ISU Accelerator-Driven Sub-critical System Characterization

ADSS Experiments Workshop
April, 2006

J. Chen, D. Beller, F. Harmon, K. Sabourov

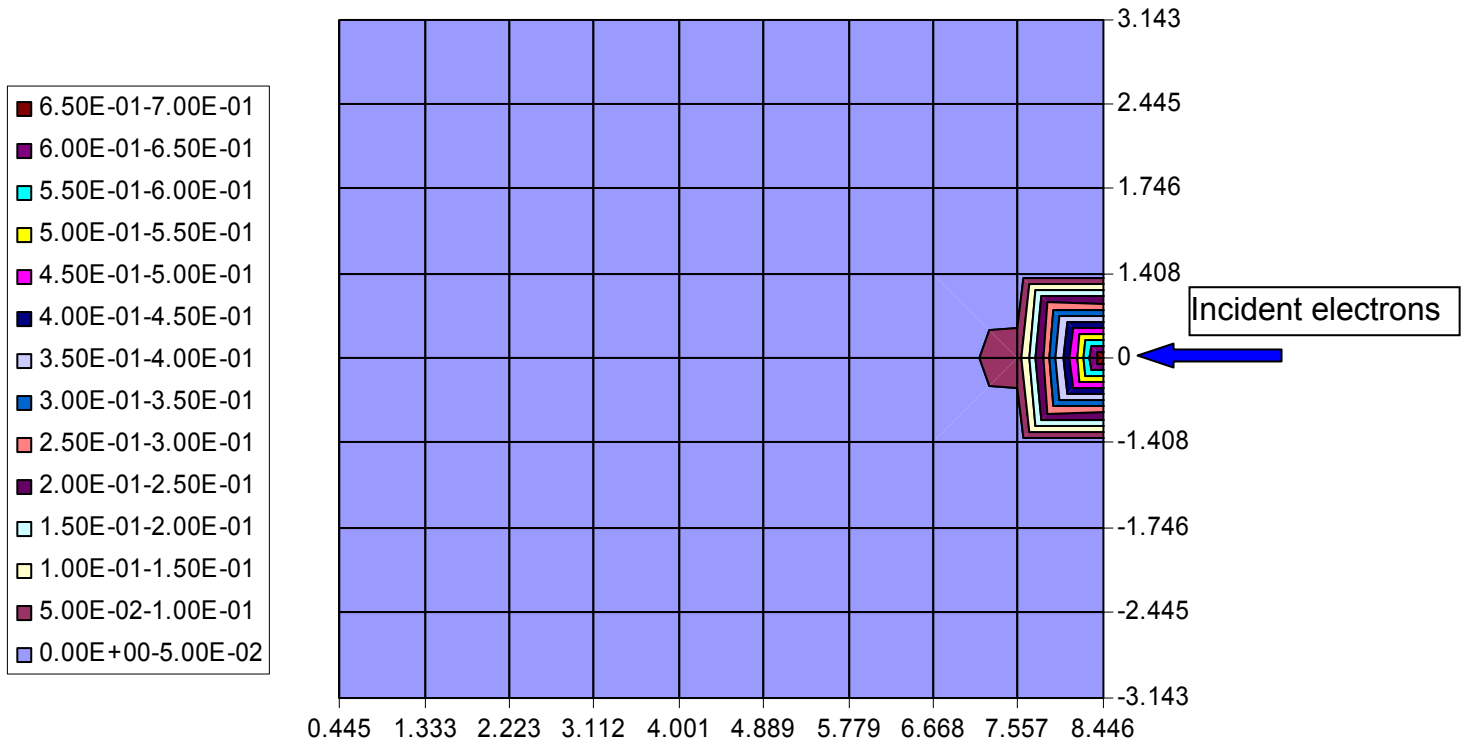
ISU RACE MCNP Simulations

- Target Simulations
- Core Characterization
- Gold Foil Activation
- MSM correction factors

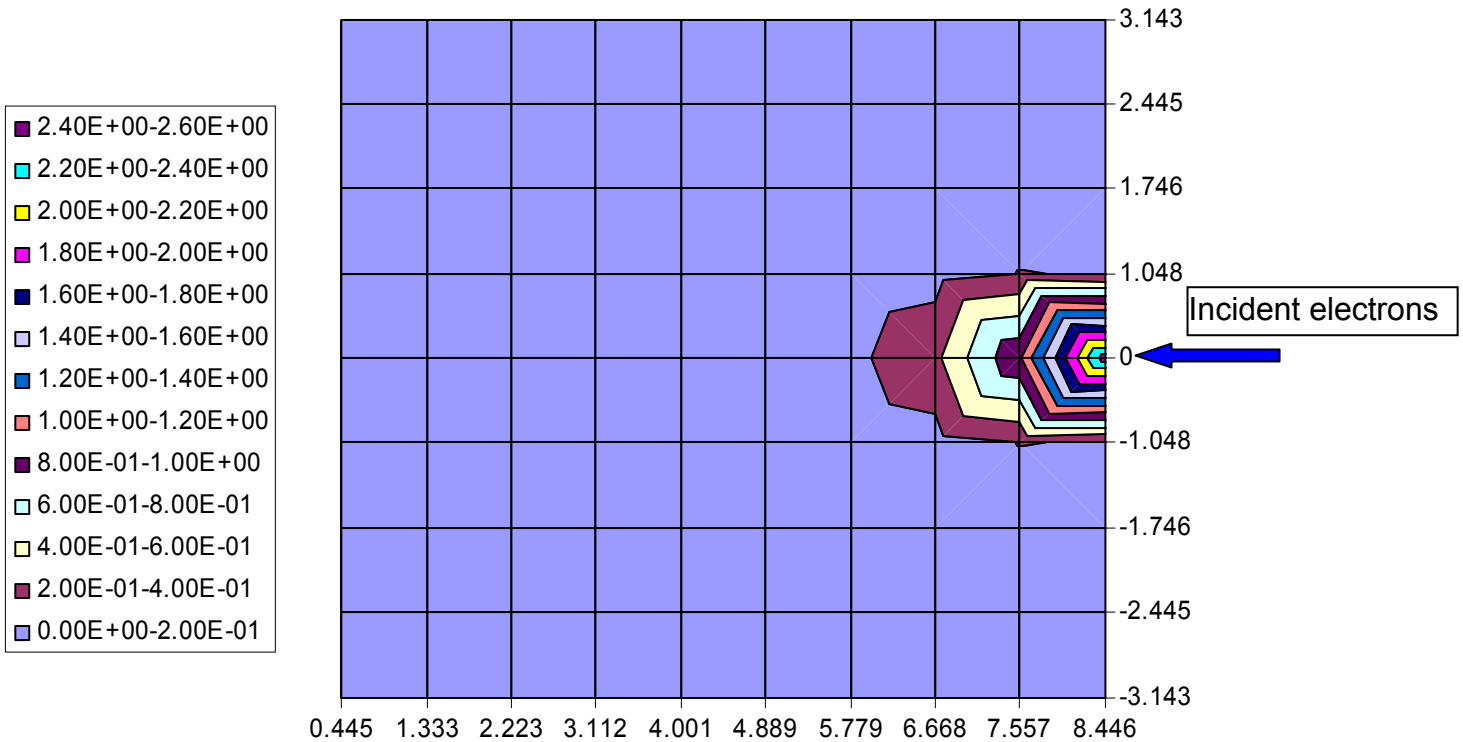
ISU RACE Target

- 2.75” diameter
- 3.5” long
- Not an alloy
- 75% W, 25% Cu

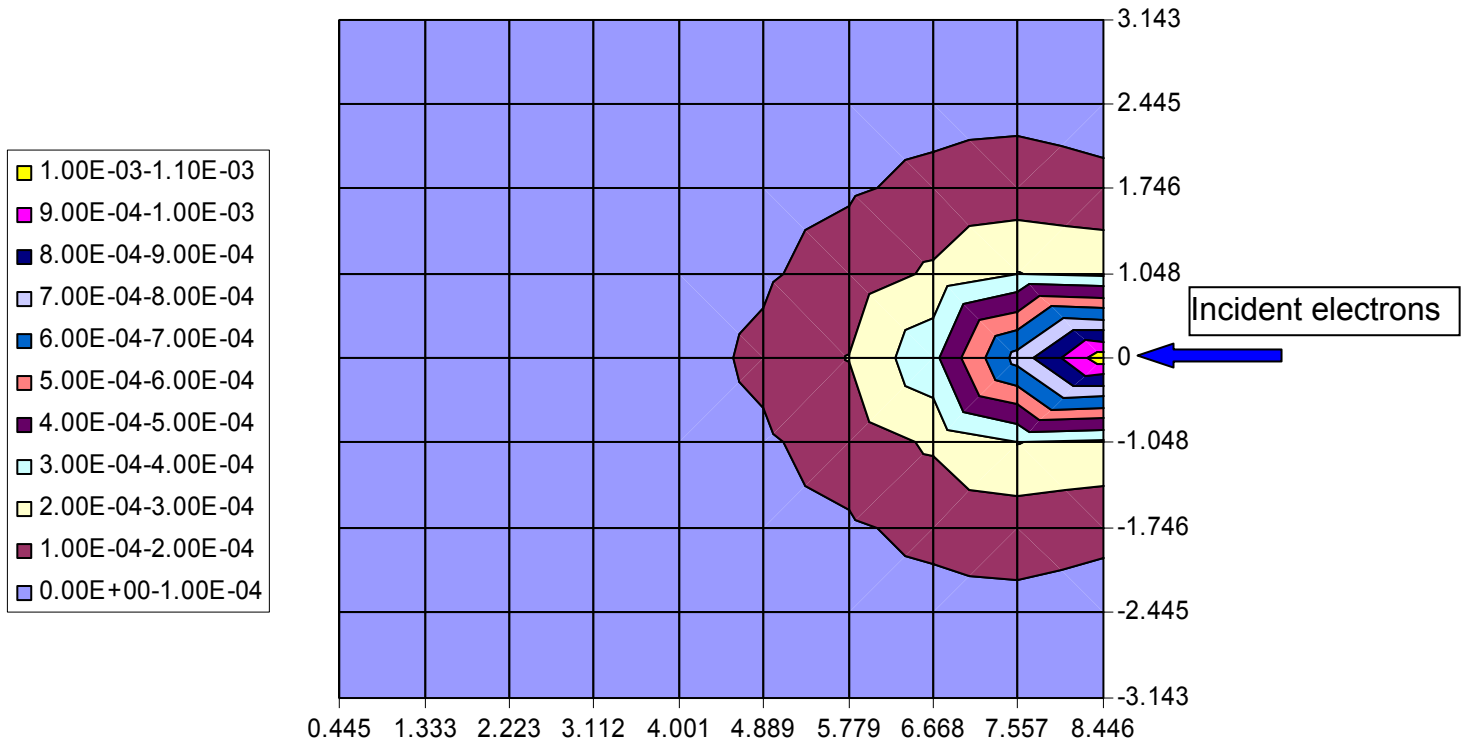
Electron Distribution (e/cm^2/incident e)



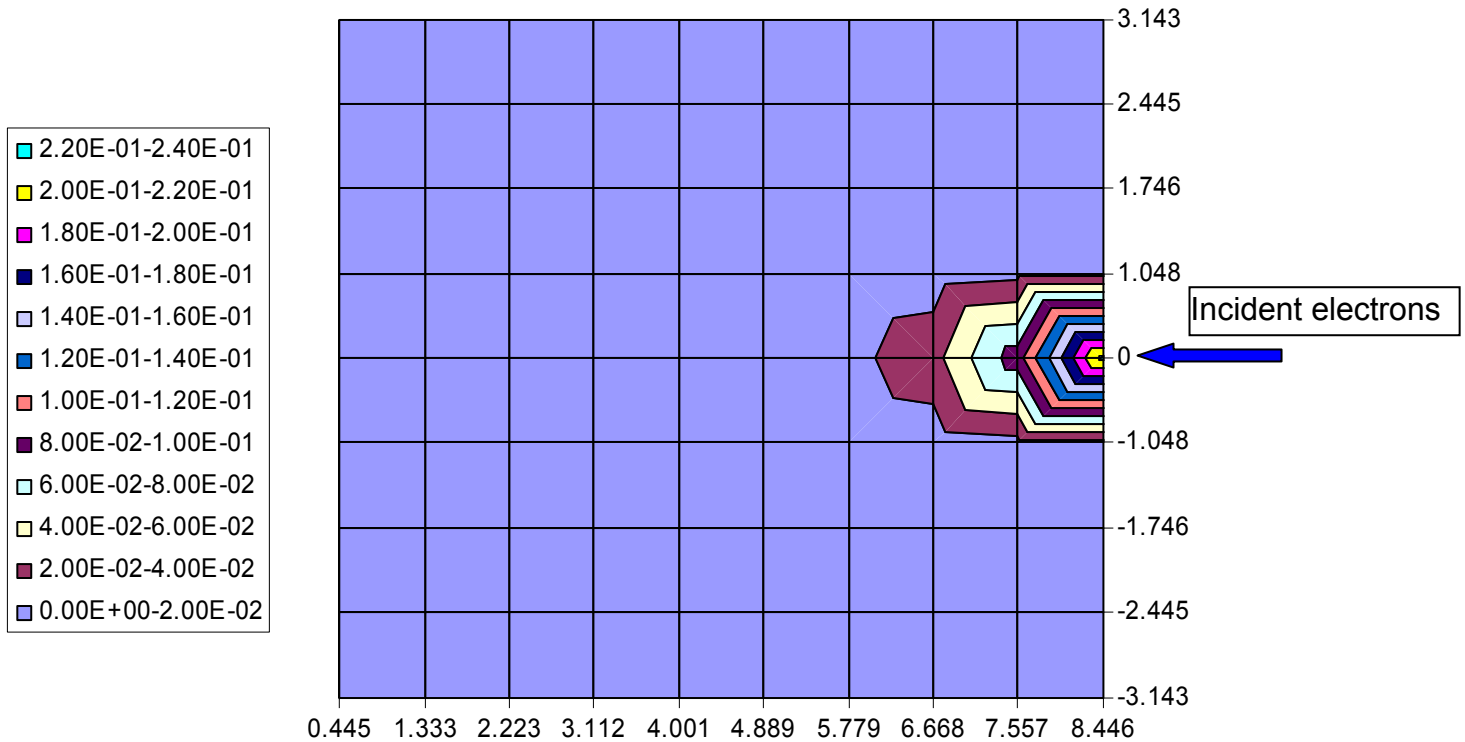
Photon fluence (photon/cm^2/incident e)



Neutron fluence (n/cm^2/incident e)



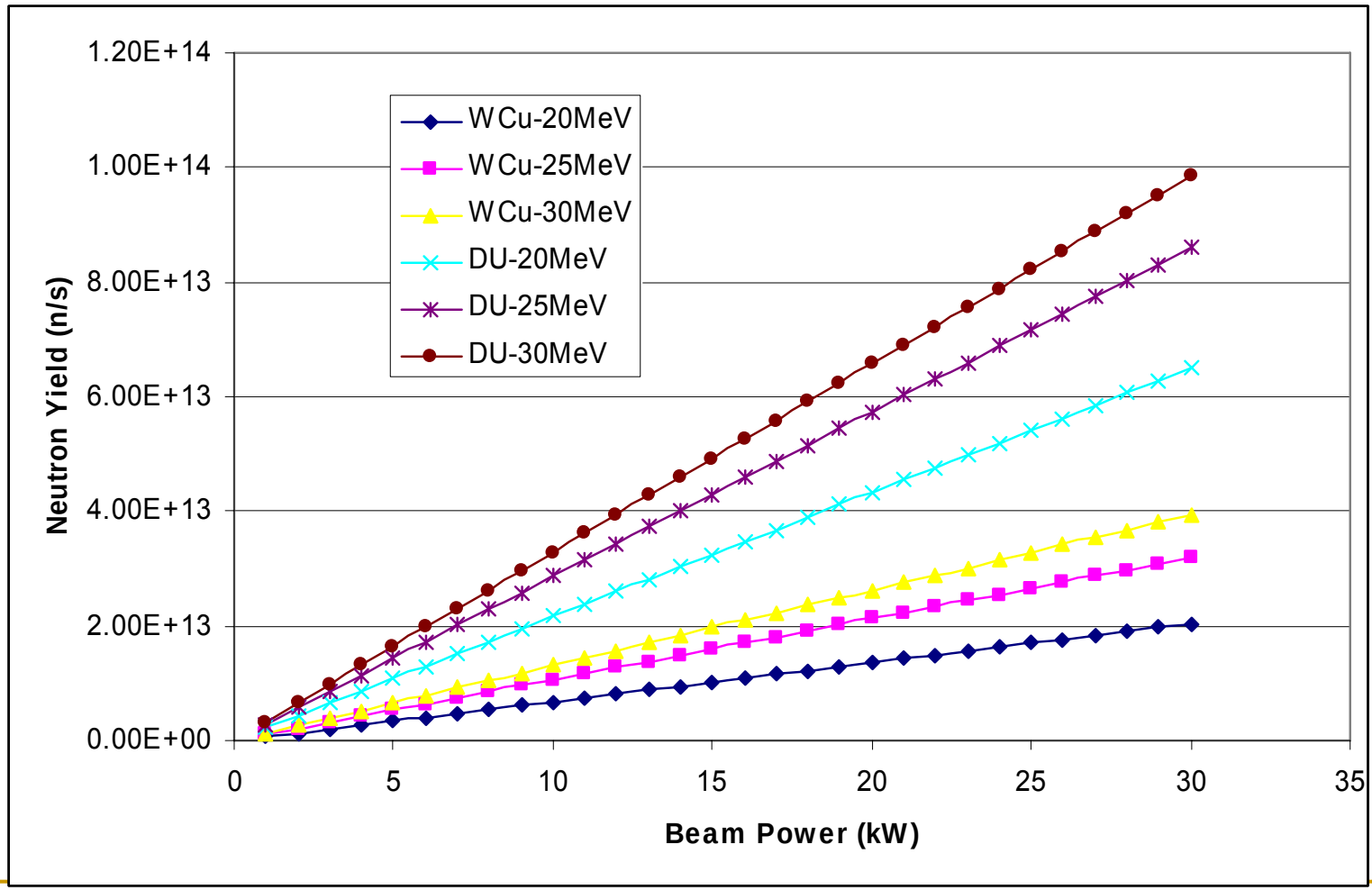
Energy deposition (MeV/gram/incident e)



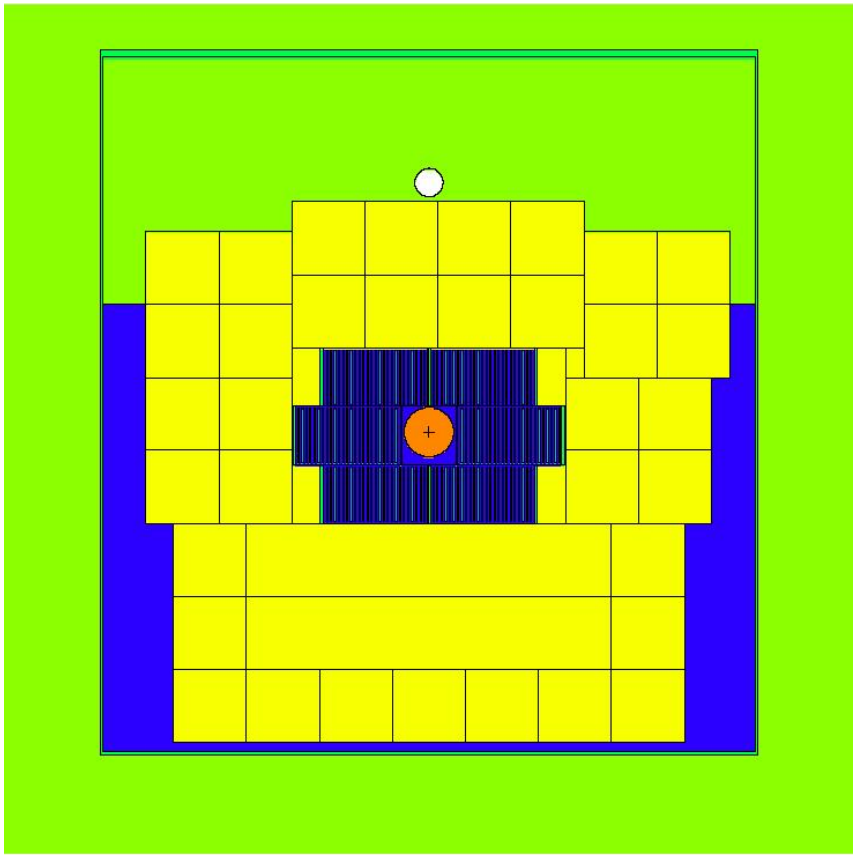
Beam Power Distribution in the Target

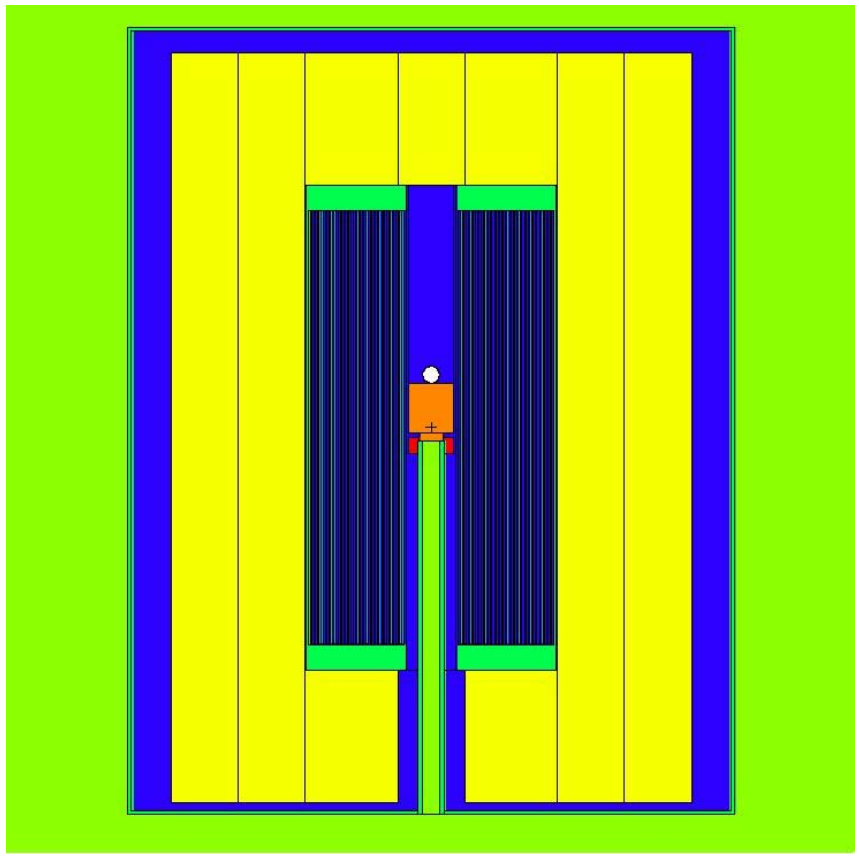
- 48.52% deposited in the target through electron collision
- 45.6% deposited in the target through photon and neutron interactions
- 5.88% carried away by the particles escaped from the target
- Most of the heat deposited in the near side of the target

Target Material: 2.9 times neutron yield can be achieved by using Depleted Uranium



ISU RACE Sub-critical System Characterization

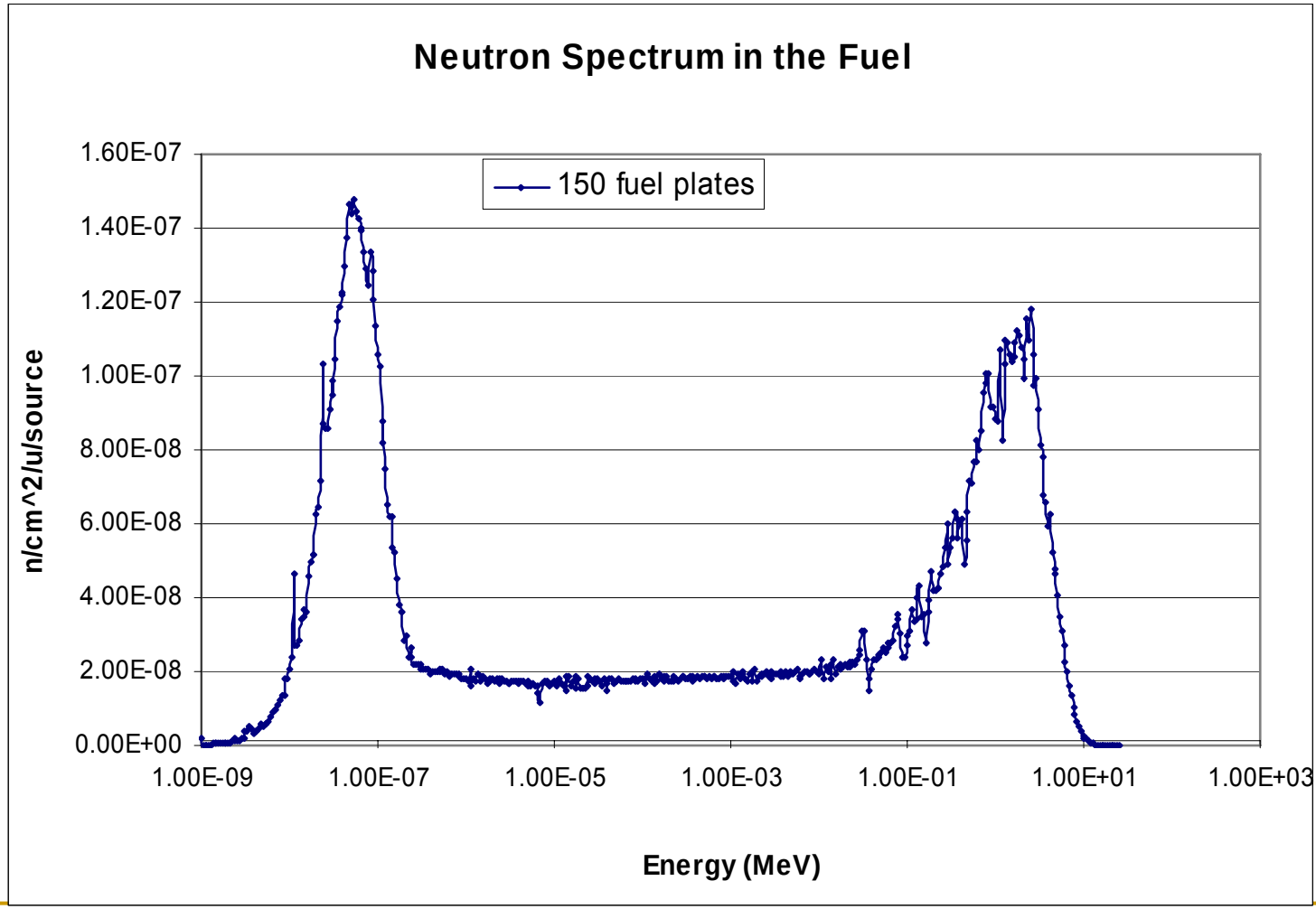




ISU RACE Sub-critical System Characterization

- 150 fuel plates in the full core geometry
- Each fuel plate is 0.08 inch thick, 3.0 inch wide, and 26.0 inch long
- The fuel is 20% enriched U-235 by weight.
- The total amount of Uranium is 7614.79 gram, with 1510.27 gram being U-235
- Maximum k-eff could be achieved by this sub-critical system is 0.94
- Source multiplication factor k_s is 0.947

ISU RACE Sub-critical System Characterization



ISU RACE Sub-critical System Characterization

- Neutron generation time calculation

$$l = \frac{\int_0^\infty P(t) \cdot t \cdot dt}{\int_0^\infty P(t) \cdot dt}$$

  - Where P(t) is the time distribution of prompt fission neutron introduced by a source neutron, and k_p (prompt multiplication factor) can be calculated as

$$k_p = \int_0^\infty P(t) \cdot dt$$

ISU RACE Sub-critical System Characterization

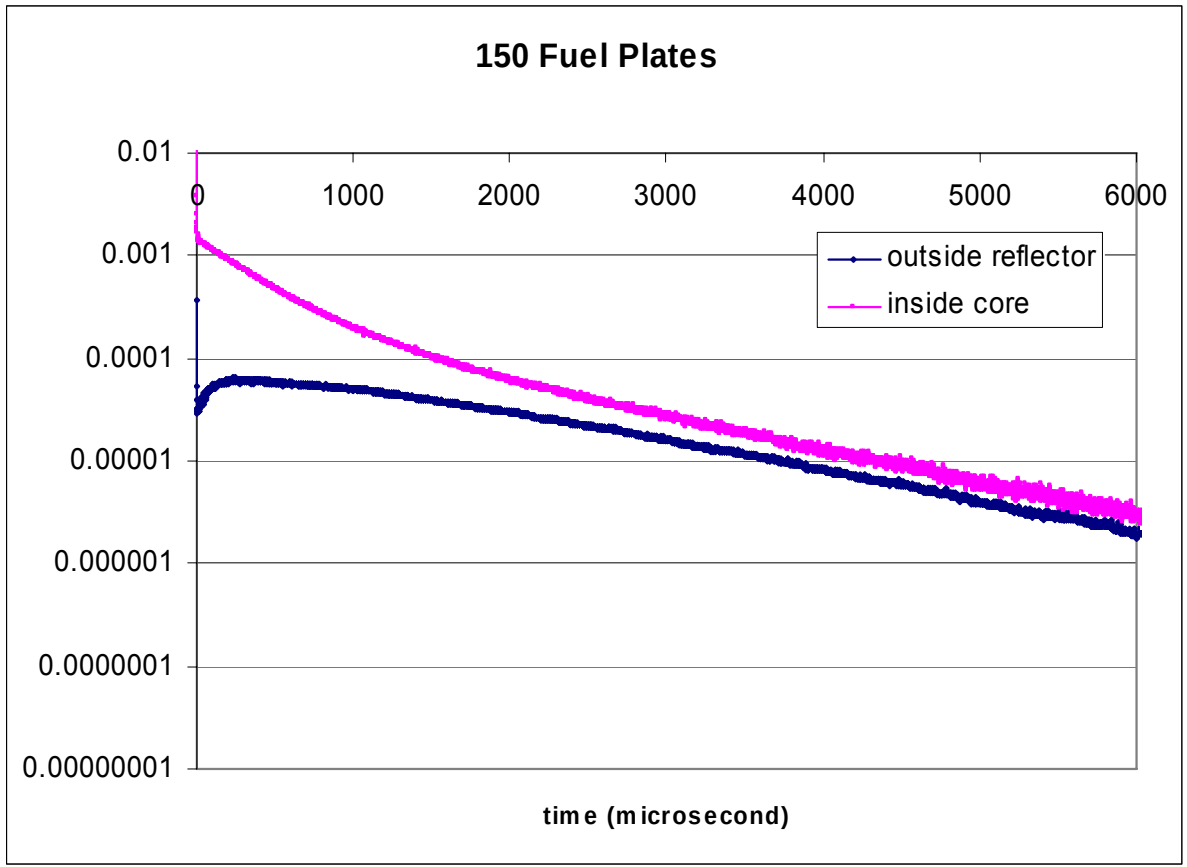
- The fission neutron time distribution is calculated in MCNP as:
  - F4:n <cell number>
  - Fm4 -1 <material number> (-6 -7)
  - SD4 1
  - T4 <time bin>
- The neutron generation time calculated using this method for ISU RACE is 132 μs

ISU RACE Sub-critical System Characterization

- Neutron flux level of ISU-RACE
  - Assume electron beam energy at 25 MeV
  - Beam power: 22.5 W (40 mA, 3 μs, 7.5 Hz)
  - Inside core: 3.50E08 nv
  - Inside reflector: 1.62E08 nv
  - Outside reflector: 1.43E07 nv

ISU RACE Sub-critical System Characterization

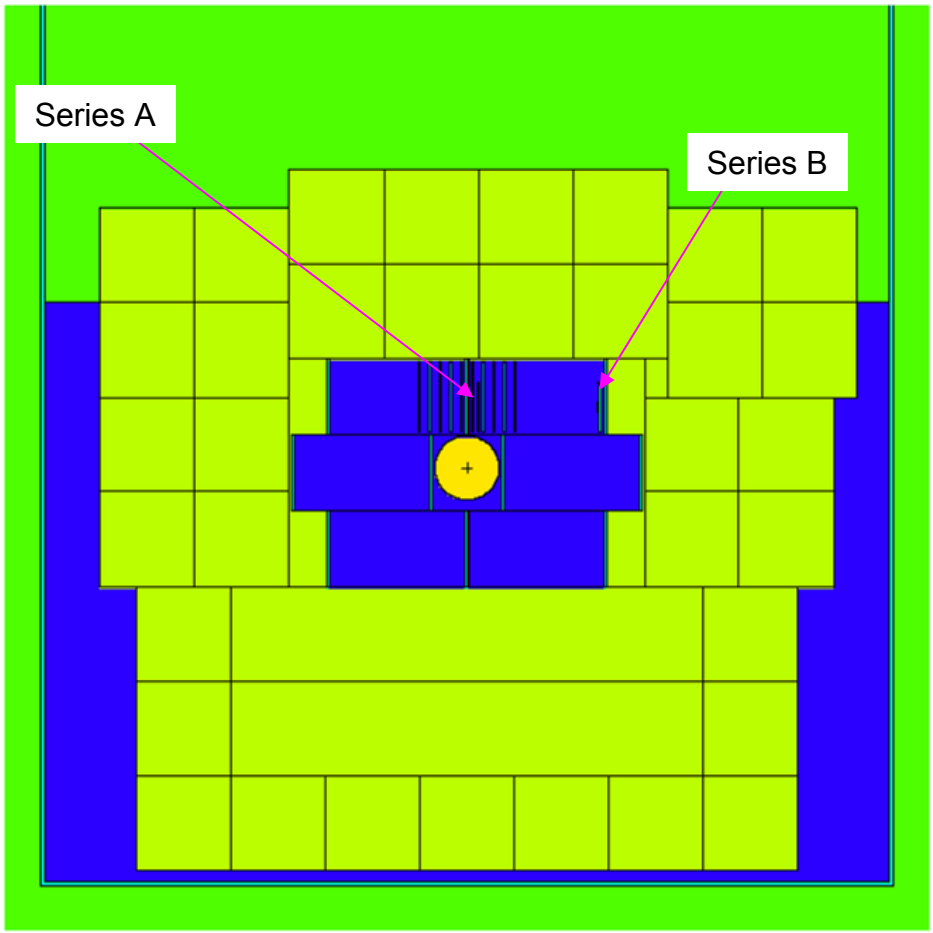
PNS time dependent neutron spectra



ISU RACE Gold Foil Activation

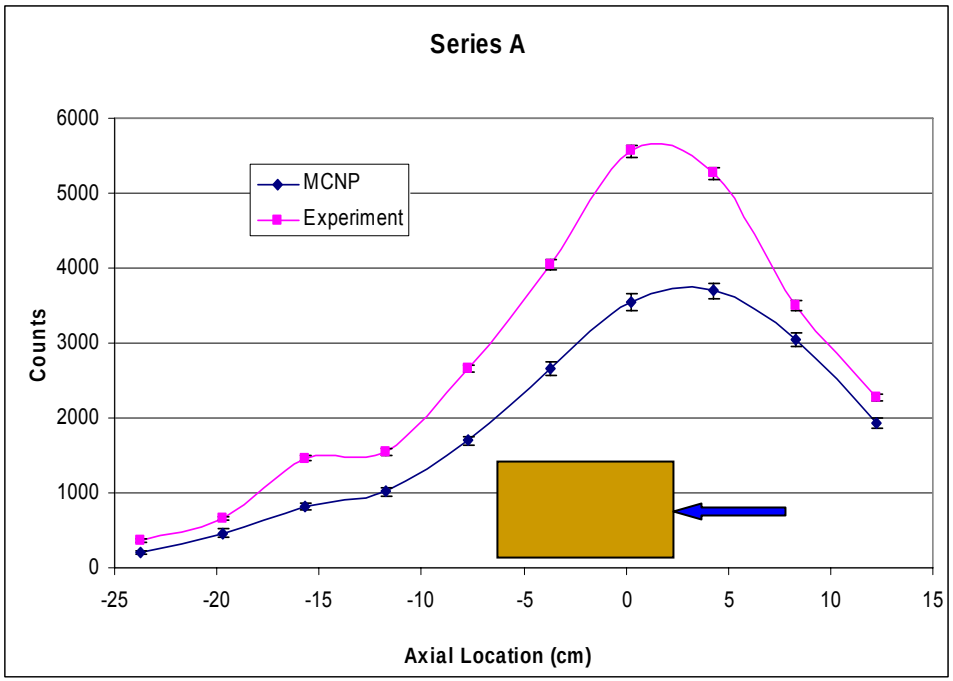
- RACE08 10 fuel plates
- Accelerator peak current 45 mA
- Pulse width 1.72 microsecond
- Repetition rate 7.5 Hz
- Irradiation time: 8 minutes
- Absolute counting efficiency: 5.92E-03

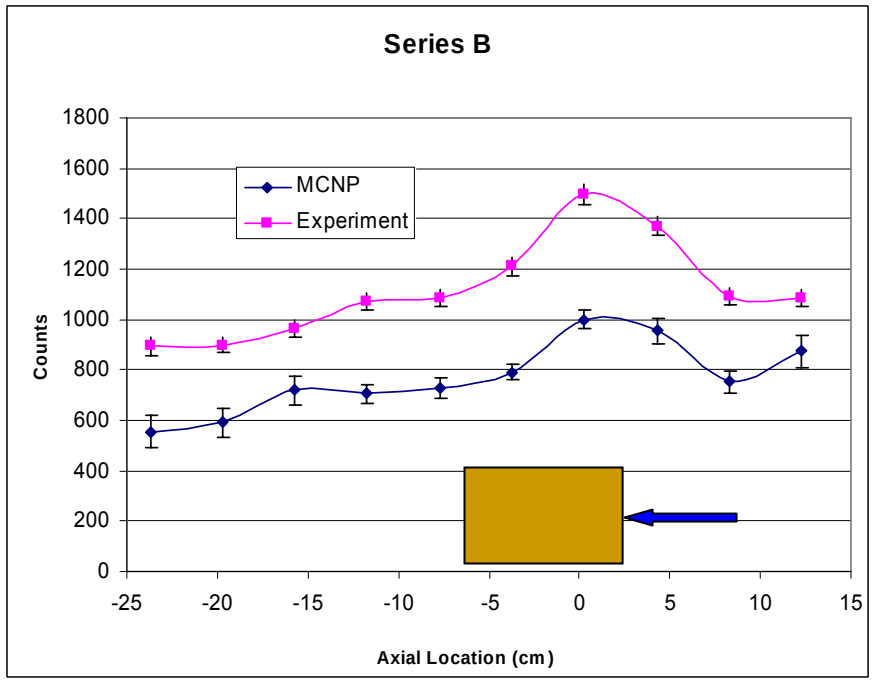
ISU RACE Gold Foil Activation



ISU RACE Gold Foil Activation

Target is located at -6.7875 cm to 2.105 cm, electron beam is incoming from the positive X-axis towards the negative X-axis direction.





ISU RACE Gold Foil Activation

Position (cm)	Series A			Series B		
	Simulation	Experiment	Difference	Simulation	Experiment	Difference
-23.7225	199±18	357±21	44.22%	555±64	894±35	37.96%
-19.7225	464±49	661±27	29.88%	592±57	900±32	34.26%
-15.7225	814±43	1464±25	44.41%	718±58	964±32	25.47%
-11.7225	1017±53	1547±40	34.26%	706±38	1072±33	34.11%
-7.7225	1698±61	2661±52	36.20%	729±41	1088±34	32.97%
-3.7225	2663±89	4046±64	34.19%	791±31	1211±35	34.65%
0.2775	3541±120	5557±75	36.27%	1000±39	1497±39	33.18%
4.2775	3700±103	5263±73	29.70%	954±49	1369±37	30.28%
8.2775	3041±92	3500±60	13.12%	752±45	1094±34	31.29%
12.2775	1927±66	2266±48	14.96%	873±62	1083±33	19.35%

ISU RACE Gold Foil Activation

- Possible contribution to the systematic bias
  1. Accelerator peak current 45 mA could be varying from pulse to pulse
  2. Pulse width 1.72 microsecond could also change from pulse to pulse
  3. Irradiation time: 8 minutes may not be so precise
  4. Absolute counting efficiency: 5% uncertainty
- Number 1 & 2 could give large bias to determine how much electrical charge has been delivered during the accelerator run time

ISU RACE MSM Correction Factors

- Source Multiplication Experiment will be performed for the approach to criticality
- The source importance and detector efficiency could be changed due to the change in the core configuration
- MSM factors can be calculated by MCNP
  - Fixed source calculation to obtain count rate ratio
  - k-eff calculation to obtain the ratio of reactivities

ISU RACE MSM Correction Factors

$$\left(\frac{\rho_2}{\rho_1}\right)_{MSM} = \left(\frac{\rho_2}{\rho_1}\right)_{CALC}\left(\frac{T_2}{T_1}\right)_{CALC}\left(\frac{C_1}{C_2}\right)_{EXP}$$

where T is the calculated detector count rate,

ρ is the reactivity, defined as (k-1)/k,

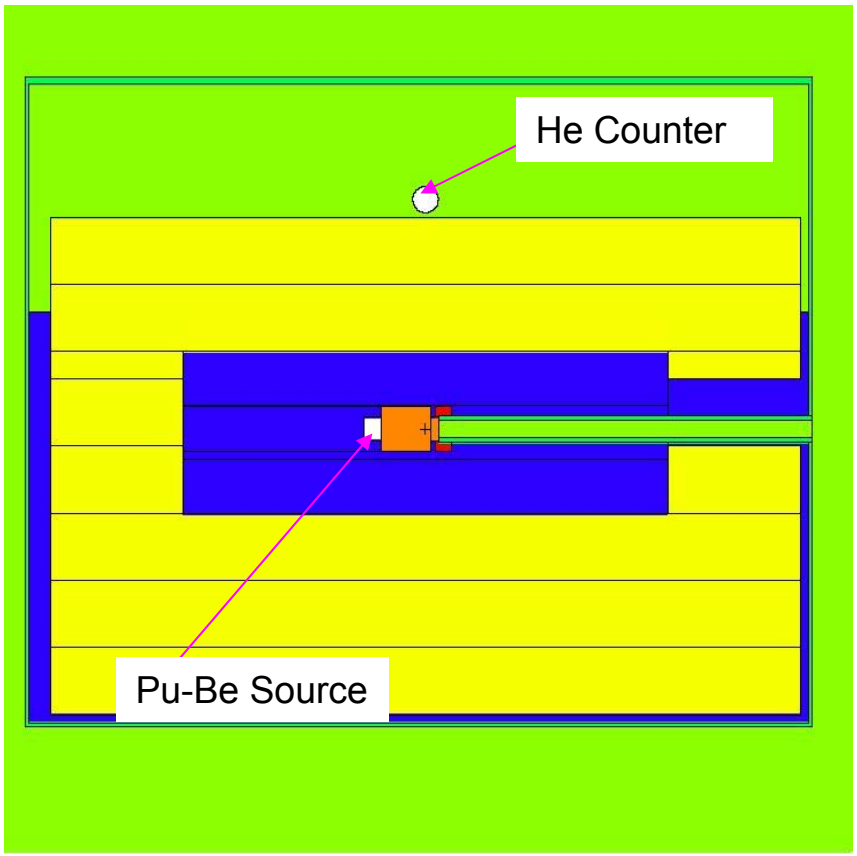
C is the detector count rate from experiment measurement.

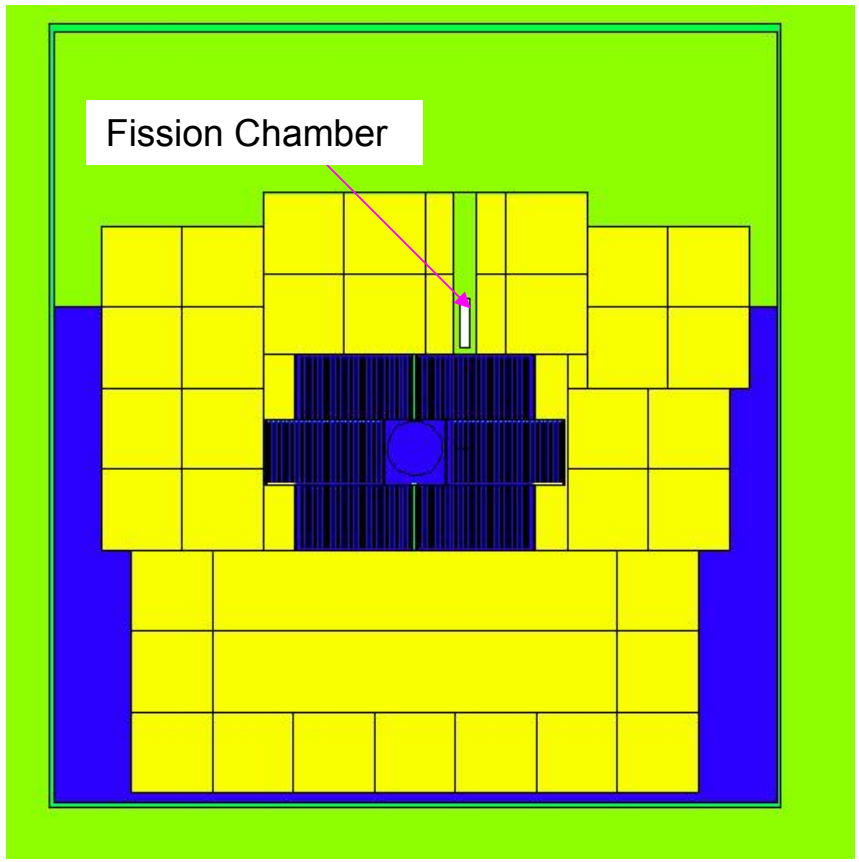
Reference: George Imel, et al., “The TRADE Source Multiplication Experiments”, PHYSOR, 2004

k-eff measurements using "approach to criticality" type experiment

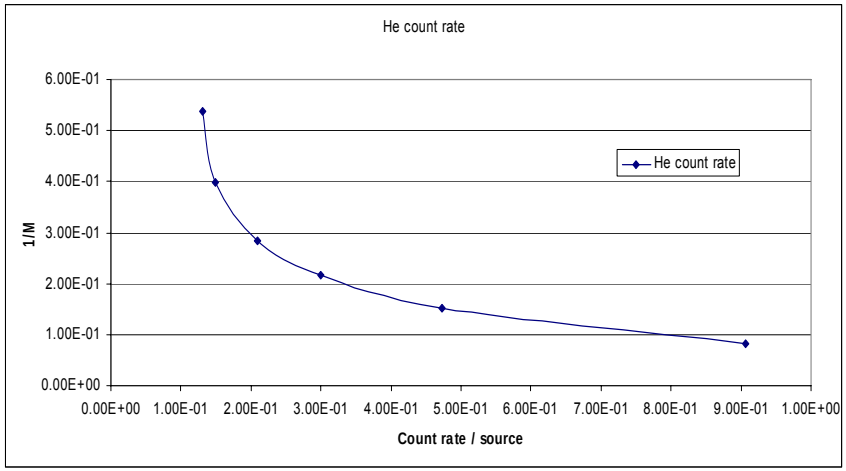
- BF_3_1 $k_{eff} = 0.83 +/- 0.02$
- BF_3_2 $k_{eff} = 0.770 +/- 0.003$
- ^3He $k_{eff} = 0.89 +/- 0.04$
  - with the errors only statistical

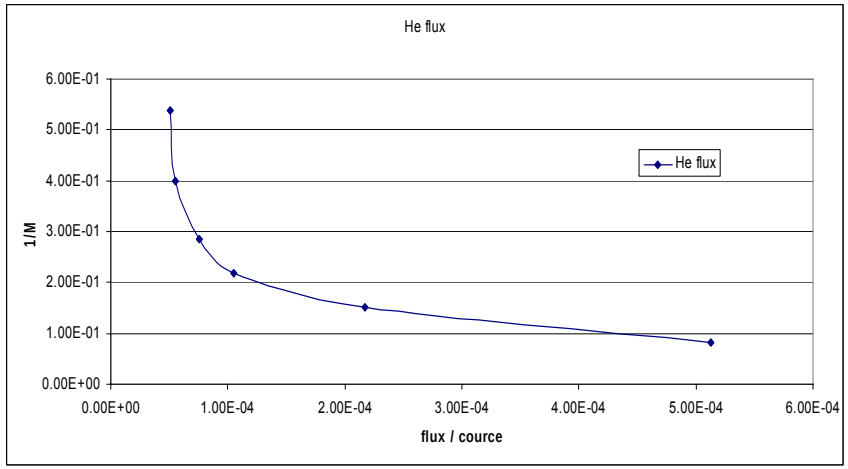
ISU RACE MSM Correction Factors

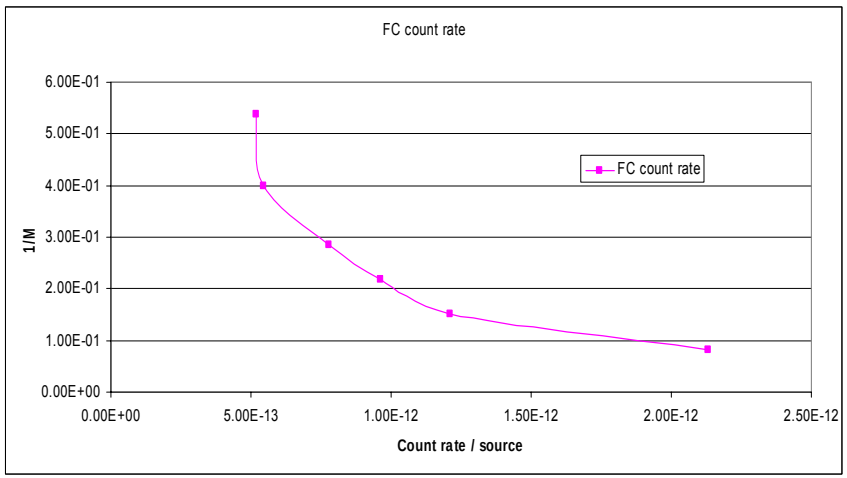


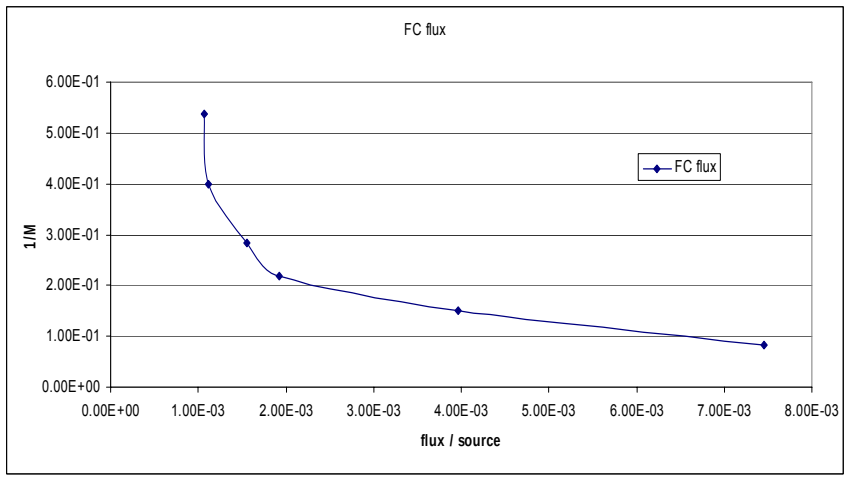


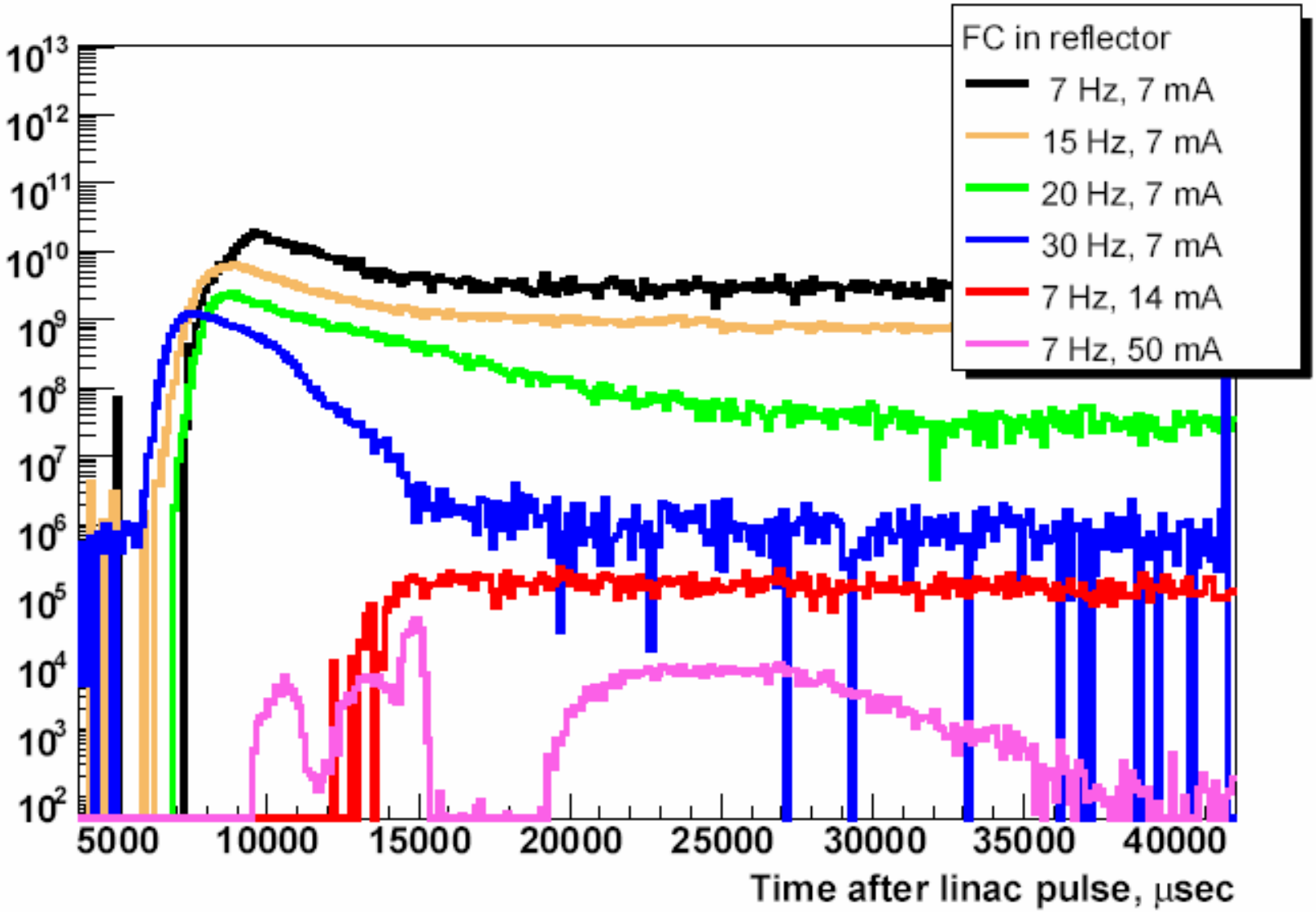
ISU RACE MSM Correction Factors





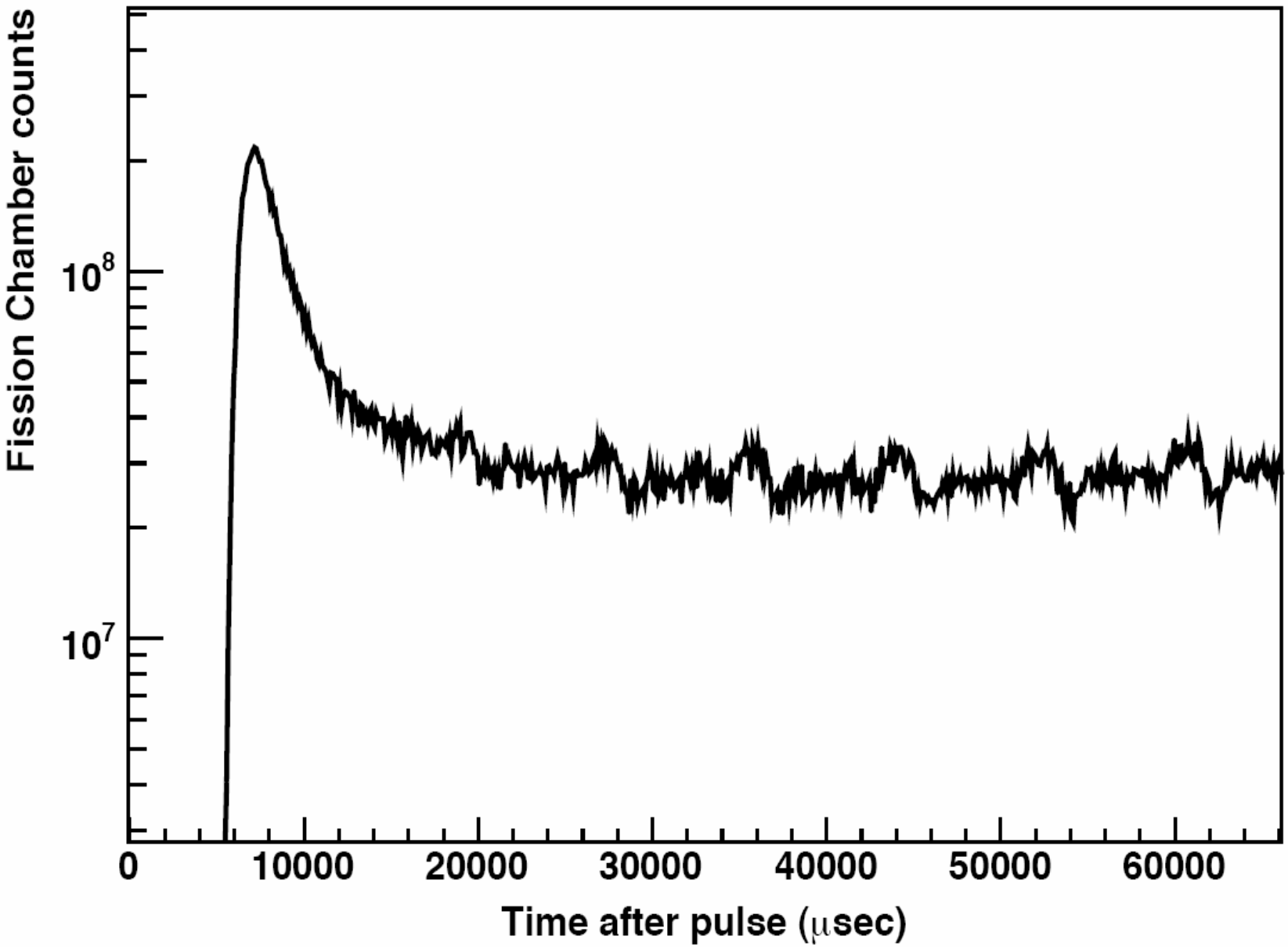





FC in reflector
7 Hz, 7 mA
15 Hz, 7 mA
20 Hz, 7 mA
30 Hz, 7 mA
7 Hz, 14 mA
7 Hz, 50 mA
10^13
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
5000
10000
15000
20000
25000
30000
35000
40000
Time after linac pulse, μsec

ISU RACE MSM Correction Factors

Configuration	F.C. FM	He FM	ρ	F.C. MSM	He MSM
1-tray	5.17E-13	0.131	-1.16	0.318	0.534
2-tray	5.44E-13	0.149	-0.663	0.531	0.823
3-tray	7.80E-13	0.210	-0.397	0.618	0.977
4-tray	9.64E-13	0.300	-0.278	0.714	0.976
5-tray	1.21E-12	0.473	-0.178	0.885	0.965
Full-Core	2.13E-12	0.906	-0.090	1.00	1.00


Fission Chamber counts
10^8
10^7
0
10000
20000
30000
40000
50000
60000
Time after pulse (μsec)

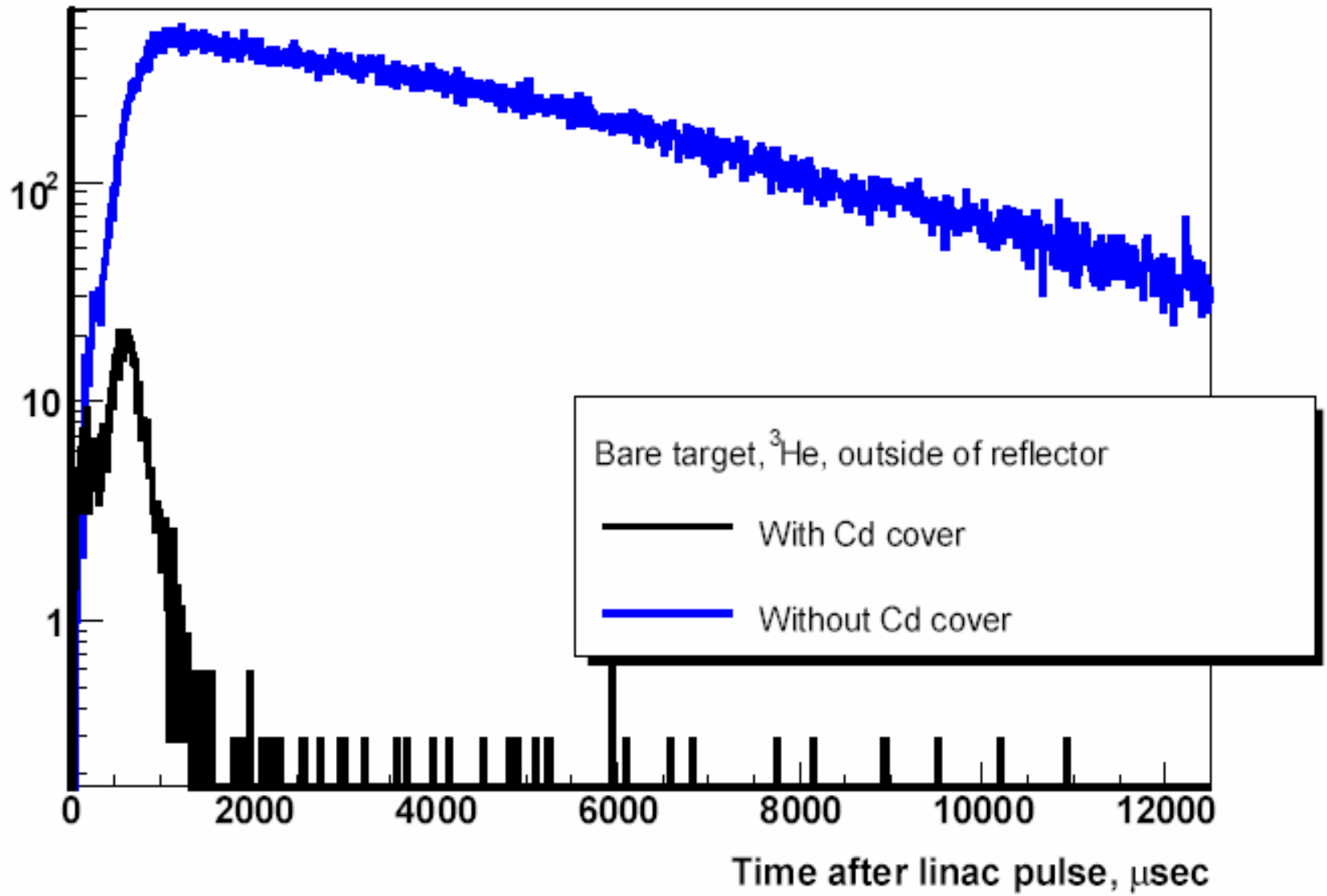
ISU RACE kinetics

- α=600/sec
  - β=700 pcm and Λ=160 μs ➔ ρ = -12.6\$ & k_{eff}=0.92.
- Area method
  - ρ = -0.09\$ & k_{eff} =0.999, which is
  - obviously wrong, as we don't have the first 5 ms.
  - Taking the expo and constant fit and extrapolating it to zero-time results in
  - ρ = -8.3\$ & k_{eff} = 0.95, consistent with the pure fit method
  - one exponent doesn't describe the neutron flux decay, as most of the TRADE data shows

Parametric study of reflector density effects

Graphite Density (g/cm^3)	β	Λ (μs)	α (s^{-1})	k_{eff} by Area Method	k_{eff} by α method
1.86	0.0054	166	514	0.959	0.906
1.80	0.0053	164	562	0.960	0.907
1.73	0.0068	162	610	0.949	0.910
1.67	0.0075	160	663	0.944	0.911

Effect of impurities on β & Λ?


10^2
10
1
0
2000
4000
6000
8000
10000
12000
Time after linac pulse, μsec
Bare target, ^{3}He, outside of reflector
With Cd cover
Without Cd cover

Bare target ^{3}He outside of tank w/bare target in water

- illustrates good recovery time of the fast pre-amp, and gamma and epithermal neutron flux out of target
  - signals after 50 microseconds
  - peak at short times (probably the gamma-flash)
  - peak at around 600 microseconds, about time-of-flight for thermal neutrons
  - Indications ➔ might be not as much the gamma-flash, but a very high flux of neutrons swamps neutron counters and overloads pre-amps
- more data with Ion Chambers and FC with Cd covers might be very useful