Simulations in support of RIA Target Area R&D

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RIA R&D Participants
(now starting 2nd year of funded effort)

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Lawrence Berkley National Lab: L. Heilbronn

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Michigan State U./National Superconducting Cyclotron Lab: *I. Baek, V. Blideanu*, G. Bollen, D. Lawton, P. Mantica, D. Morrissey, R. Ronningen, B. Sherrill, A. Zeller

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Outline

NSCL

MICHIGAN STATE UNIVERSITY

- Ronningen
  - Examples of Simulations for Fragment Pre-Separator Area Pre-Conceptual Design
    - Quadrupole radiation damage simulations
    - Beam Dump simulations
    - Bulk Shielding
- Remec
  - Examples of Simulations for ISOL Target Area Pre-Conceptual Design
    - Two-step target simulations
    - Large-scale simulations examples

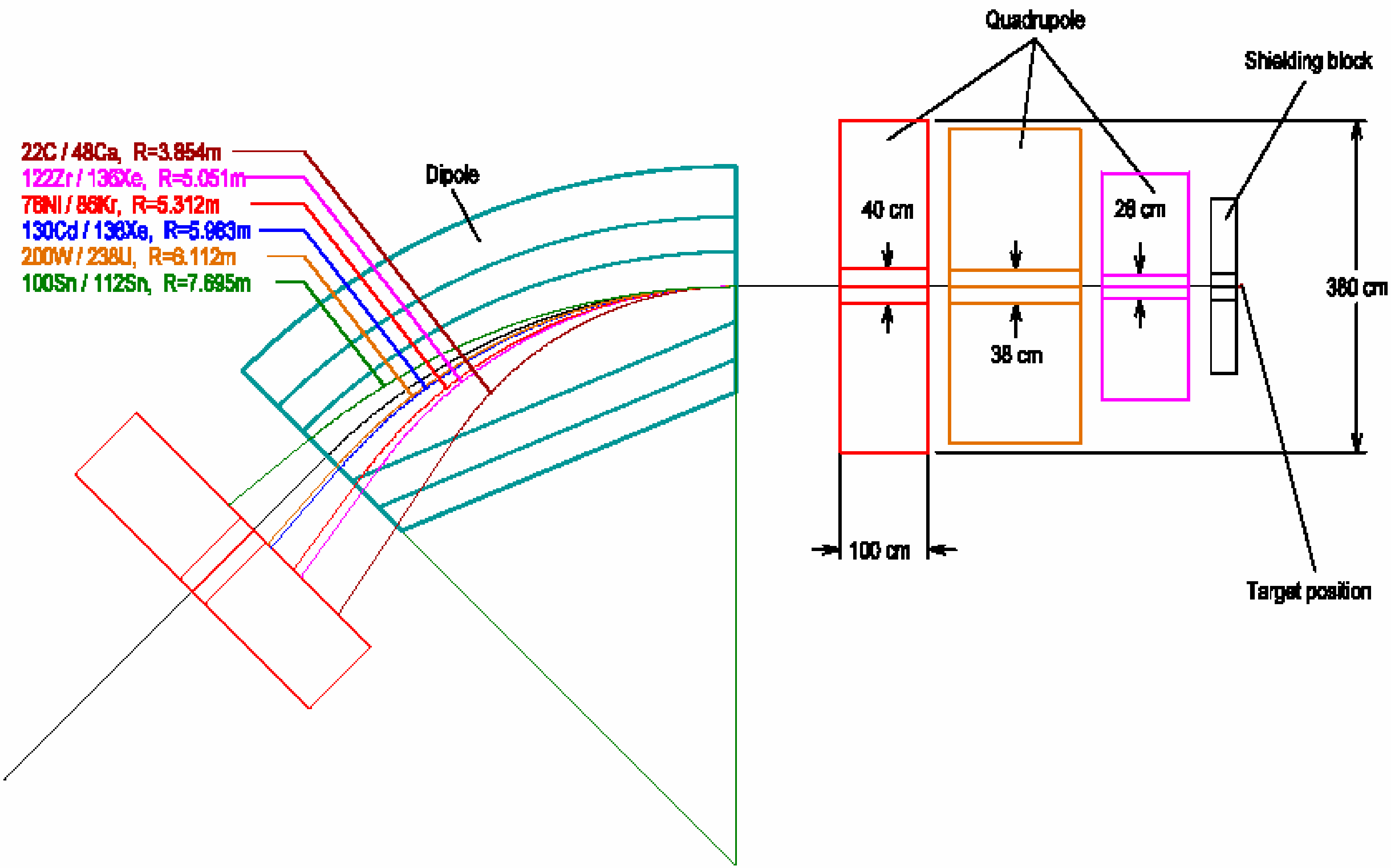
A Sampling of RIA Primary Beams

Current technology limits U to about 130 kW.

All the rest are 400 kW.

ION	A	Z	ENERGY (MeV/nucleon)
H	1	1	1019
^{3}He	3	2	777
D	2	1	622
O	18	8	560
Ar	40	18	566
Kr	86	36	510
Xe	136	54	470
U	238	92	400

Where Do Primary Beam and Fragments Go?

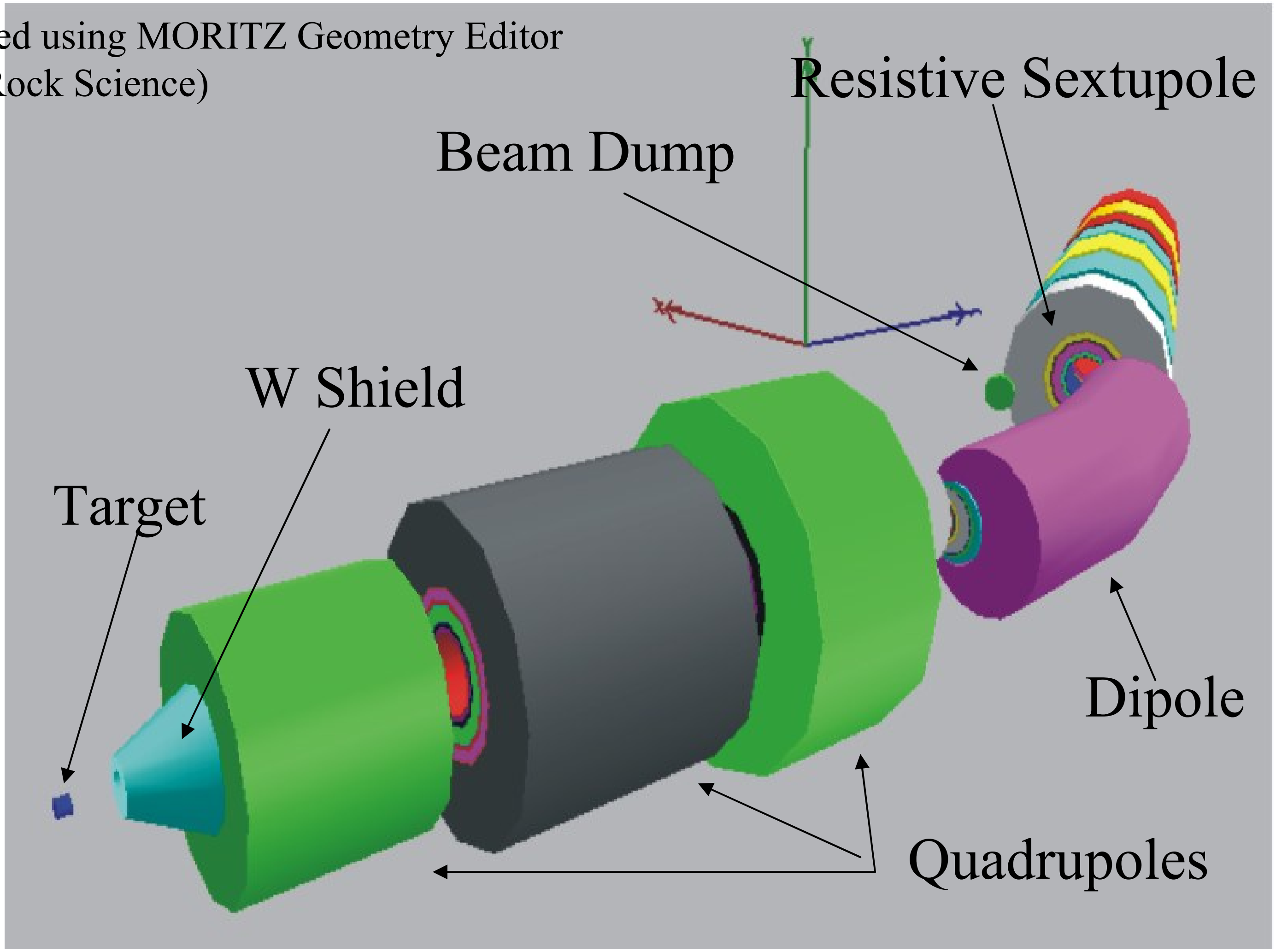


Sample Beam-Fragment Combinations

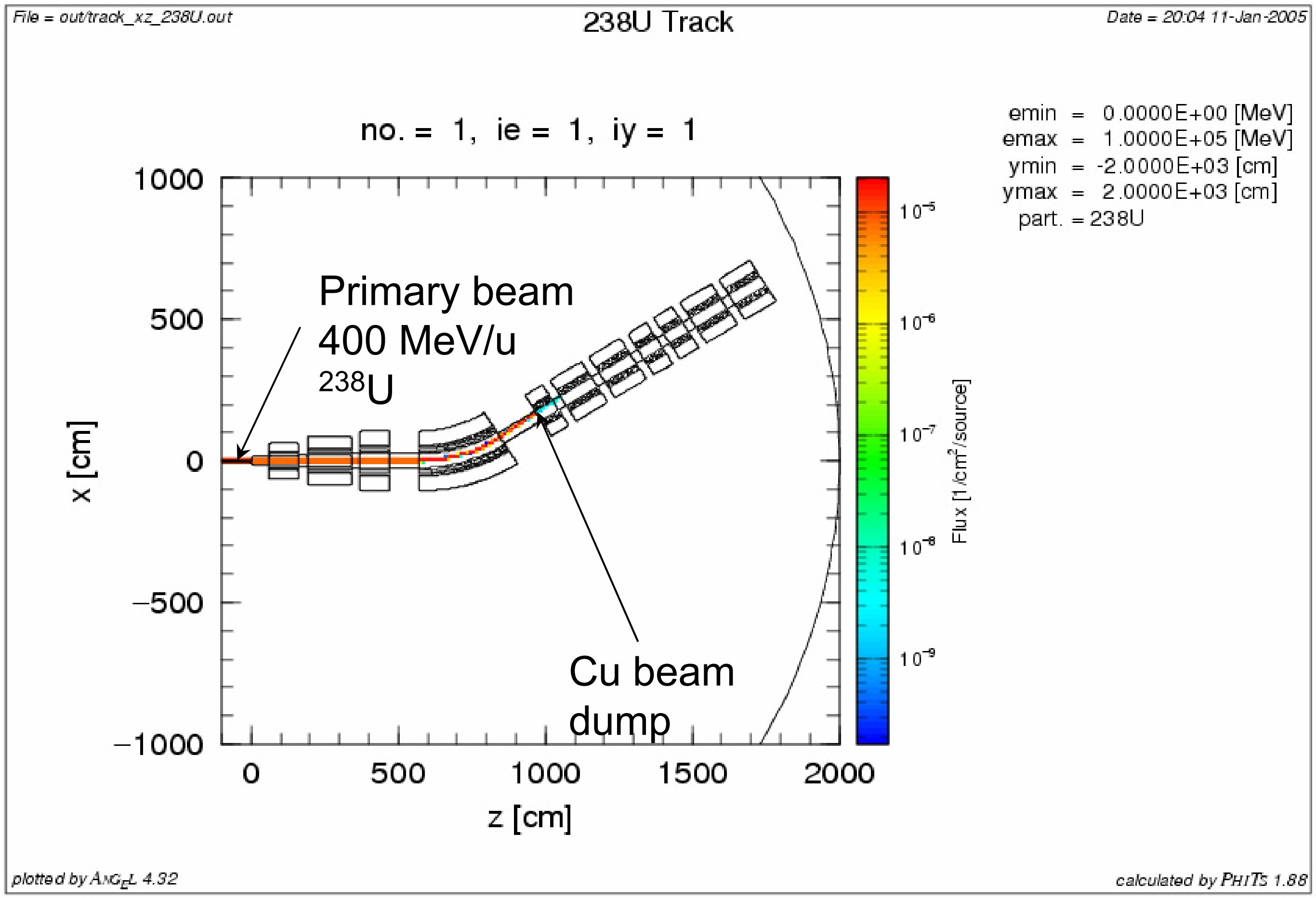
Fragment	Beam	Charge State	Fraction	Beam Energy MeV/u	Target Thickness mg/cm2	Fragment Brho	Beam Brho	Ratio	Beam Power in Target (kW)	Dump Power (kW)
122Zr	136Xe	54	1	500	3500	9.015	6.8786	0.763017194	153	247
130Cd	136Xe	54	1	500	3320	7.846	7.0896	0.903594188	139	261
78Ni	86Kr	36	1	520	5300	8.33	6.6832	0.802304922	150	250
22C	48Ca	20	1	350	3300	9.959	5.7971	0.582096596	89.2	310.8
200W	238U			400	1100	7.4968		0.923100523	102	
		92	0.04				6.9203			11.92
		91	0.29				6.9963			86.42
		90	0.6				7.0741			178.8
		89	0.06				7.1536			17.88
		88	0.003				7.2349			0.894
100Sn	112Sn	50		500	4000	4.843	5.6286	1.162213504	186	

Simple Geometry of Fragment Pre-Separator for Simulations

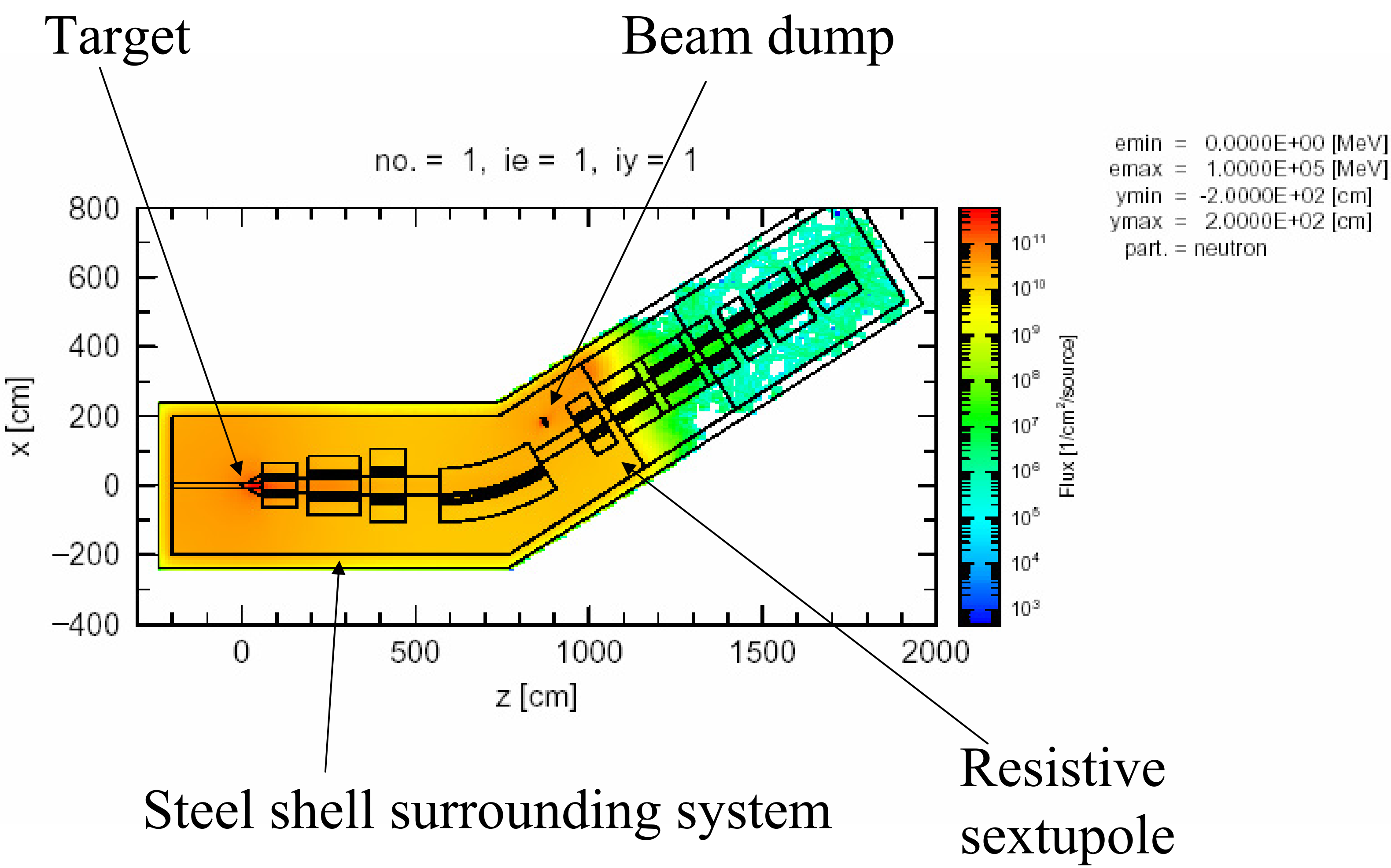
Developed using MORITZ Geometry Editor (White Rock Science)



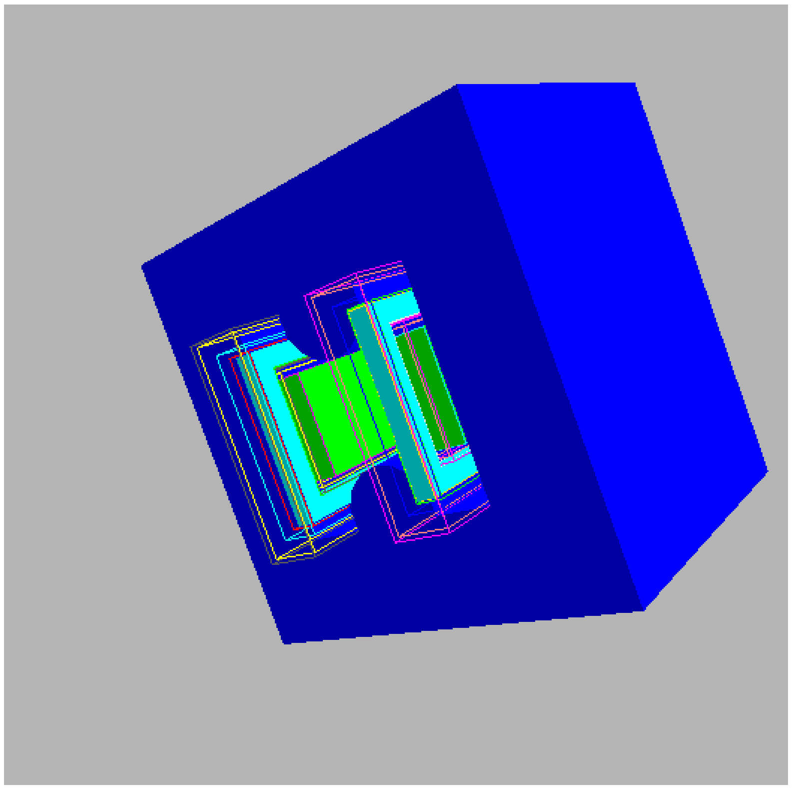
Transport of Primary Beam using PHITS



Neutron Flux in Pre-Separator using PHITS: 48Ca beam at 500 MeV/u



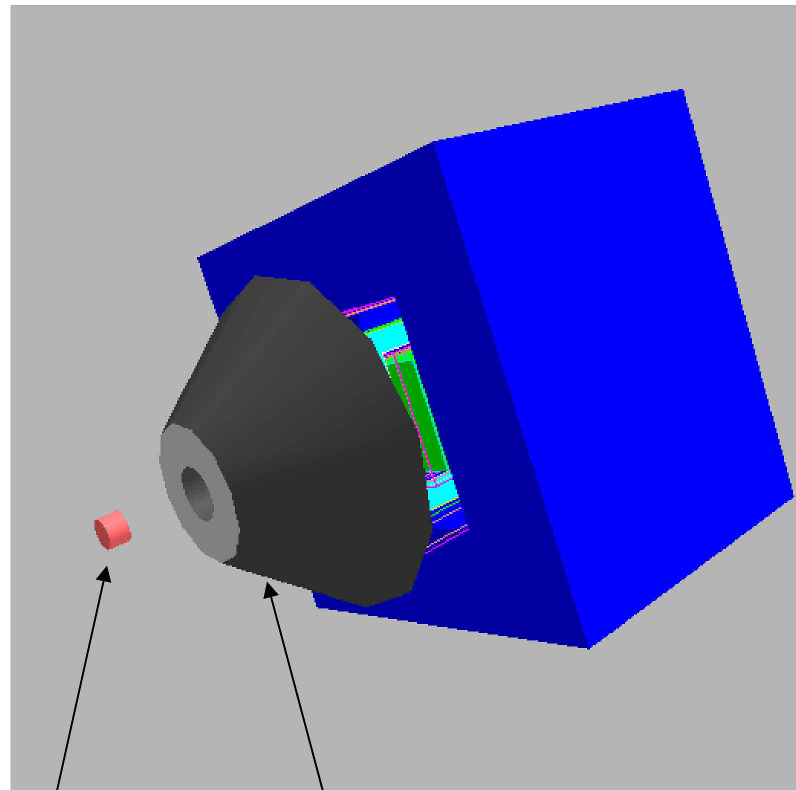
“Realistic” Quadrupole Geometry using BNL Design with Realistic Material Compositions



Frames are cryostat walls

HTS Coil: Ag+BSCCO

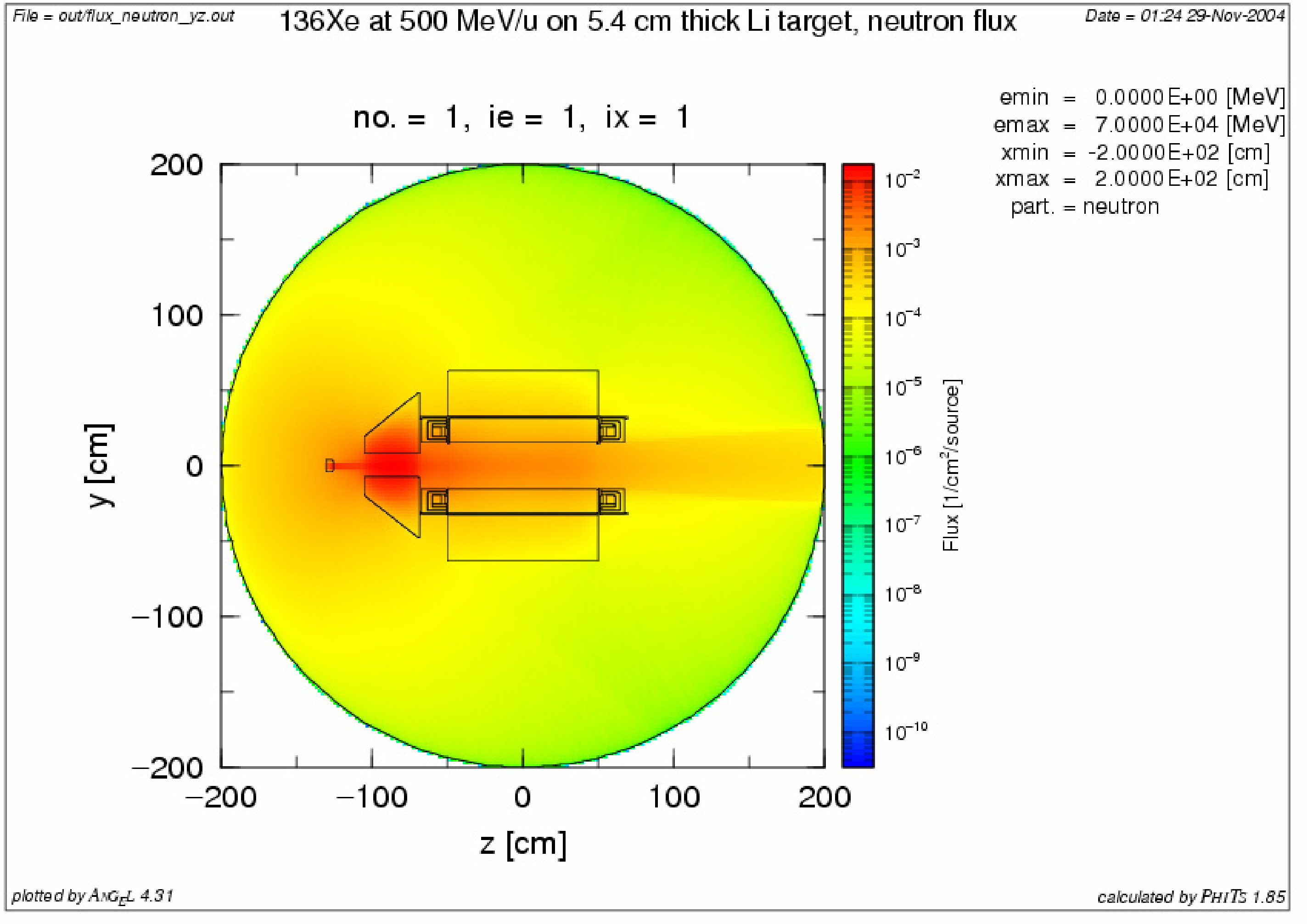
Insulator: AlO+He



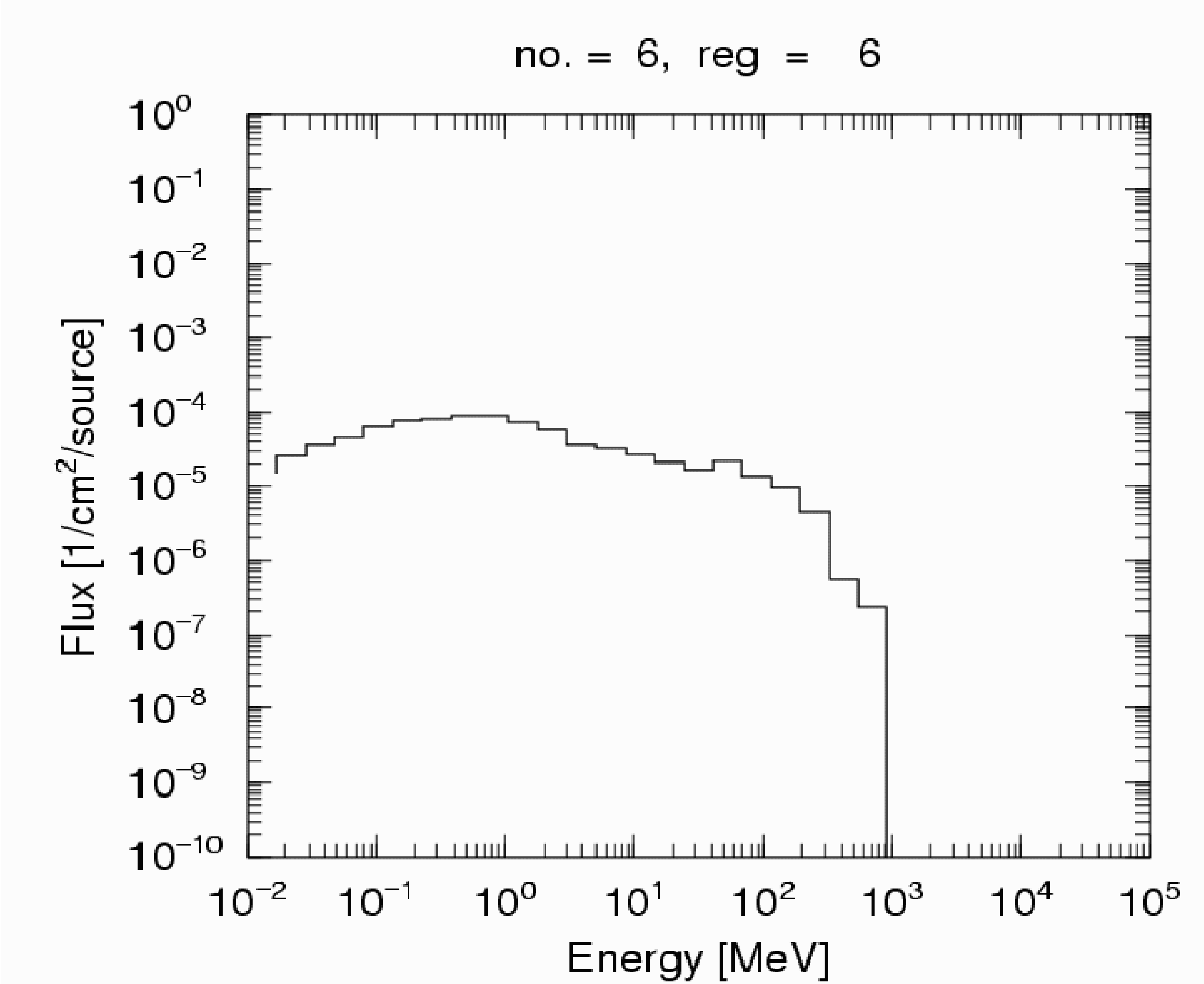
Target

Hevimet shield

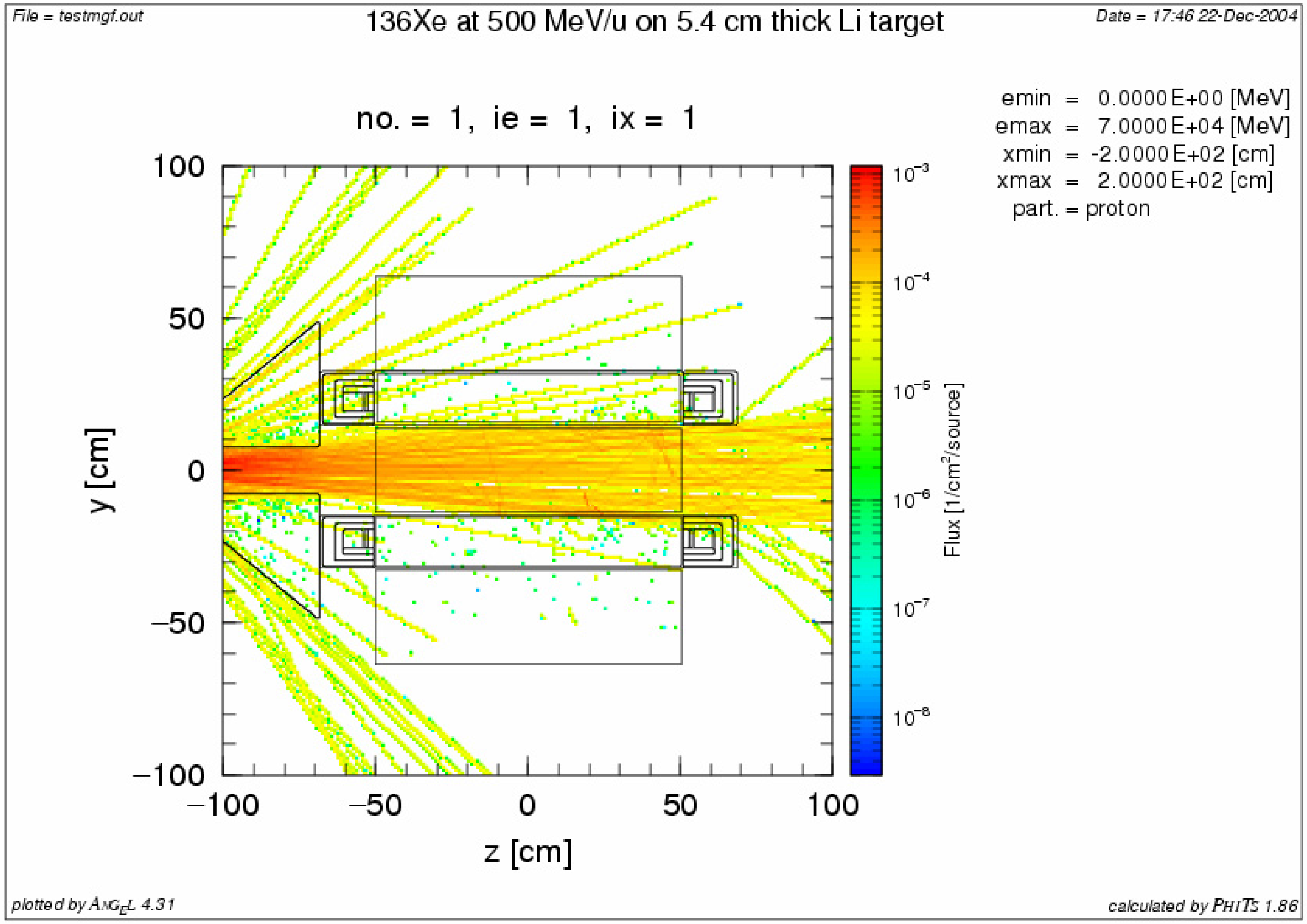
Neutron Flux in Target, 1st Quad Area - No Magnetic Field



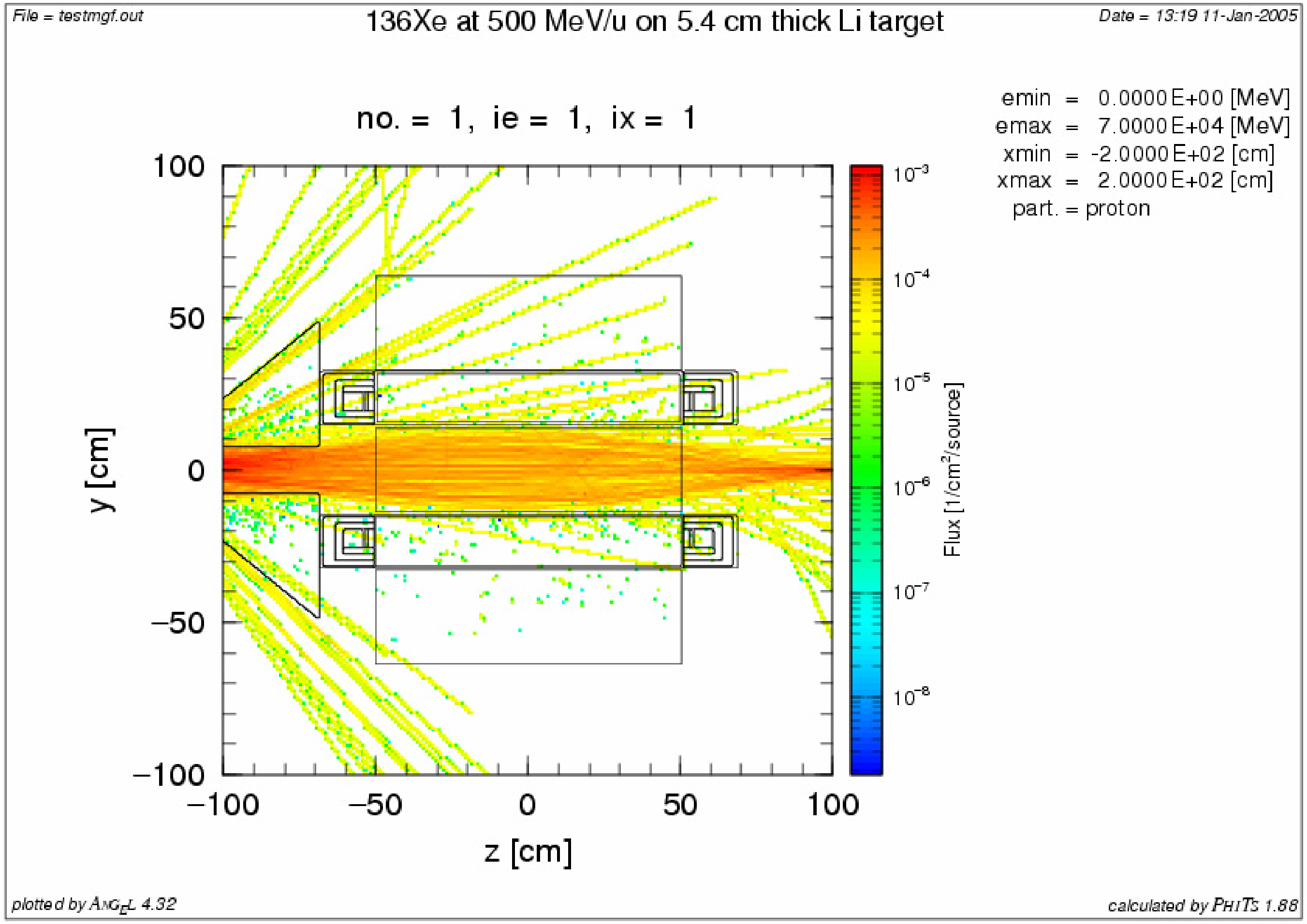
Neutron spectrum at the coil for ^{136}Xe at 500 MeV/u (PHITS simulation)



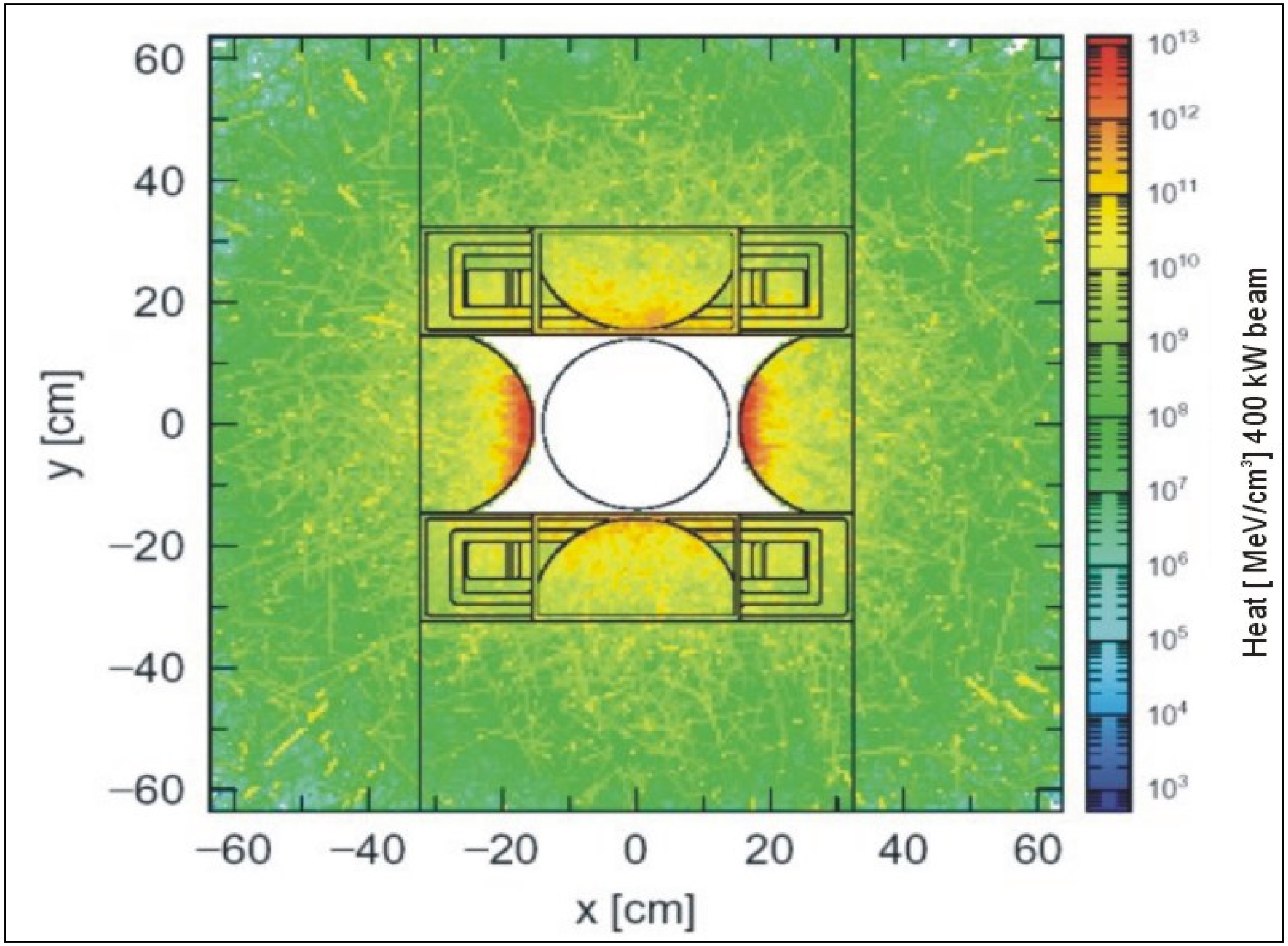
Protons – no magnetic field



Protons – Quadrupole magnetic field ON



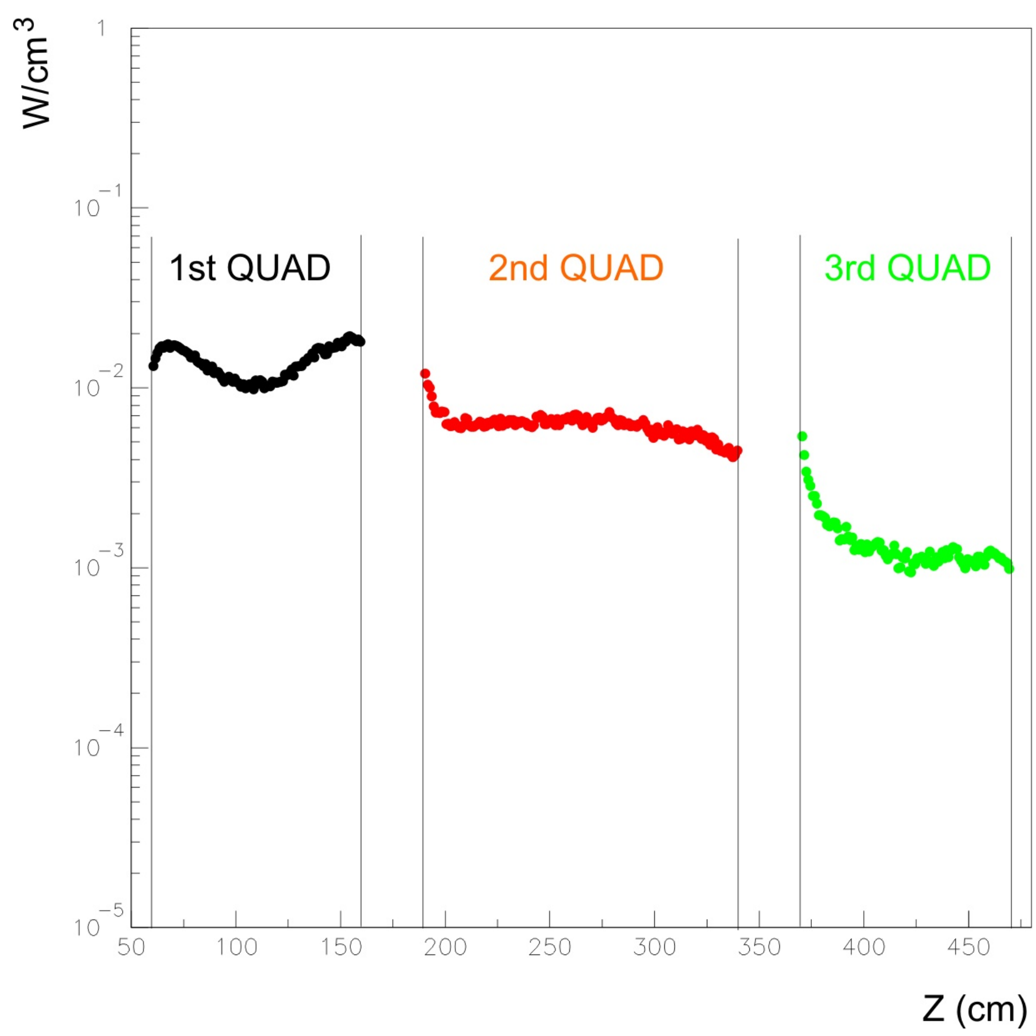
Total Heat Tally



Triplet heat – no magnetic fields

- Like the peak magnetic field determining the conductor requirements, the **maximum dose in a single area determines the coil life time**.
- Note the dose is a factor of two higher than calculations done for a single quad. This is because of the enclosure reflecting low energy neutron back into the coils.
- The **peak doses** on each subsequent quad is only reduced by a **factor of two** due to both the reflected neutrons and the high flux of very energetic ones (>100 MeV).

Heat deposition in the coils for 400 KW 48Ca beam



Coil Life Estimate

Using an average density of 10 g/cm^3, 10 mW/cm^3 give a dose rate of 1 Gy/s

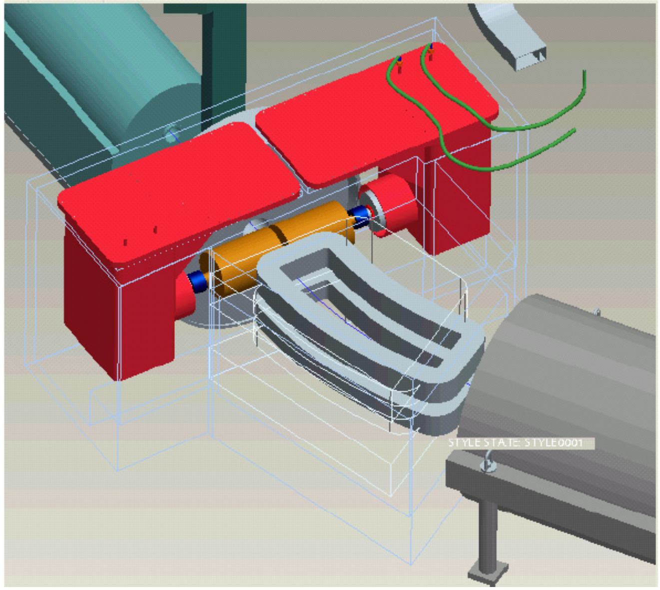
With 10^7 s per year operation, this is 10 MGy dose.

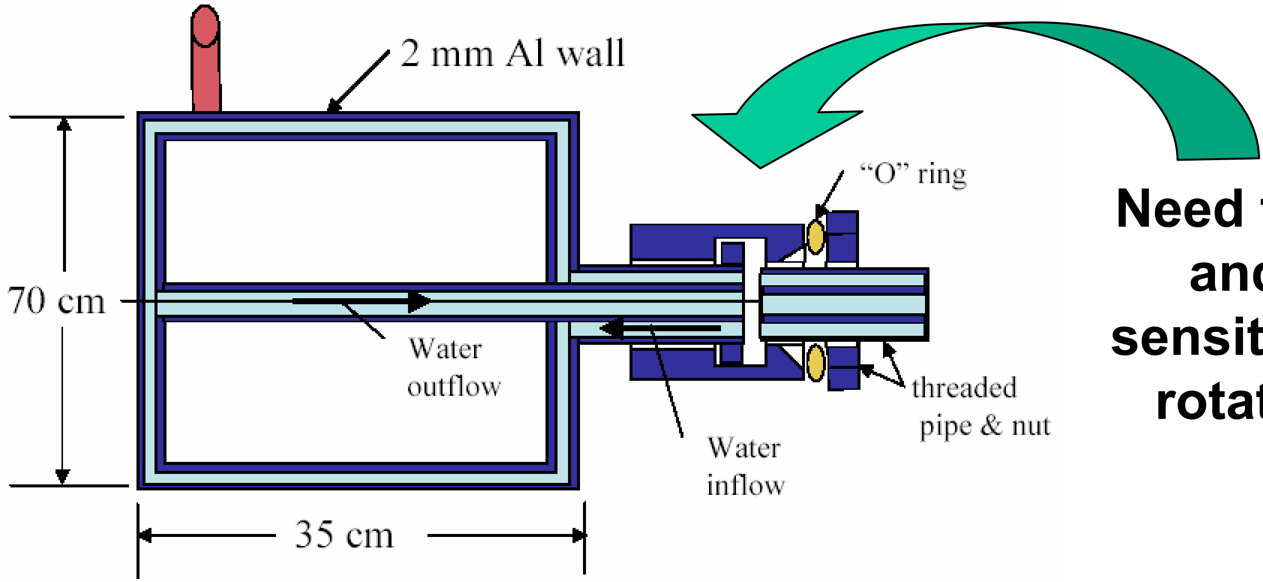
If HTS is as radiation resistant as Nb_3Sn (500 MGy), then coils last 50 years.

Plan to test HTS 12/05 at LBNL with protons. It will be compared with Nb_3Sn, which has known tolerance.

Advanced beam dump designs

- To mitigate radiation damage, rotating beam dump concepts are being considered
- In particular, a rotating barrel-shaped dump has been designed capable of withstanding a 1cm-diameter beam spot
- U beam stops in cooling water, avoiding high DPA values in structural material

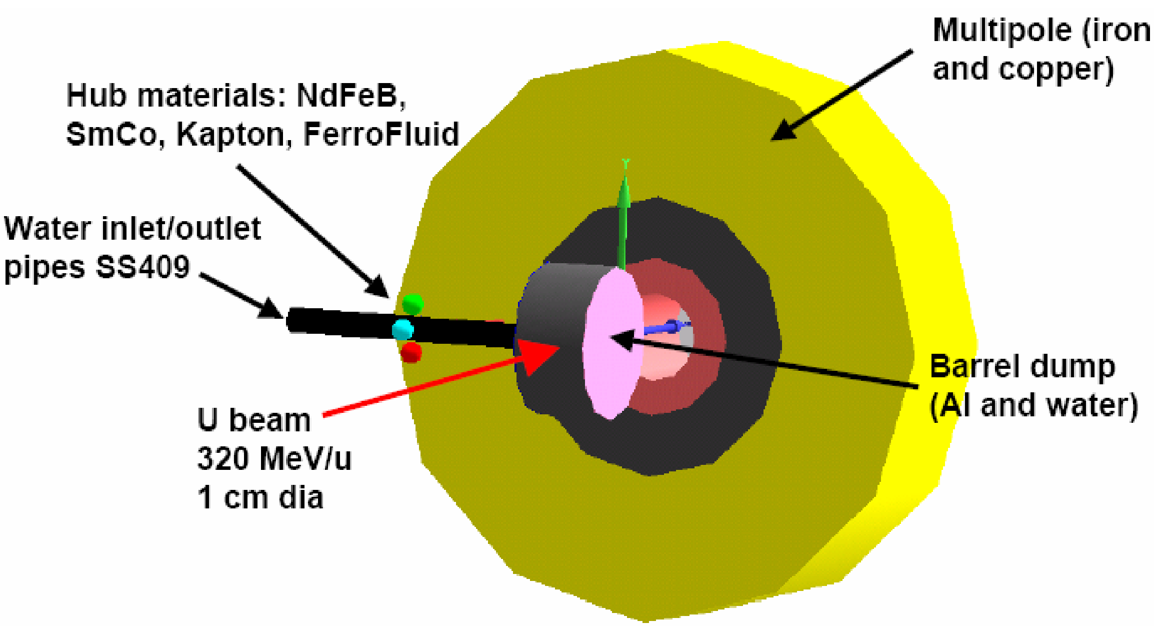




Need to address prompt and decay dose to sensitive components in rotating vacuum seal

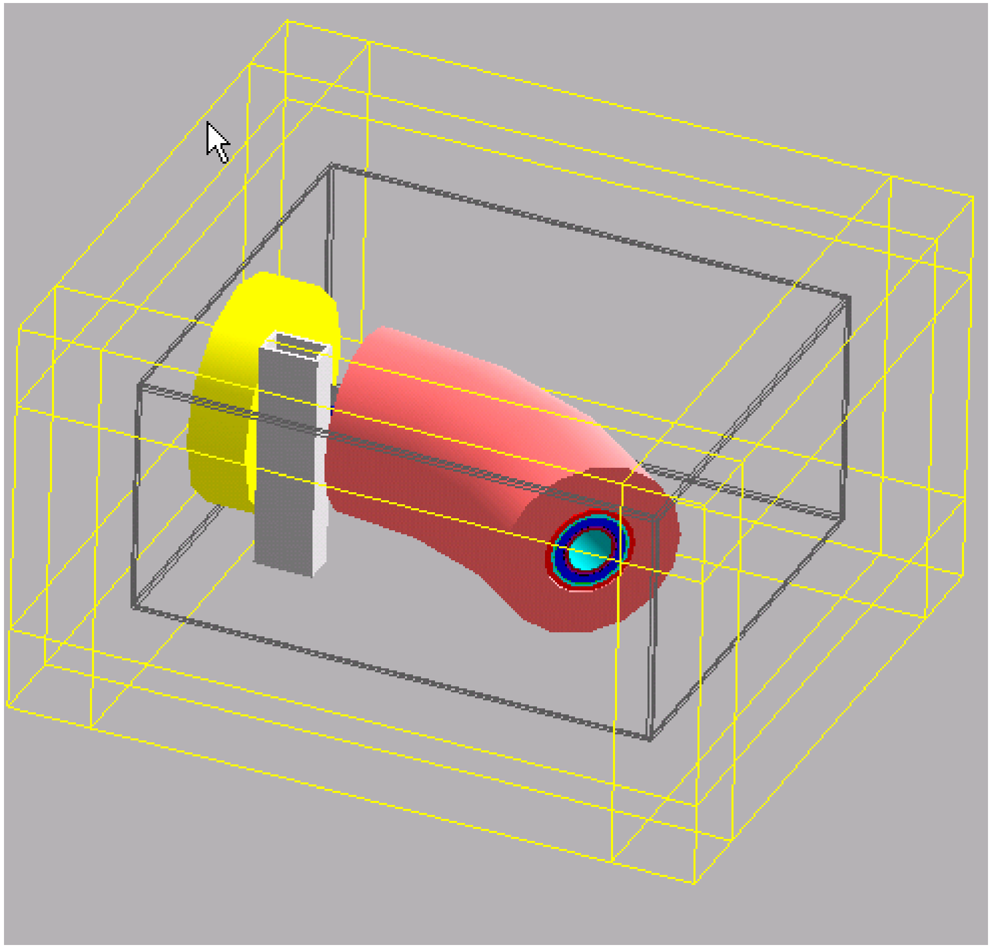
Radiation transport results

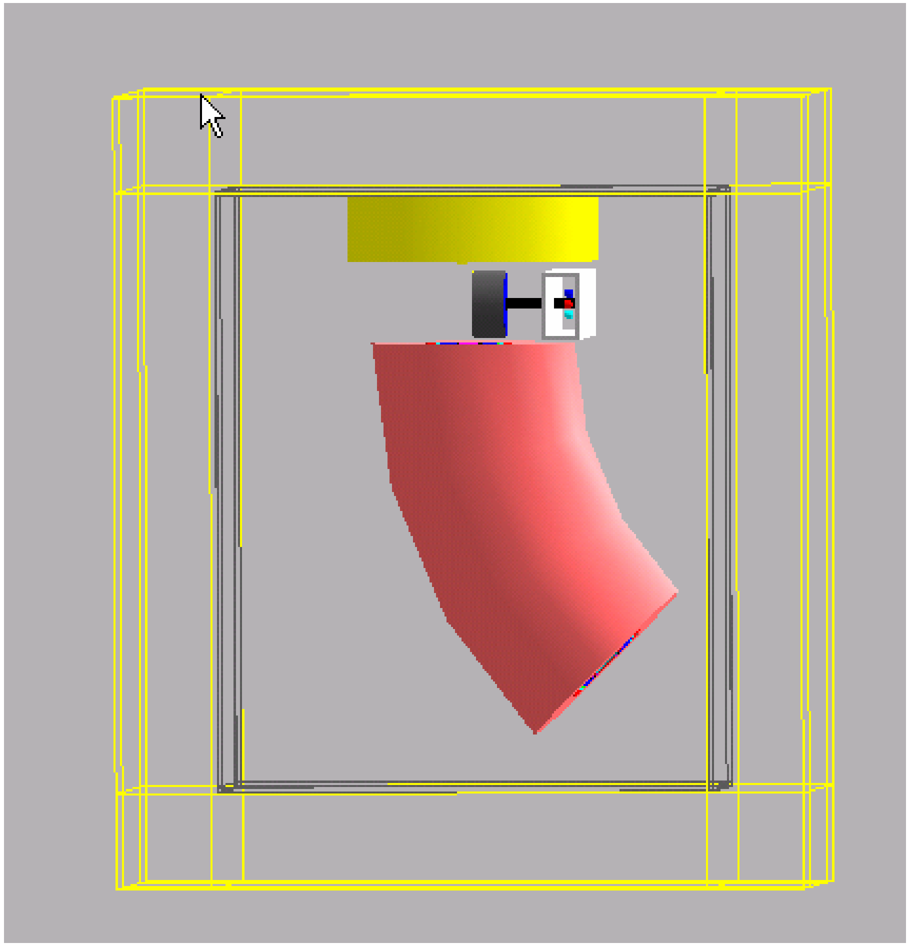
- We have used the heavy ion transport code PHITS to simulate particle transport in pre-separator area
- Model includes barrel beam dump, steel water inlet/outlet pipes, hub region with representative materials and downstream multipole magnet



- Assumed operation with a 320 MeV U beam with 1 cm-diameter spot size at a current of 3×10^{13} pps

Vacuum enclosure and dipole included





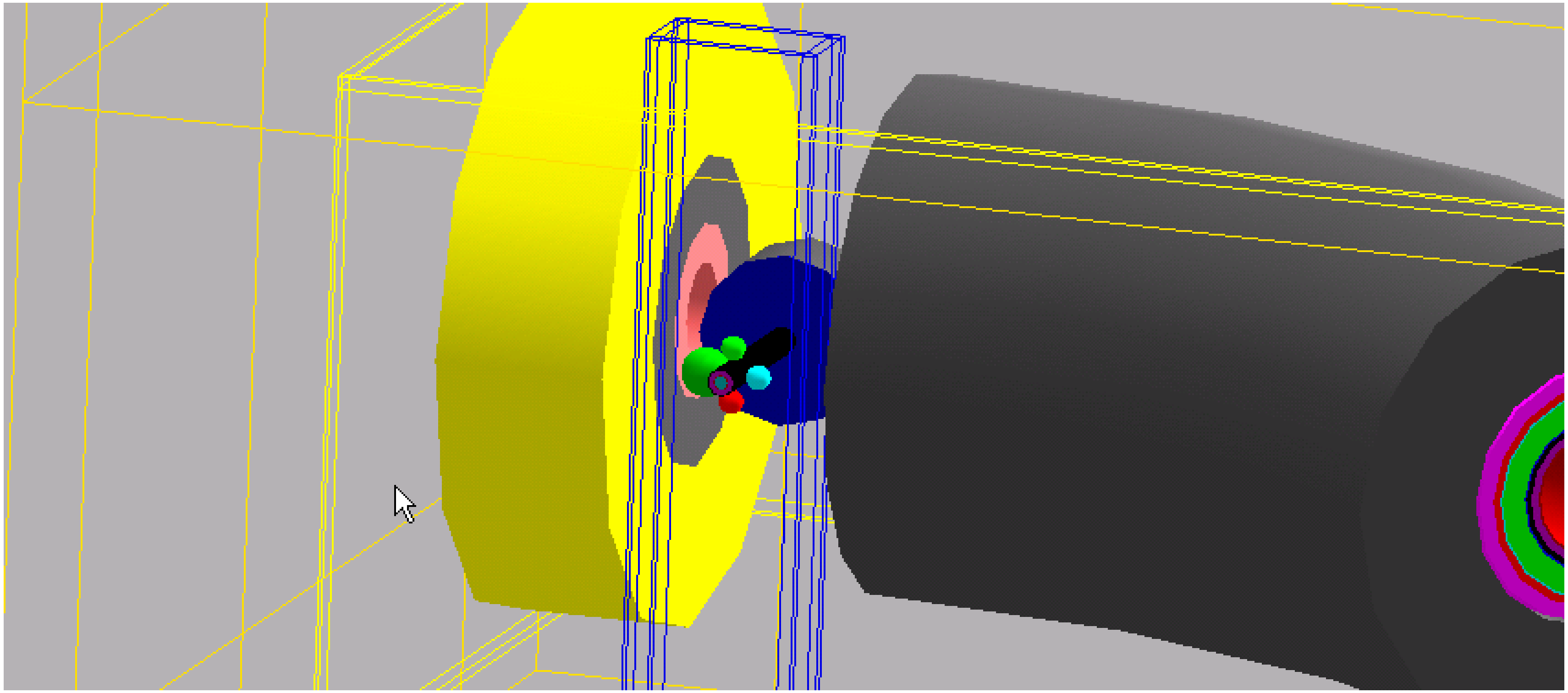
Radiation transport results: prompt dose and DPA

Material	Density (g/cc)	Effective dose (MGy/yr*)	Dose limit (MGy)	DPA/yr*
NdFeB	6	0.29	0.1	4.5E-06
SmCo	8.82	0.15	100	5.9E-06
Kapton	1.42	0.74	10	7.6E-07
FerroFluid	1.42	1.08	>1?	7.1E-07

*Assumed that fragmentation line is operating at full power for one-third of the calendar year

- **Dose to NdFeB magnet exceeds recommended limit after ~ 2 months of full power operation: shielding needed to extend lifetime**
- **DPA in the hub materials found to be negligible**
- **Maximum DPA rate in the Al barrel ~0.03 DPA/yr* (most of the primary beam stops in water); maximum DPA in multipole ~5x10^{-4} DPA/yr***
- **Peak energy deposition in multipole = 0.03 W/cc, with 2.1 kW total**

Borated (5 wt%) polyethylene shielding around NdFeB magnet (5 cm thick spherical shell)

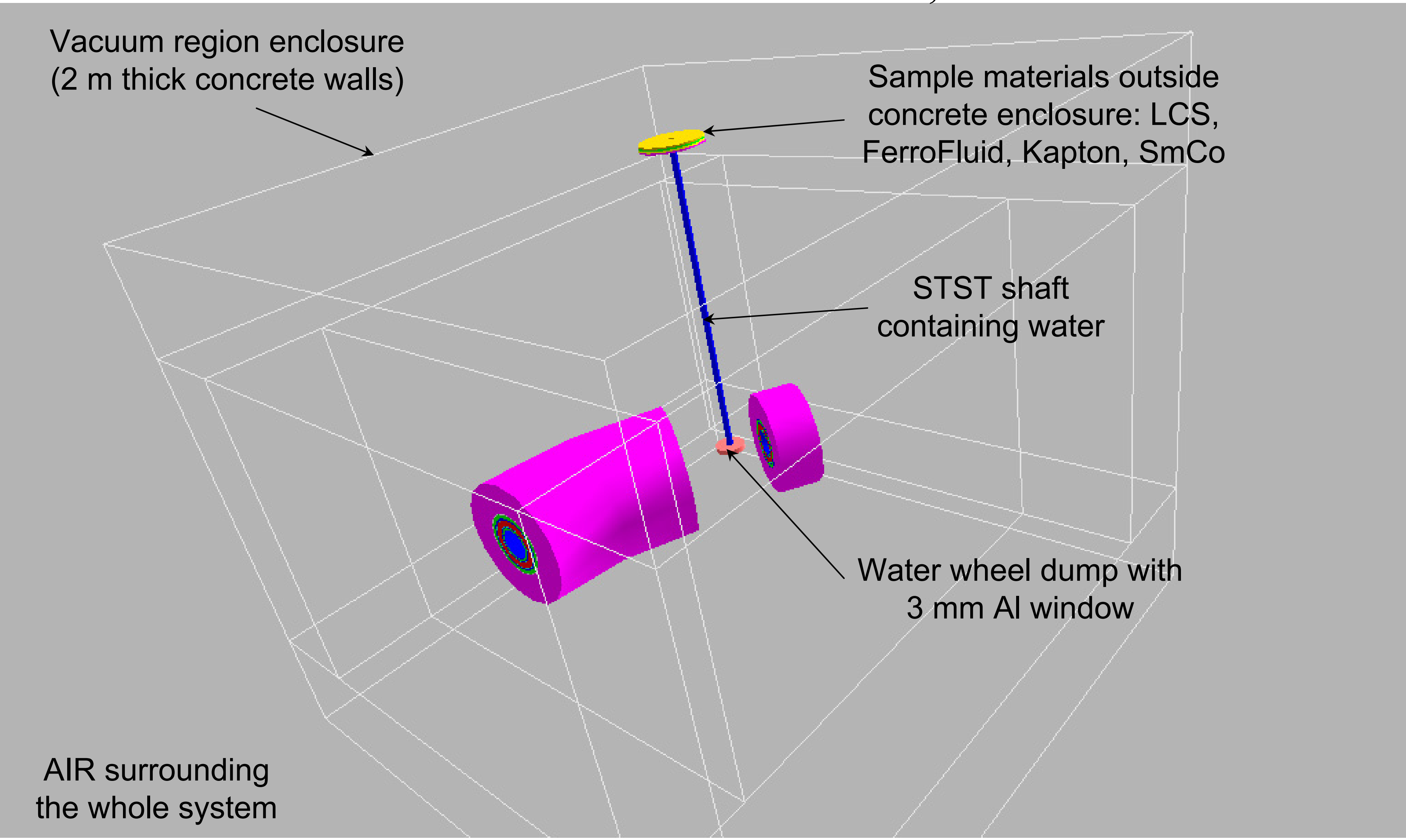


Material	Density (g/cc)	Effective dose (MGy/yr*)	Limit (MGy)
NdFeB	6	0.05	0.1

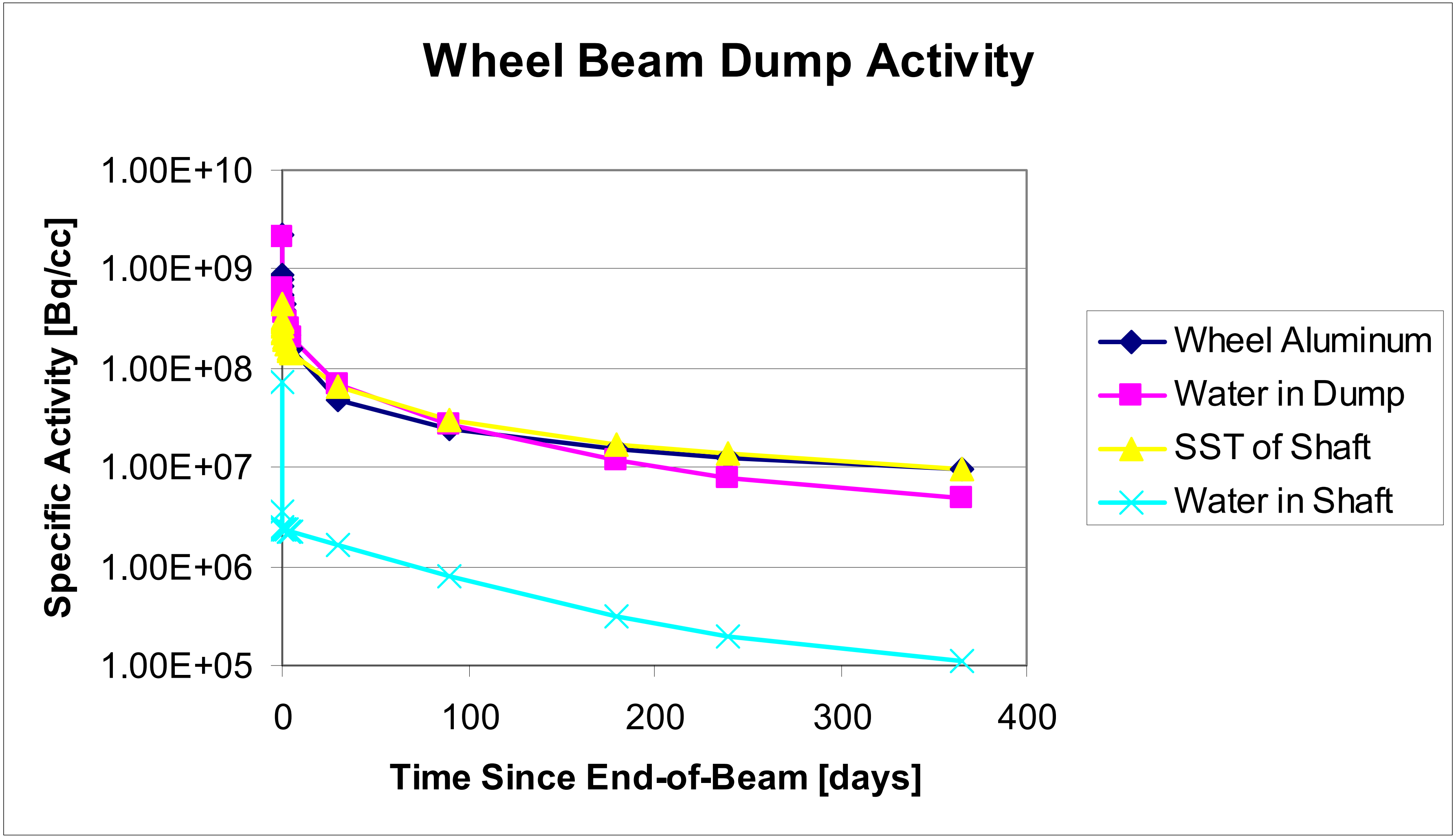
* Assumes operational for 1/3 of each year

Simplified geometry model

136Xe at 341 MeV/u, 3.74x10^{13} ions/sec



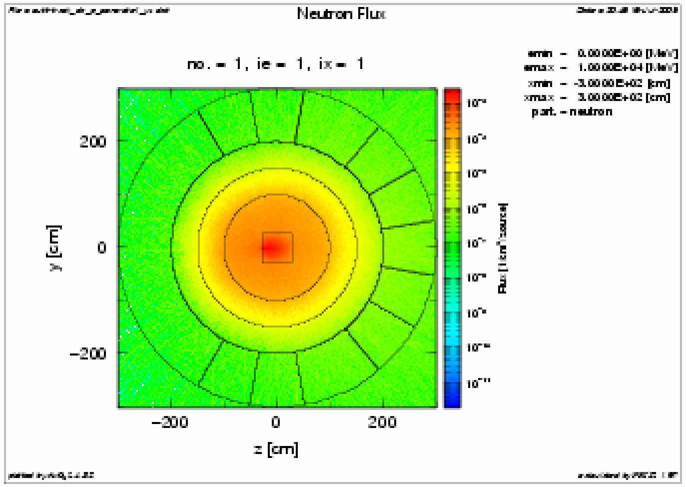
Investigate Radioactivity Inventory for Components



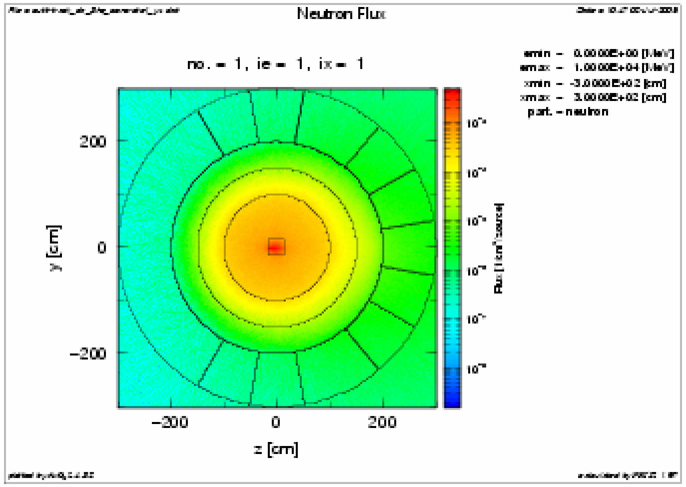
"Top-Ten"	90 days after EOB		Xe Beam					
no.	nuclide	[Bq/cc]	[Bq]	[%]	nuclide	[W/cc]	[W]	[%]
1	Be 7	1.25E+07	1.60E+11	47.2	Be 7	6.76E-07	8.62E-03	40.1
2	H 3	2.76E+06	3.52E+10	10.4	Y 88	1.82E-07	2.32E-03	10.8
3	I 125	2.16E+06	2.76E+10	8.2	Sb124	1.07E-07	1.37E-03	6.4
4	Xe127	1.05E+06	1.34E+10	4.0	Cs134	8.78E-08	1.12E-03	5.2
5	Y 88	4.21E+05	5.36E+09	1.6	Xe127	5.10E-08	6.50E-04	3.0
6	Rb 83	4.11E+05	5.25E+09	1.6	Cs136	4.04E-08	5.15E-04	2.4
7	In113m	3.53E+05	4.50E+09	1.3	Rb 83	3.47E-08	4.43E-04	2.1
8	Sn113	3.53E+05	4.50E+09	1.3	Sr 85	2.90E-08	3.69E-04	1.7
9	Sr 85	3.46E+05	4.42E+09	1.3	Rb 82	2.87E-08	3.66E-04	1.7
10	Kr 83m	3.38E+05	4.31E+09	1.3	Nb 95	2.40E-08	3.06E-04	1.4
	top-10 sum=	2.07E+07			top-10 sum=	1.26E-06		
	total activity	2.66E+07	[Bq/cc]	(3.38744E+11 [Bq])				
	total decay heat	1.69E-06	[W/cc]	(2.14929E-02 [W])				
	(beta)	7.56E-07	[W/cc]	(9.63692E-03 [W])	44.8%			
	(gamma)	9.30E-07	[W/cc]	(1.18560E-02 [W])	55.2%			
	(alpha)	2.02E-17	[W/cc]	(2.57106E-13 [W])	0.0%			
	activated atoms	2.51E+15	[/cm**3]					
	(A=60-180:all)	2.79E+15	[/cm**3]					
	(A=60-180:activated)	5.29E+14	[/cm**3]					

"Top-Ten"	90 days after EOB		Uranium Beam					
no.	nuclide	[Bq/cc]	[Bq]	[%]	nuclide	[W/cc]	[W]	[%]
1	Be 7	7.49E+06	9.55E+10	38.1	Be 7	4.04E-07	5.15E-03	16.4
2	H 3	1.60E+06	2.04E+10	8.1	Po210	2.61E-07	3.33E-03	10.6
3	Nb 95	9.49E+05	1.21E+10	4.8	Nb 95	1.23E-07	1.57E-03	5.0
4	Zr 95	6.42E+05	8.19E+09	3.3	Zr 95	8.77E-08	1.12E-03	3.6
5	Rh103m	6.41E+05	8.17E+09	3.3	Rh106	7.55E-08	9.63E-04	3.1
6	Ru103	6.40E+05	8.17E+09	3.3	Po216	6.38E-08	8.13E-04	2.6
7	Y 91	5.55E+05	7.08E+09	2.8	Ru103	6.09E-08	7.77E-04	2.5
8	Sr 89	4.71E+05	6.01E+09	2.4	Rn220	5.91E-08	7.54E-04	2.4
9	Pa233	3.89E+05	4.97E+09	2.0	Po213	5.87E-08	7.49E-04	2.4
10	Po210	3.02E+05	3.85E+09	1.54	Y 91	5.39E-08	6.87E-04	2.19
	total activity	1.96E+07	[Bq/cc]	2.50435E+11 [Bq])				
	total decay heat	2.46E-06	[W/cc]	(3.14304E-02 [W])				
	(beta)	6.80E-07	[W/cc]	(8.66643E-03 [W]	27.57%			
	(gamma)	5.97E-07	[W/cc]	(7.61780E-03 [W]	24.24%			
	(alpha)	1.19E-06	[W/cc]	(1.51461E-02 [W]	48.19%			
	activated atoms	1.85E+15	[/cm**3]					
	(A=60-180:all)	1.24E+15	[/cm**3]					
	(A=60-180:activated)	3.16E+14	[/cm**3]					

Proton, ^{3}He, ^{238}U Comparison



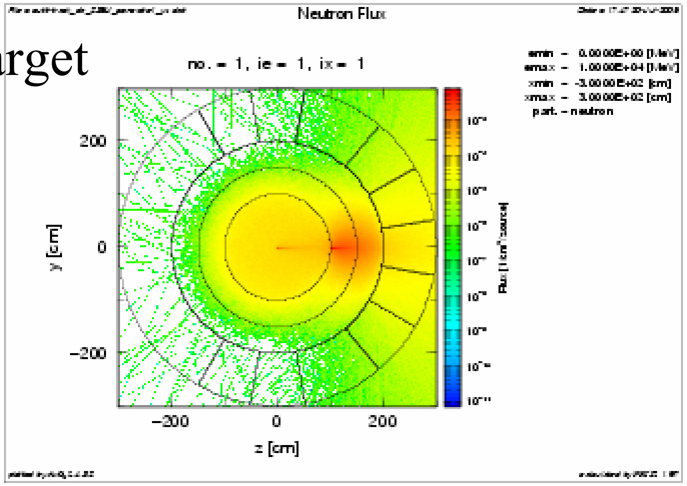
proton : **1 GeV**



He-3 : **777 MeV/u**

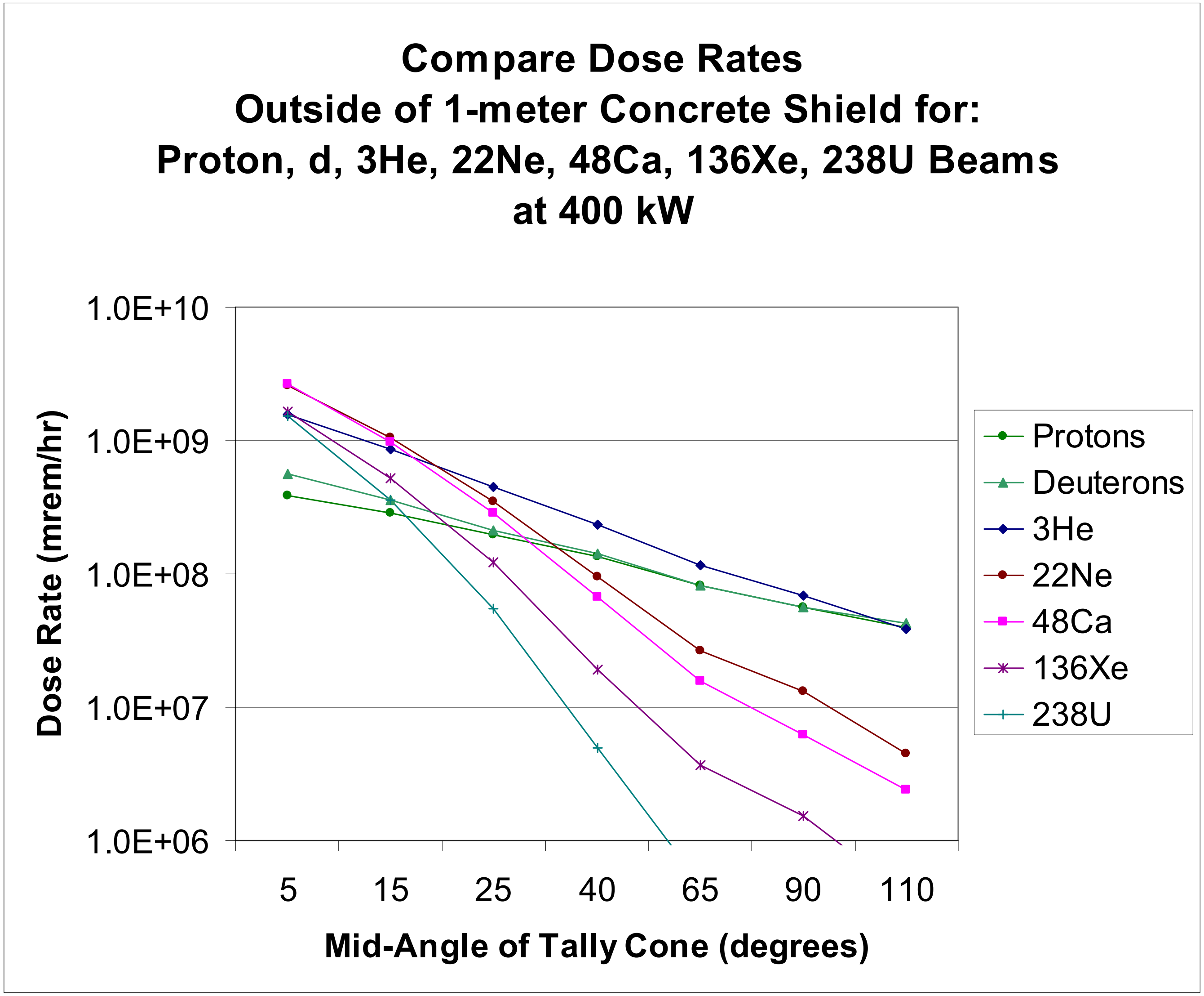
Beam on stopping Cu target

Beam direction



U-238 : **400 MeV/u**

Compare Effective Dose Equivalent for Different Beams



Results for Proton Beam and Concrete Shield