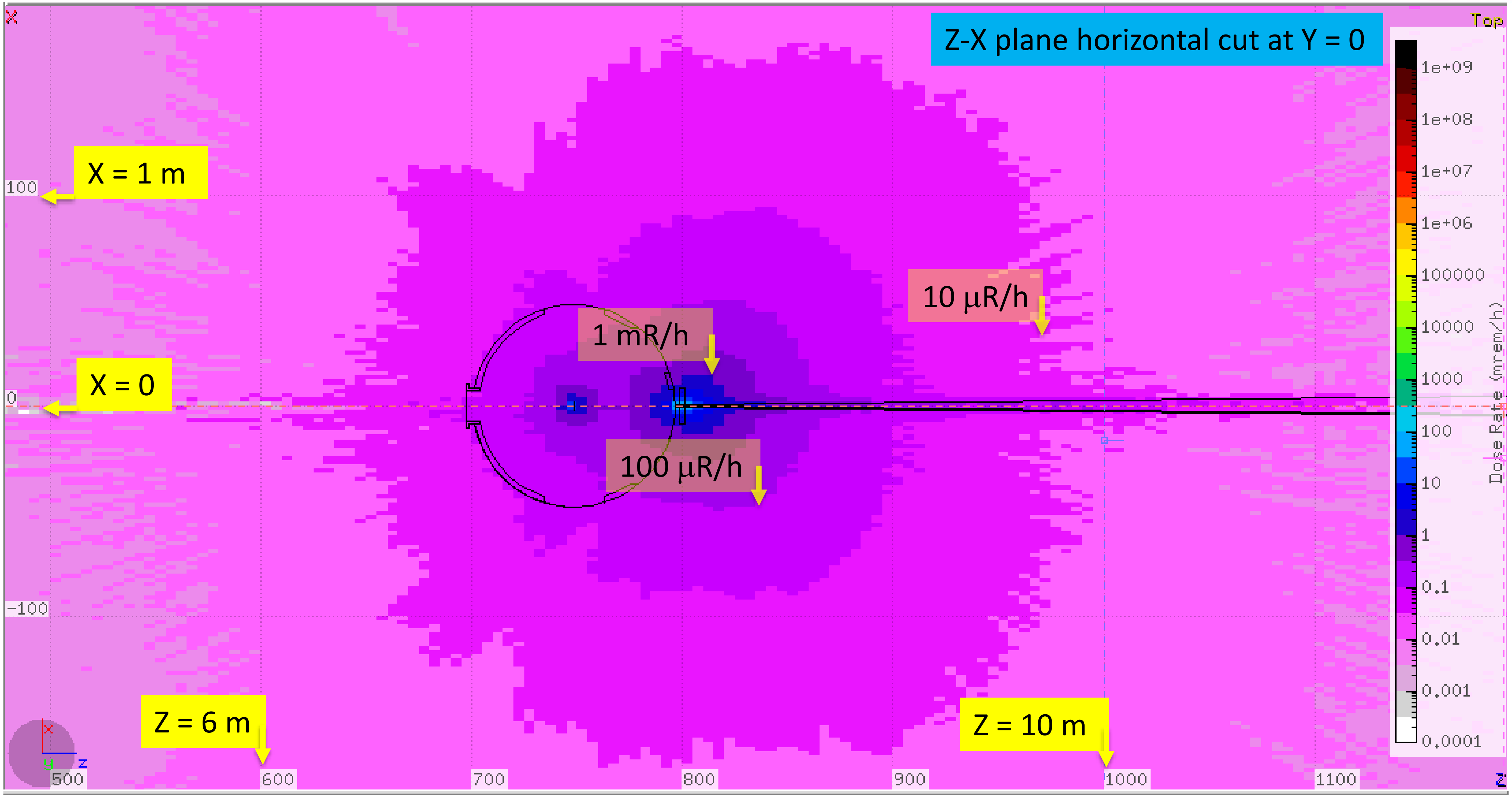
A factor of ~2 increase when the stray fields are taken into account

Dose rates along Z in 2 m thick, 4 m wide air layer above ground in the vicinity of Hall C





Activation in the Hall 1 hour after stop



ERR Charge #6

- Are the radiation levels expected to be generated in the hall acceptable?
  - First preliminary evaluations tell Yes, however the final beam line design still needs to be evaluated
- Is any local shielding required to minimize the effects of radiation in the equipment?
  - The answer is also Yes. It will be dependent on the final design of the beam line and detailed calculations taking into account stray magnetic fields.
  - Damage to electronics and materials in the Hall need to be evaluated by the Experiment
- Dose rate accumulation at the CEBAF boundary is expected to be reasonable for 2-yr operations, and could be optimized