TRIUMF

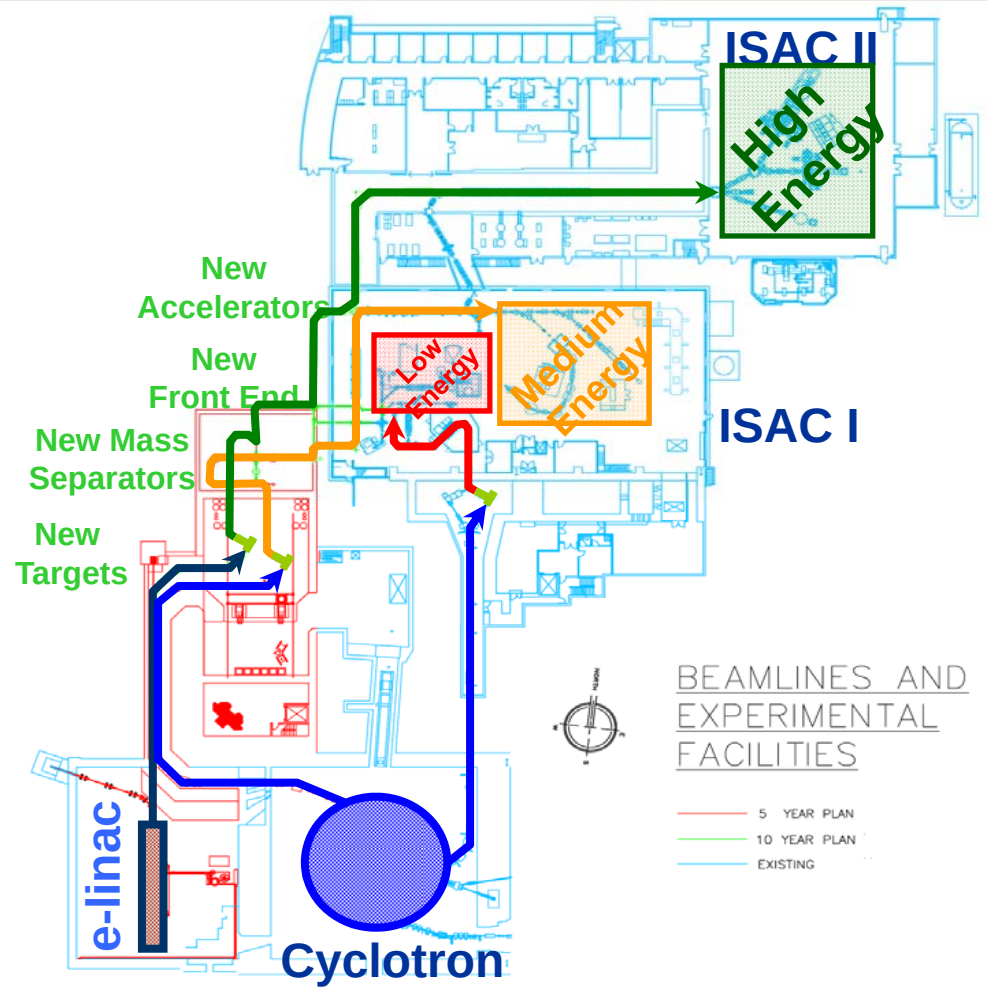
Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

Shielding for a 500 kW Electron Accelerator at TRIUMF

A comparison of FLUKA and Point Kernel Method for Shielding

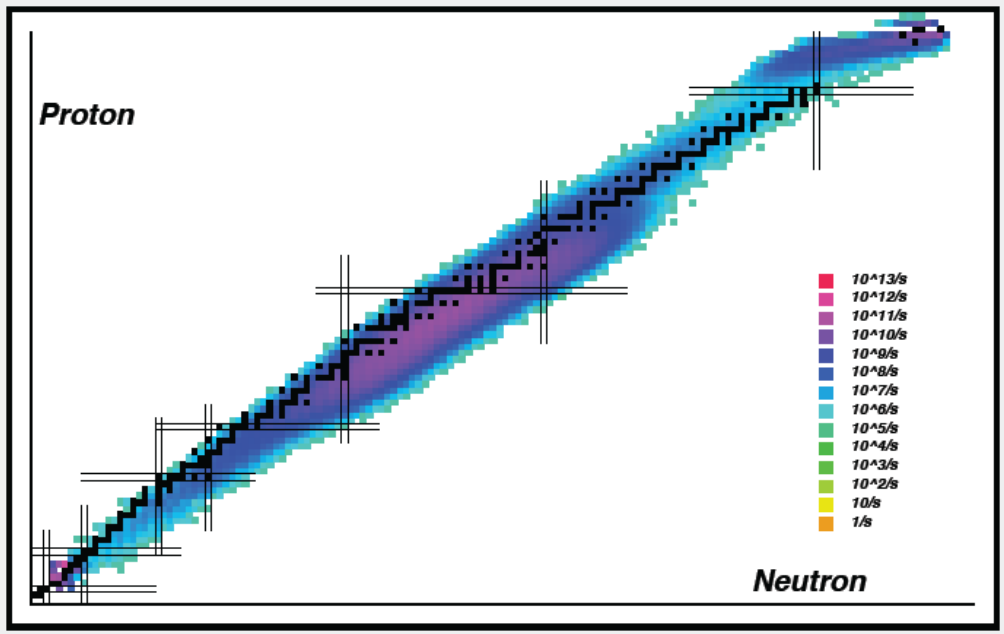
Anne Trudel | TRIUMF

Advanced Rare IsotopE Laboratory



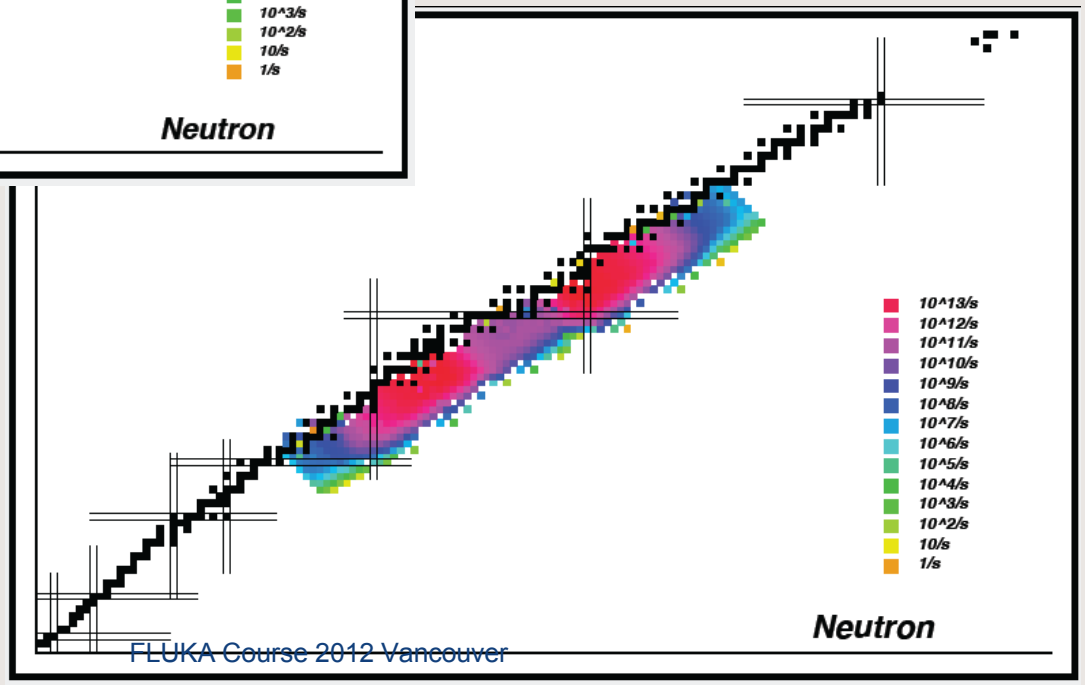
- Expand program with:
  - three simultaneous beams
  - increased hours of delivered RIB per year
  - new beam species
  - less pernicious residual activity with electrons on UC targets

ARIEL RIB Species

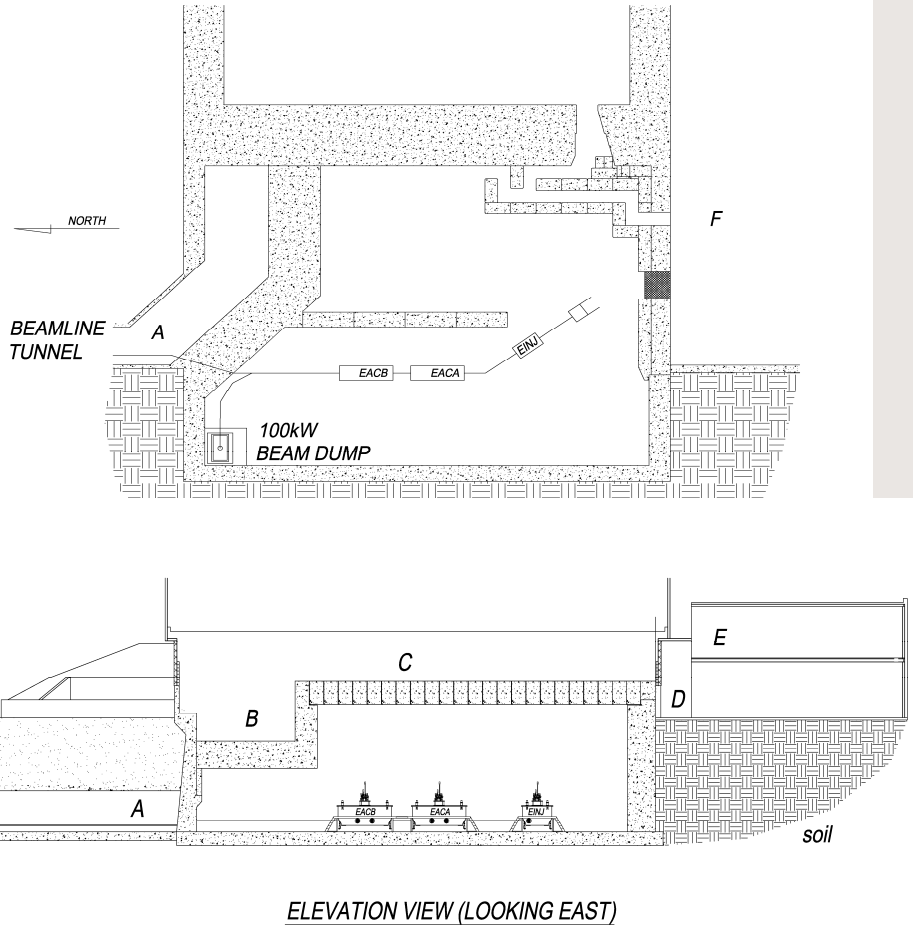


10 uA 500 MeV protons on UCx

10 mA 50 MeV electrons on UCx



500 kW e-linac (50 MeV & 10 mA)



- SCRF linac will comprise three cryo-modules
- Accelerator is located in the re-purposed Proton Hall adjacent to the cyclotron
- Beam is directed north into the beam line tunnel to the ARIEL RIB production targets.
- 100 kW shielded beam dump in the NW corner of the e-Hall
- Shielding added on the north side of the e-Hall to fully isolate the e-Hall and BL4N (500 MeV protons)
- Local shielding wall in the e-Hall to provide some protection for the klystron and cryogenic equipment.

Shielding – Point Kernel Method

Use point kernel method since regulatory agency uses this as a baseline for safety analysis.

$$H = H_0(\theta) \times 10^{-\left[\frac{1}{TVL_1}+\frac{(t-TVL_1)}{TVL_n}\right]} \times {}^{1}/_{d^2}$$

Radiation	Dose Rate (Sv·m2/hr·kw)	Tenth Value Layer in Concrete (cm)	
		TVL-1	TVL-n
Neutron	1.73×10^{1}	53.2	36.6
Gamma (0°)	1.50×10^{4}	56	49
Gamma (90°)	5.00×10^{2}	51	46

Dose Rate Criteria & Results

Criteria for shielding based on Dose Rate outside shielding of :

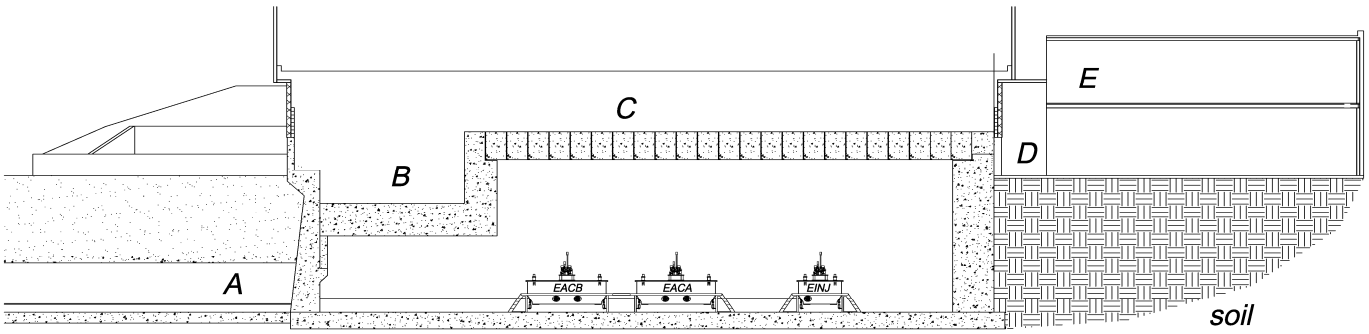
1. H < 50 mSv/hr for a worst case accidental full loss of the beam;
2. H < 10 uSv/hr for chronic losses in low occupancy areas
3. H < 1 uSv/hr for chronic losses in high occupancy areas.

Chronic losses over 10 meter accelerator length 1:1E5/meter or 1:1E4 total.

Therefore H-full < 50 mSv/hr is equivalent to Hchronic < 5 uSv/hr.

(Expect that 1E-4 is conservative for chronic loss.)

Point loss assumed to be at worst case location for each of the different locations outside shielding assessed.



ELEVATION VIEW (LOOKING EAST)

In excess of 5 uSv/hr

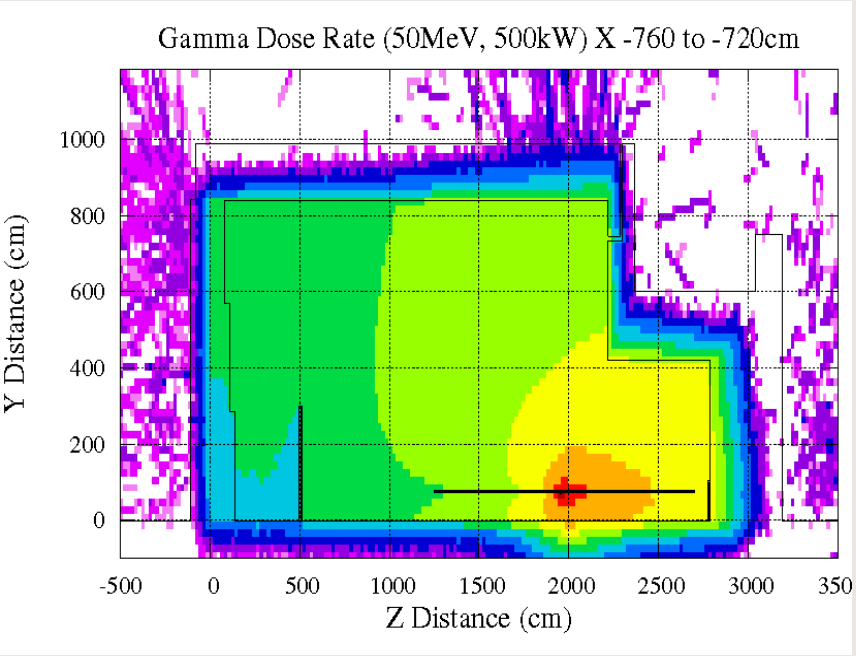
Location	Distance (m)	Concrete Thickness (cm)	Gamma Attenuation	Gamma Dose (µSv/hr)	Neutron Attenuation	Neutron Dose (µSv/hr)	Total Dose (µSv/hr)
A	4.6	360	6.25E-08	2.22E+00	4.13E-10	1.69E-05	2.22E+00
B	6.3	180	1.57E-04	1.00E+01	3.43E-05	7.60E-01	1.08E+01
C	10.2	150	7.04E-04	1.71E+01	2.26E-04	1.90E+00	1.90E+01
D	24.9	192	8.61E-05	3.47E-01	1.61E-05	2.25E-02	3.70E-01
E1	29	340	5.22E-08	1.55E-04	1.45E-09	1.50E-06	1.57E-04
E2	33.1	192	8.61E-05	1.96E-01	1.61E-05	1.27E-02	2.09E-01
F	23.4	240	7.79E-06	3.55E-02	7.86E-07	1.24E-03	3.68E-02

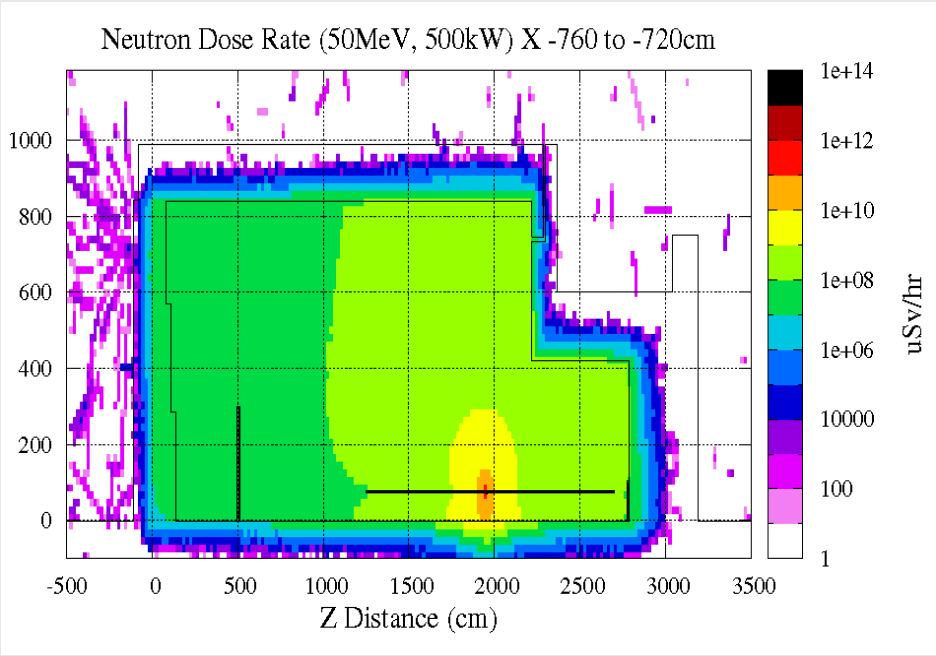
FLUKA

10 mA 50 MeV electrons onto 5 cm radius x 10cm long cylindrical iron target

- DEFAULT NEW-DEF
- BEAM location moved along with target to different loss points
- PHYSICS NEW-EVAP (no heavy fragment)
- TRANSPORT thresholds e+/e- 100 keV; photons 10 keV
- BIASING LAM-BIAS for photo-nuclear reaction (λ=0.02)
  EMF-BIAS LPB modest Ethresh < 0.001 GeV
  IMPORTANCE none used

- SCORING USRBIN DOSE-EQ with AUXSCORE for neutrons / photons / all particles (AMB74)
  USRTRACK used to for photon and neutron spectrum inside the vault
- GEOMETRY – extensive work done by M. Trinczek !!



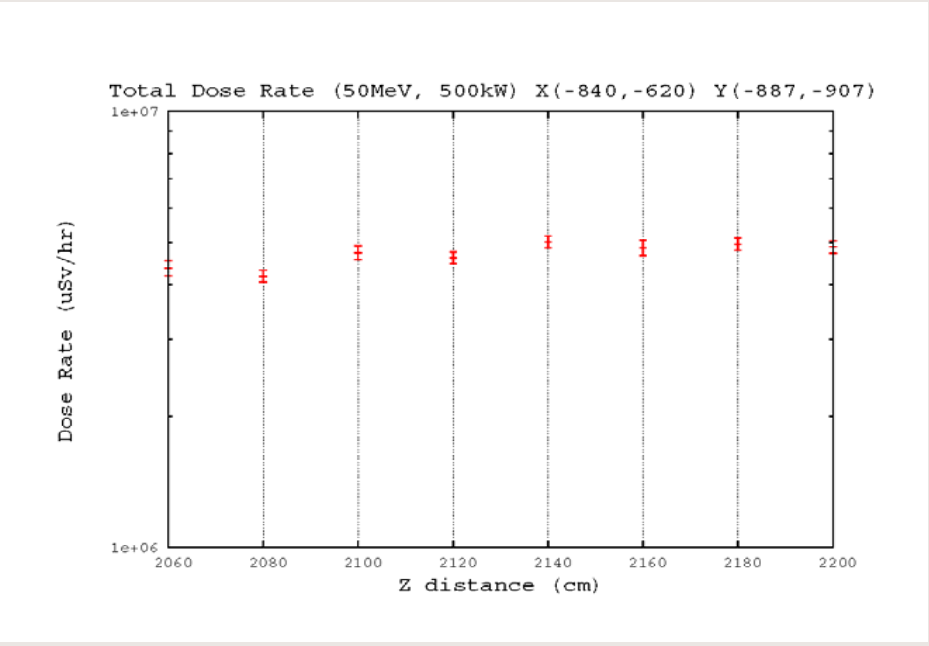


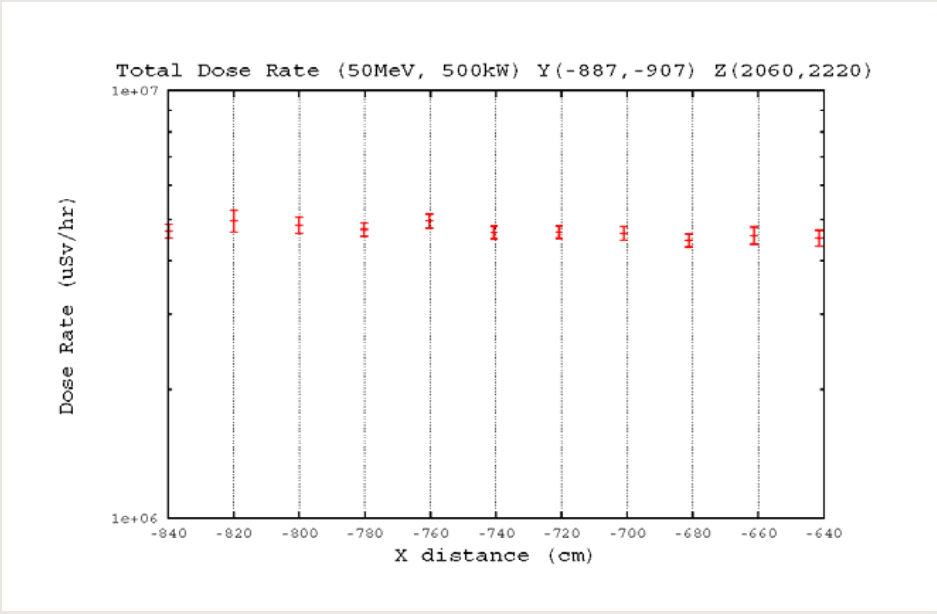
Photons dominate through the concrete shielding even in the lateral direction overhead.

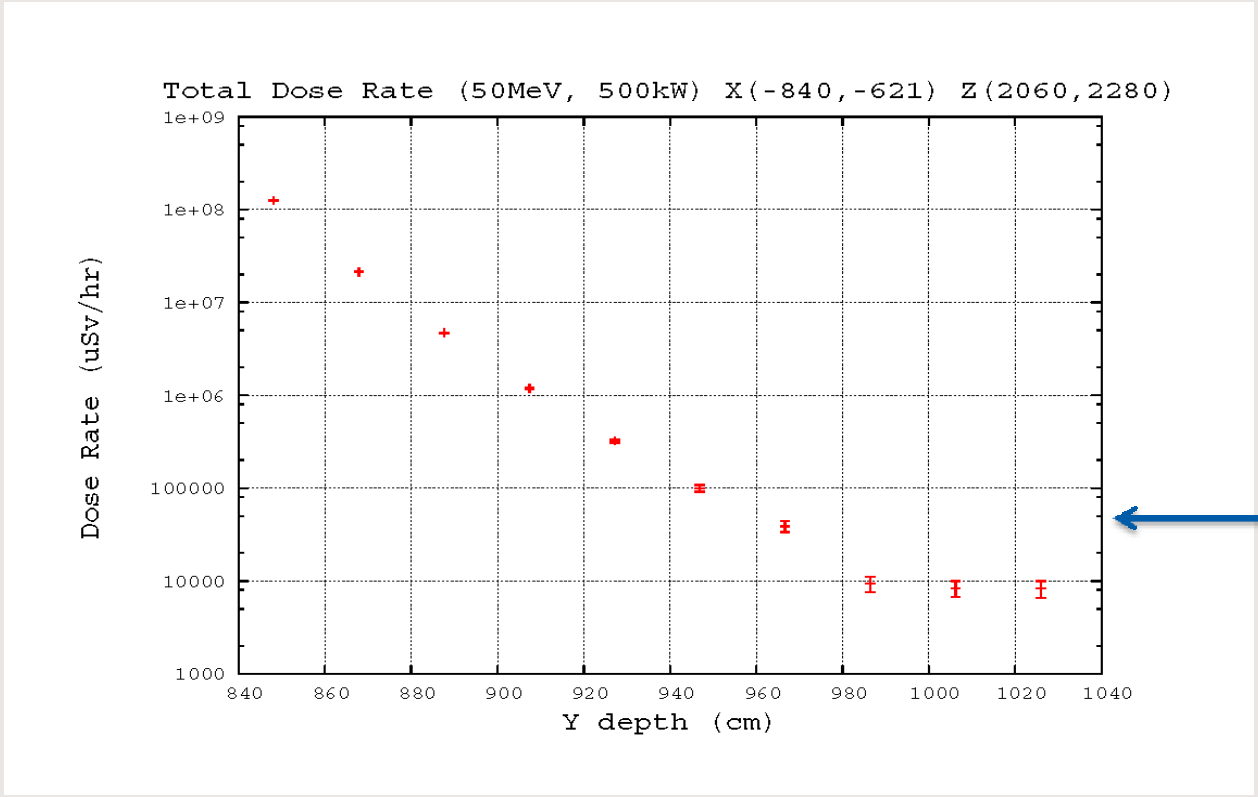
Leakage in the backward direction due to penetrations in the shielding for services.

- 1.6 E8 primaries run ;
- USRTRACK detector overhead with limited statistics (35% error)

- Consider a 1.6 x 1.6 sq.m area through the roof beam shielding
- Look at 1D projections in USRBIN at 1/3 of the way through the roof beam 150 cm thickness.
- Dose rate uniform within uncertainties therefore area suitable extracting DR profile through thickness.

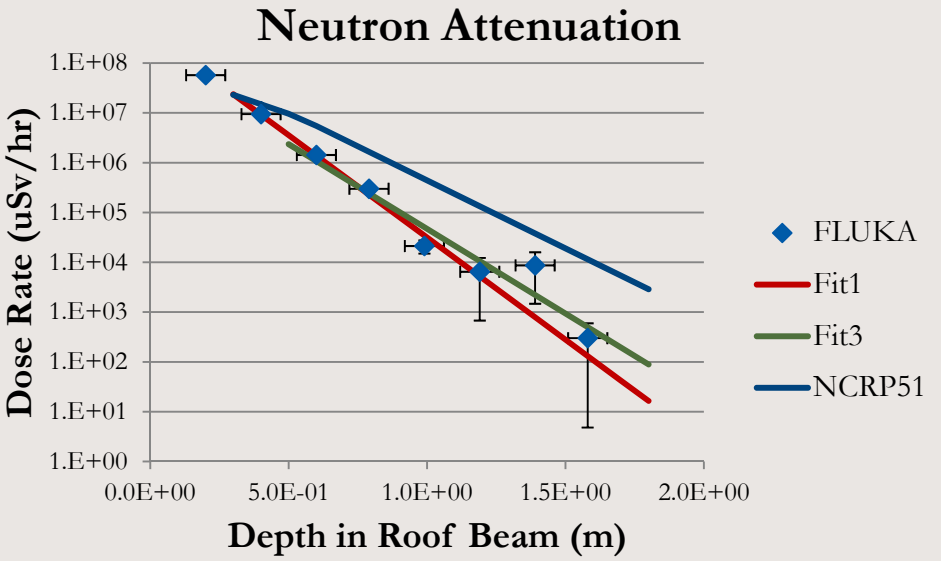


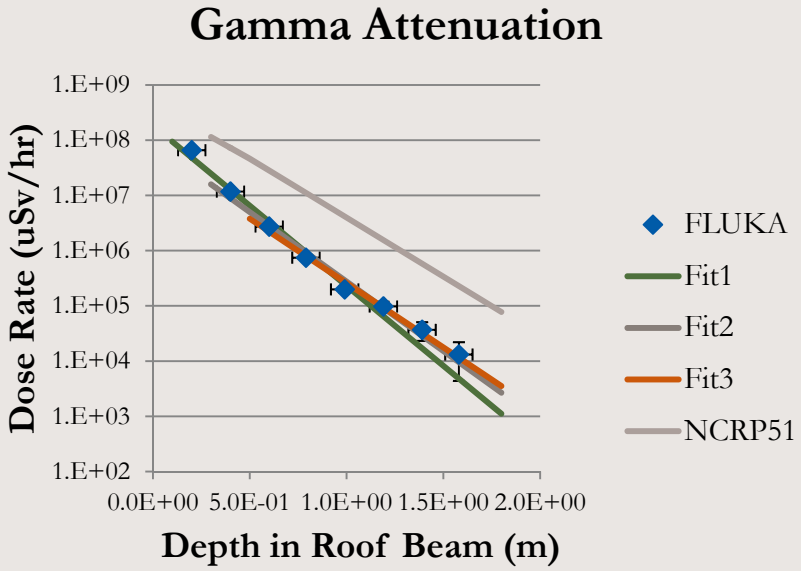




Combined neutron and photon dose rate at Location B (roof beam) is definitely below the 50 mSv/hr threshold outside shielding. Therefore the point kernel method is conservative.

FLUKA / NCRP 51 Attenuation





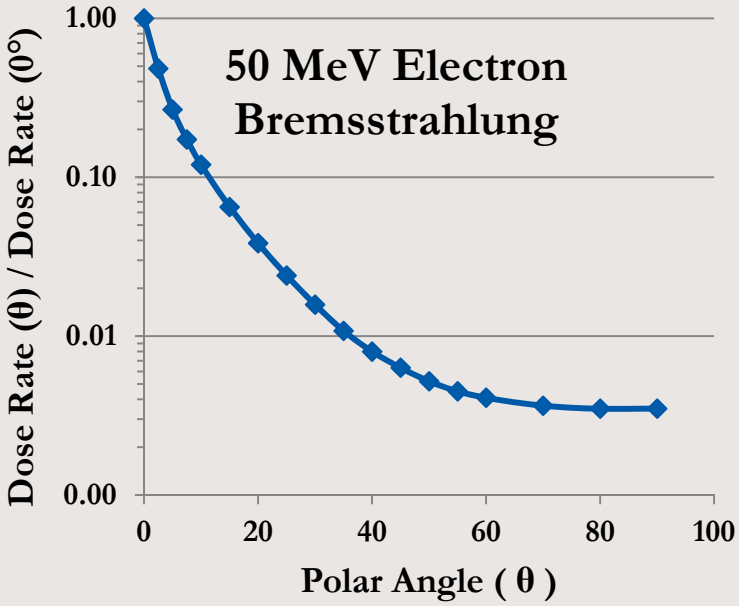
Extract attenuation lengths for neutrons and photons separately by first factoring out the geometrical $1/r^2$

Also use the harder portion of the spectrum deeper in the shield to define λ

- FLUKA / NCRP51 neutron attenuation is 27.5cm / 32.7 cm
- FLUKA / NCRP51 photon attenuation is 42.9 cm / 46.8 cm

Point Kernel Distributed Loss

- Use the bremstrahlung angular distribution to sum losses along the 10 m length of the accelerator
- Neutron distribution is isotropic



Point Kernel Method	Dose Rate (uSv/hr)		
	Gamma	Neutrons	Total
Point Source	17.1	1.9	19.0
Distributed Source	13.6	1.3	14.9

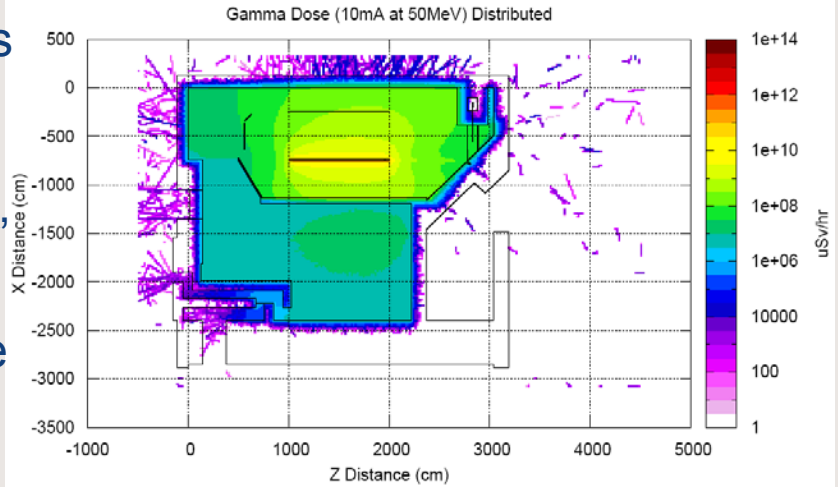
Expect a reduction of 0.79 in the dose rate for a distributed compared to a point source.

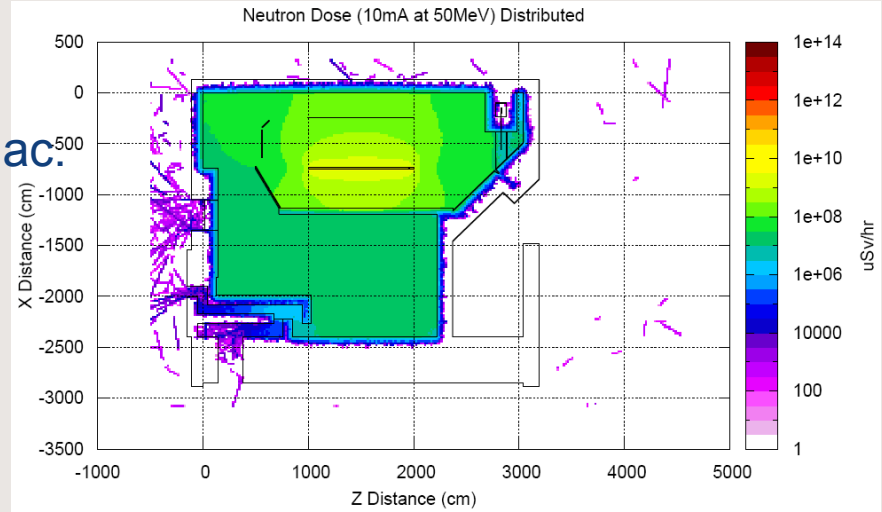
Distributed Source in FLUKA

Use a Source.f to define a distributed loss along the length of the e-Linac.

Simulate a simple loss by using a 'thicker' beam pipe and directing the beam in the horizontal plan at a fixed angle to achieve an equivalent 10 cm thickness for showering electron.

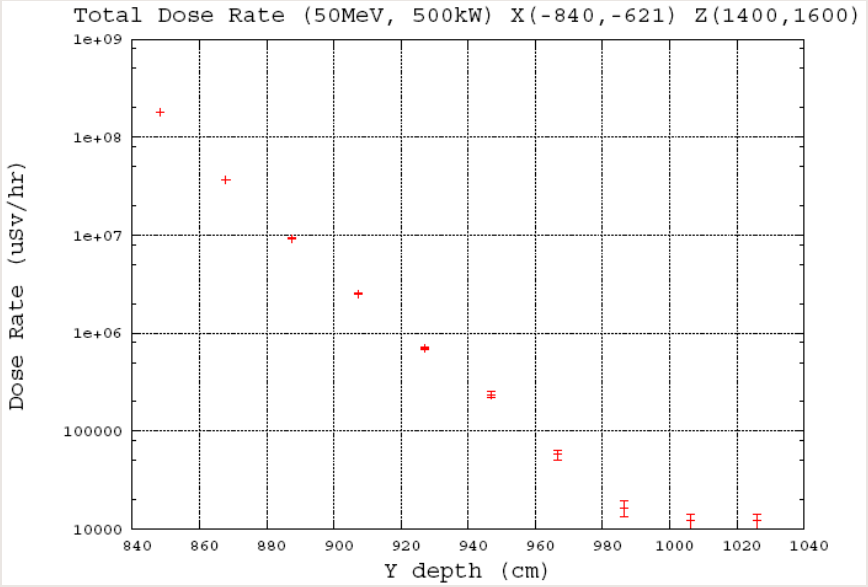
Specify direction cosines as above and randomly distribute Z over length of e-Linac.





Distributed Source FLUKA

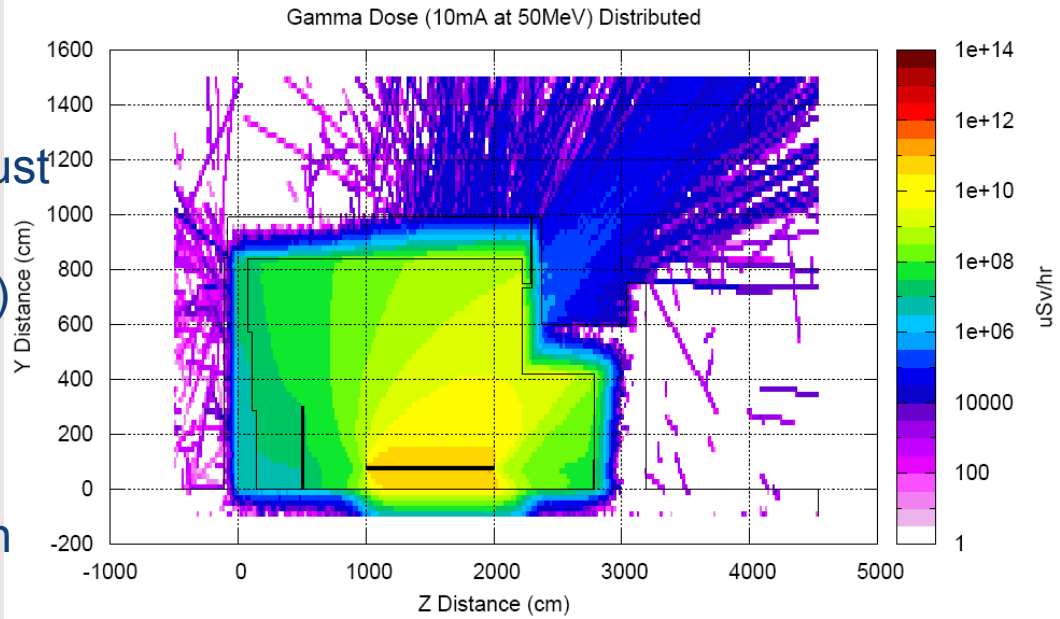
- Dose rate above the center of the 10 meter distributed loss is just above 10 mSv/hr.
- This is comparable to the FLUKA dose rate for the point source.
- Can't take full credit for additional thickness of shielding.



Further Study

Items for further study

- Parametrize the energy as a function of z-position and adjust beam pipe 'thickness'
- Include cryomodule (8-10 cm) steel and other beamline elements to better model forward direction losses.
- Study effect of showering with thinner beam pipe
- Parametrize chronic loss for the whole ring (ER linac / FEL)



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Thank you!
Merci

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