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Title: Differential Die-Away Self-Interrogation

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Differential Die-Away Self-Interrogation

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NGSI Spent Fuel Inter-Lab Meeting, December 16-17, 2013

Outline

- How DDSI works
- Conceptual design
- FY13 achievements
- Upcoming work

How DDSI Works

- Neutrons from spontaneous fission isotopes in spent fuel slow down as they scatter through a spent fuel pool, and induce fission in fissile isotopes. This increases an otherwise difficult to measure signal
- We record the time of arrival of each neutron (list-mode) to perform neutron coincidence counting. A coincidence is detection of two correlated neutrons and it is used to detect spontaneous and induced fission events
- Use list-mode data to produce a Rossi-alpha distribution (RAD), which is a histogram of times between captures of two neutrons
- RAD allows for flexible post-processing; traditional shift-register technique requires pre-selection of gate of interest

Time between captures = 10 µs, add to histogram

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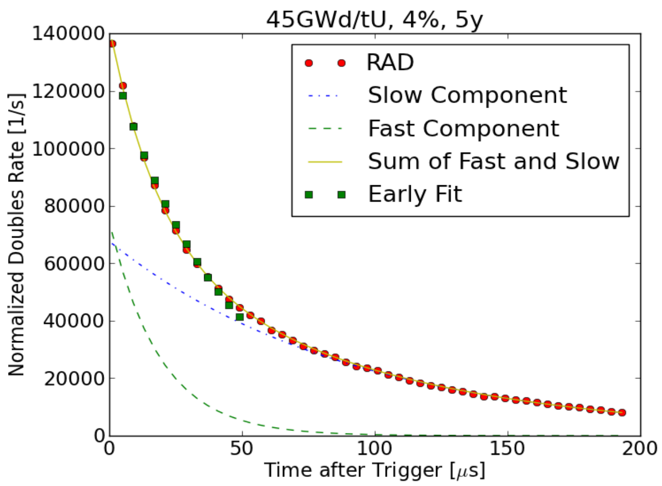
How DDSI Works

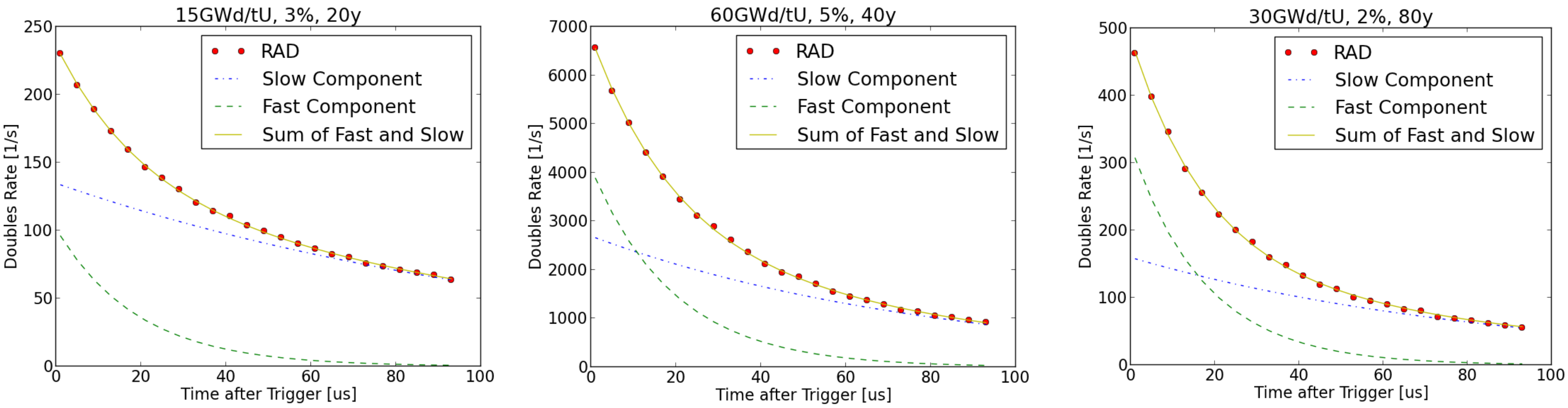
- RAD can be broken down into two components
  - *Fast Component* composed of neutrons arriving from the same fission event
  - *Slow Component* composed of neutrons arriving from different fission events in the same chain

- Fast and slow components from broken down RAD help us characterize spent fuel assemblies; they reflect fissile/fertile content



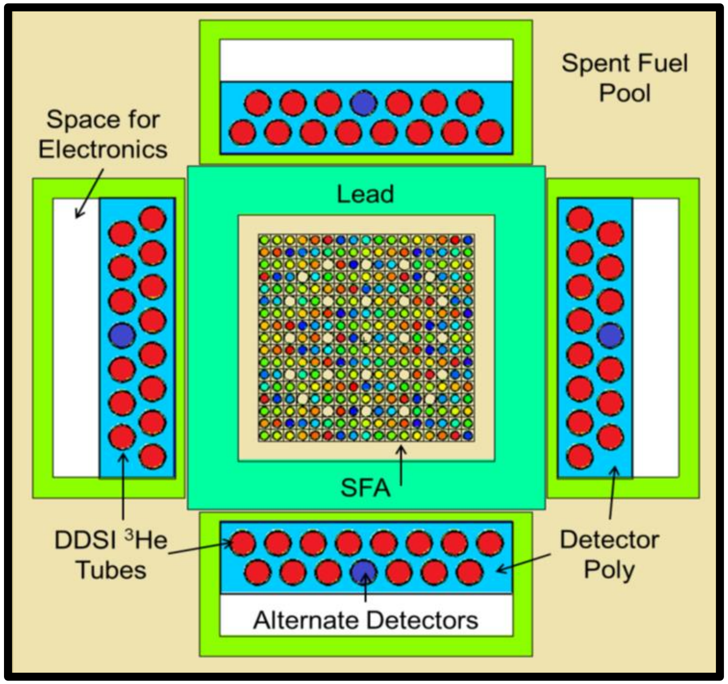
How DDSI Works

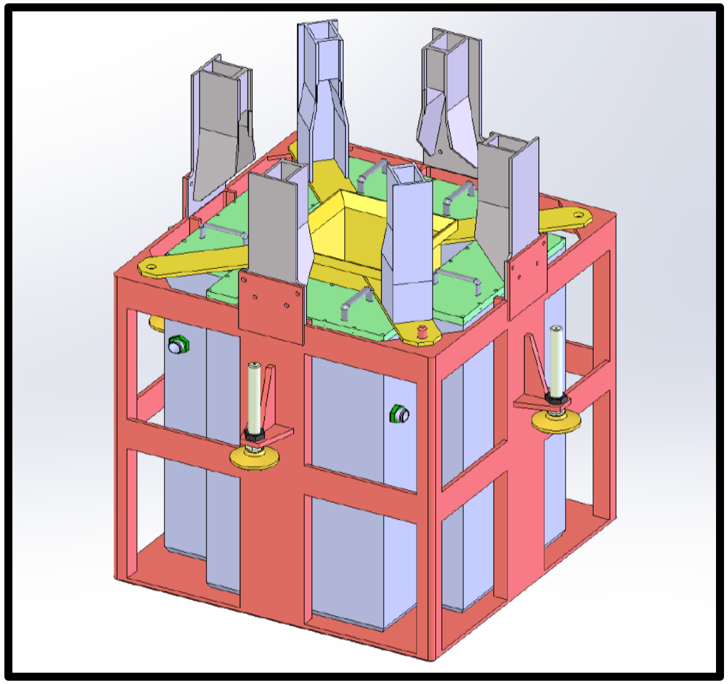
- Die-away time of the slow component along with the relative magnitudes of both components shape RAD and reflect system multiplication



Design

- 56 ^{3}He tubes, 4 detector pods, lead shield, centered assembly





- Air-filled insert for BWR assemblies

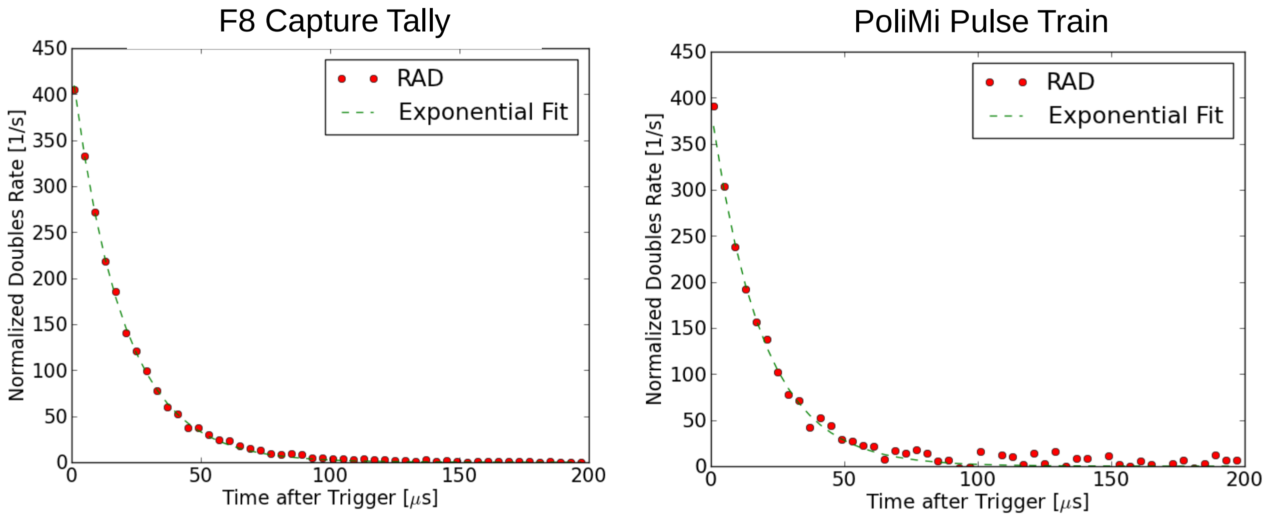
FY13: SFL Exploration

- We utilize 44 SFL2a assemblies to observe changes in parameters such as multiplication, fissile/fertile masses, fast/slow component shape
  - Initial Enrichment (IE): 2%, 3%, 4% and 5%
  - Burnup (BU): 15, 30, 45 and 60 GWd/tU
  - Cooling time (CT): 1, 5, 20, 80 years

  = 44 SFAs

FY13: Pulse Train Simulation

- MCNPX PTRAC capability and MCNPX-PoliMi used to produce pulse trains including accidentals
- Algorithms developed to build Rossi-alpha distributions from pulse trains
- Very good agreement between pulse train RAD and F8 capture tally RAD production (MCNPX approximation, free of accidentals)



DNNG
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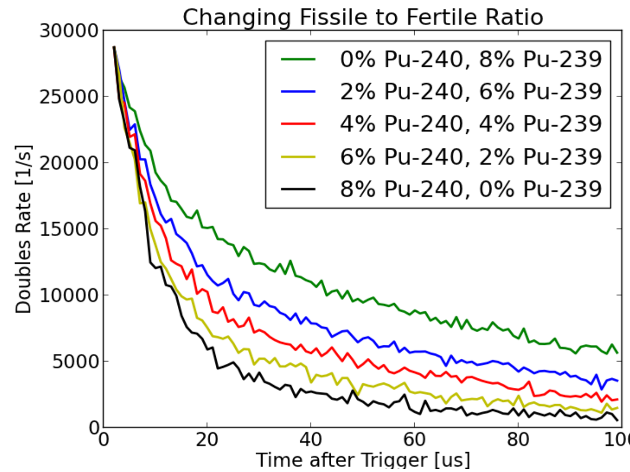
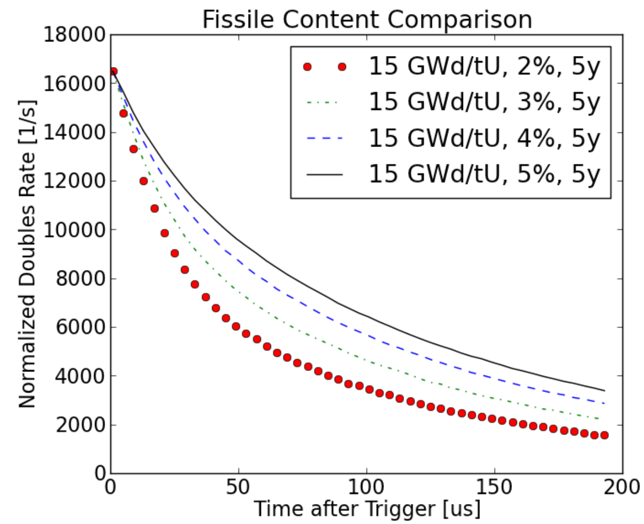
FY13: RAD Dependence on Fissile/Fertile

- The shape of the RAD is strongly affected by the fissile/fertile material
- Relative magnitude of the slow and fast components change with addition of fissile or fertile material, and change the shape of the RAD as a result
- Longer, slower die-away of slow component with more fissile material and fewer neutron absorbers



Homogenized Assemblies

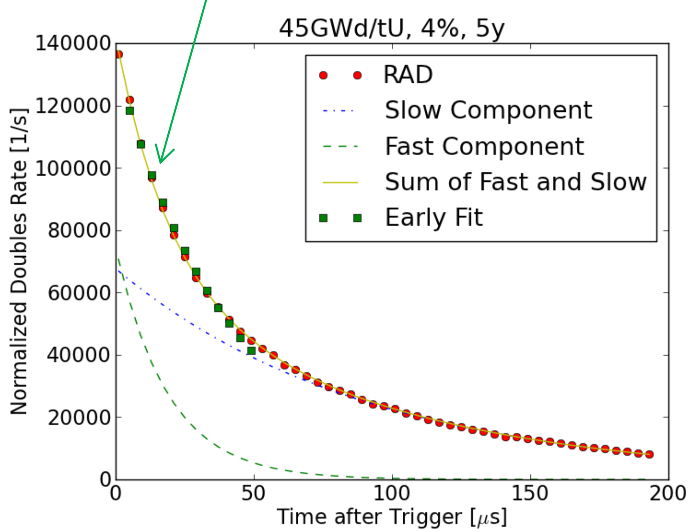


SFL-2a Assemblies

FY13: Determining Multiplication

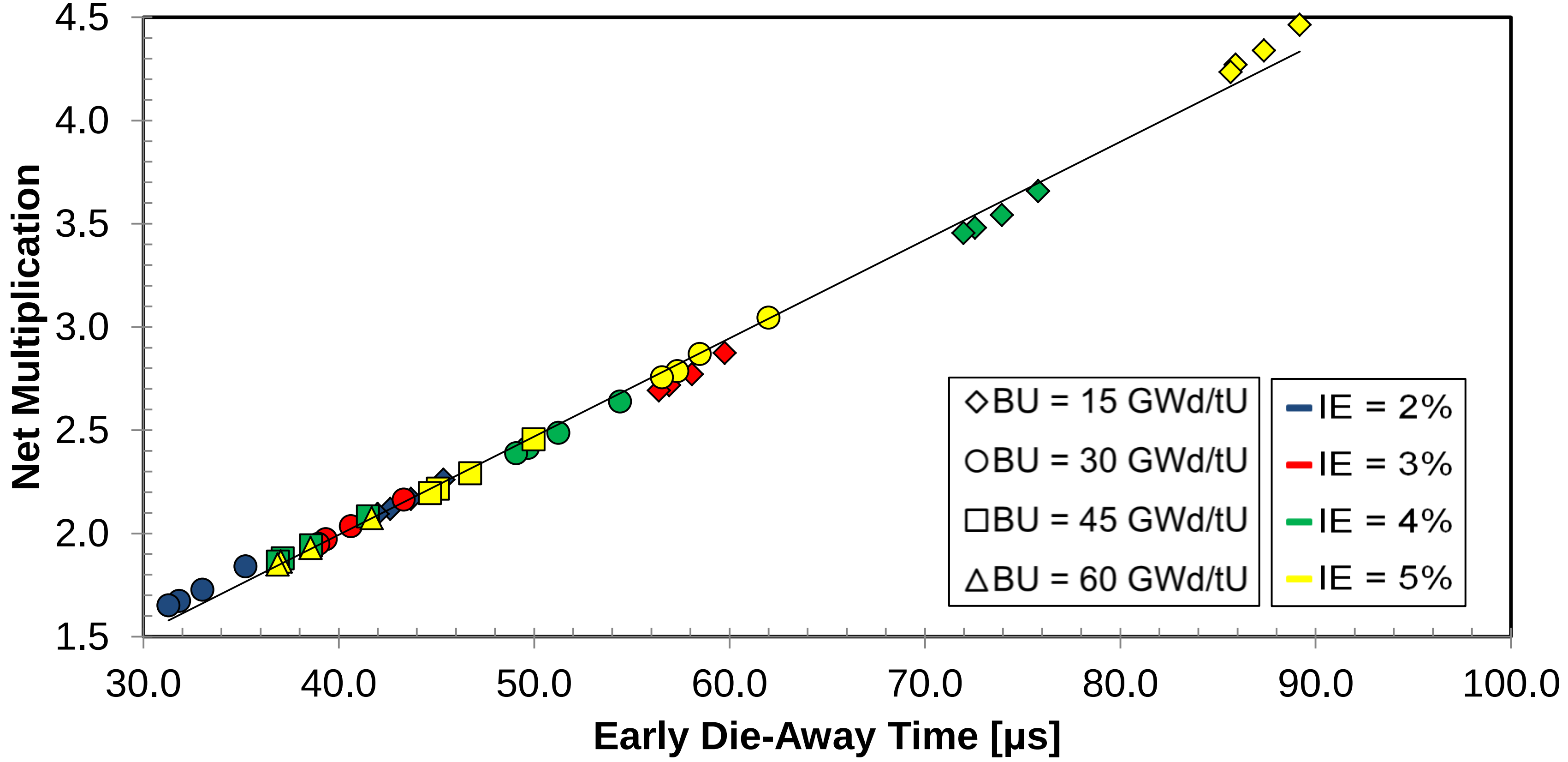
- Ratio of doubles count rate in a late gate over total counts (singles) has been used in the past, and is sensitive to (α,n) neutrons
- We found that a single exponential fit to the early time-domain of the RAD correlates very well with multiplication

Early die-away time domain



- Insensitive to neutrons from other sources besides spontaneous fission
- Improvement upon previously used method of Doubles/Singles to determine multiplication

FY13: Determining Multiplication



FY13: Determining Multiplication

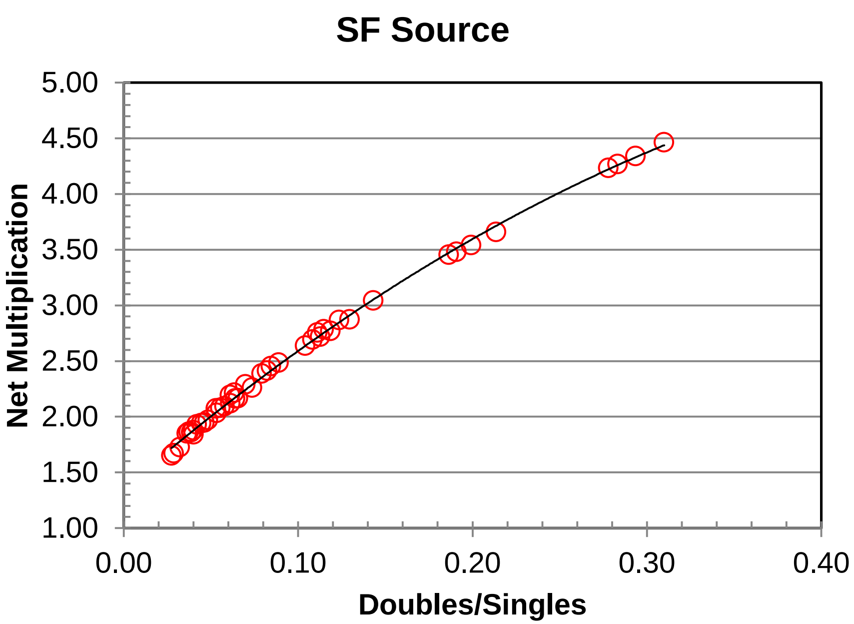
- The worst case for (α,n) influence is the 15 GWd/tU, 5% IE, 80 year cooled assembly with the highest alpha ratio of all SFL2a assemblies considered

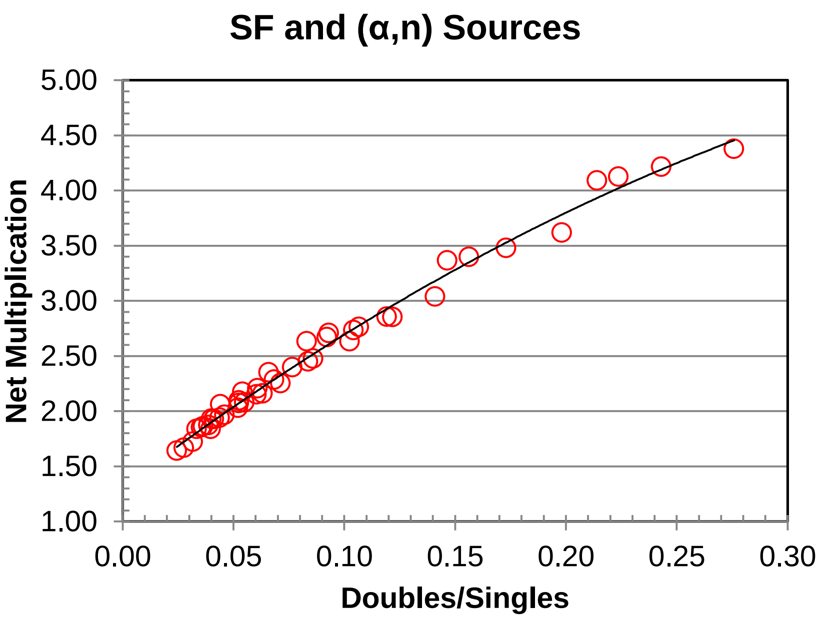
- Alpha ratio = $\frac{(\alpha,n) neutrons}{SF\ neutrons}$

	SF Source Only	(α,n) Source Only	Combined Sources
T_{early} [μs]	86	86	86
D/S	0.28	0.18	0.21

FY13: Determining Multiplication

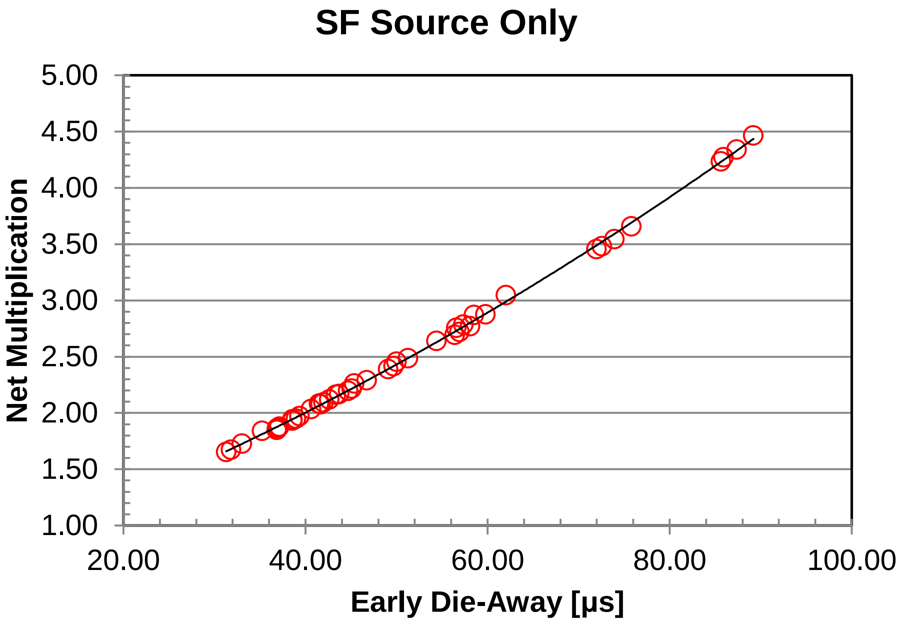
- D/S changes with SF or (α,n) source

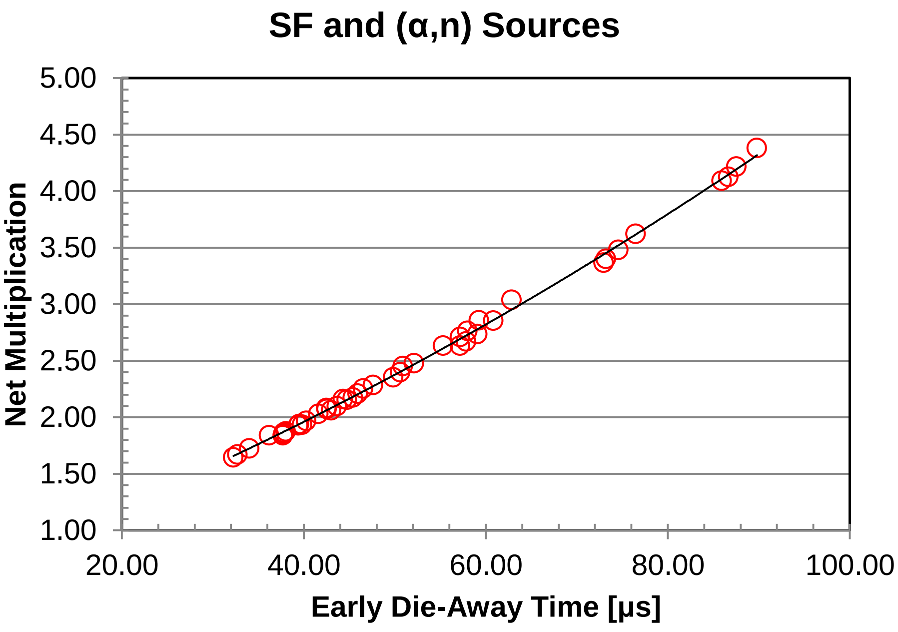




FY13: Determining Multiplication

- Early die-away **does not change** with SF or (α,n) source

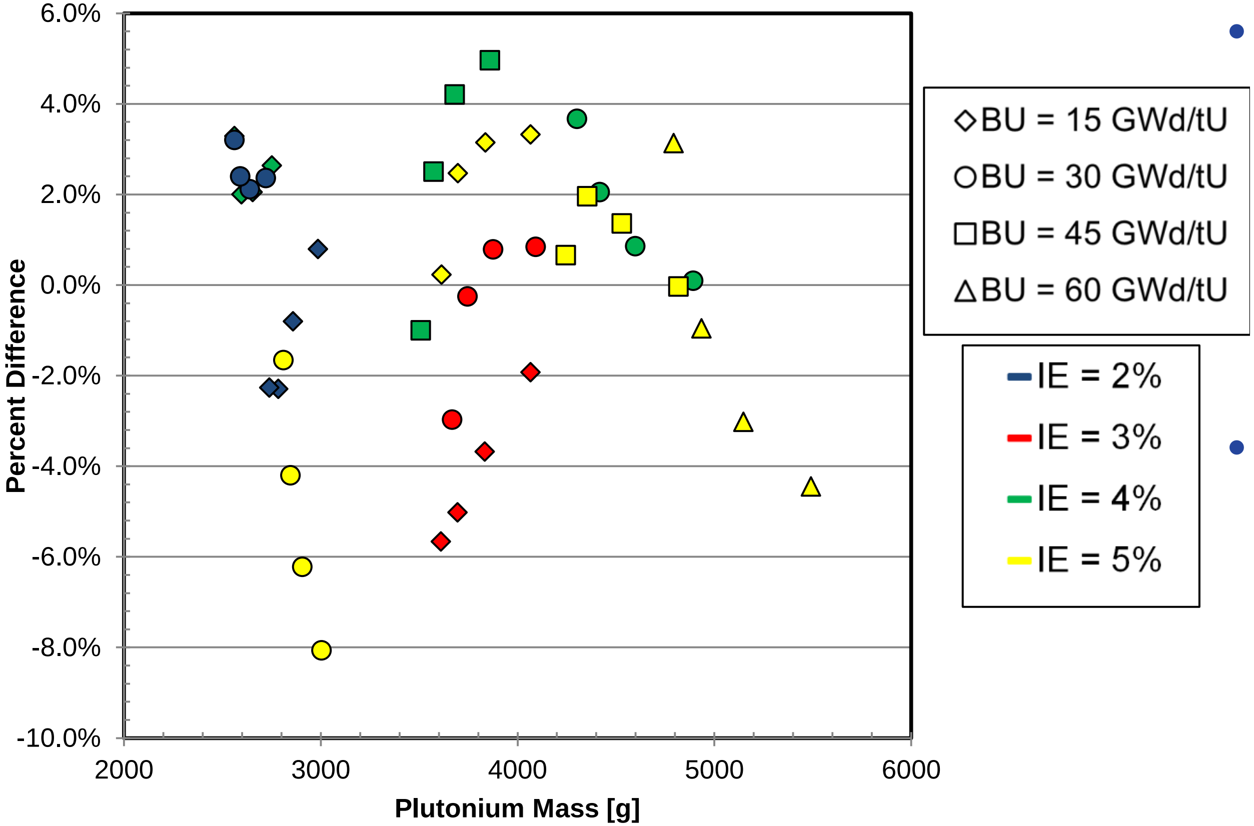




FY14: Total Pu Mass Determination

- Building upon DDA work on the same topic, we apply the same physics but utilize the early die-away time instead of multiplication, eliminating two calibration constants
- $M_{pu} = c(CT)\,\frac{\tau_{early}+2e}{\tau_{early}+e}\left(\frac{PN}{\tau_{early}+2e}\right)^{d(CT)}$
- Compute calibration constants c, d, and e
- Determine total Pu mass with mean variation of 2.5%

FY14: Total Pu Mass Determination



- For some IE/BU combinations, longer CT are more accurate. Others, short CT are more accurate.
- When Multiplication is used instead of early die-away, we find the same calibration constant as DDA

Upcoming work

- Simulate assemblies to be measured at CLAB
- Carry out experiments to validate simulations
- Work toward initial enrichment and burnup determination
- Partial defect detection with SFL6
- Simulate SFL 3 and 4 to verify multiplication and total Pu correlations for more unusual fuel assemblies
- Utilize isotope-specific pulse trains from homogenized assemblies to further develop discrimination ratio

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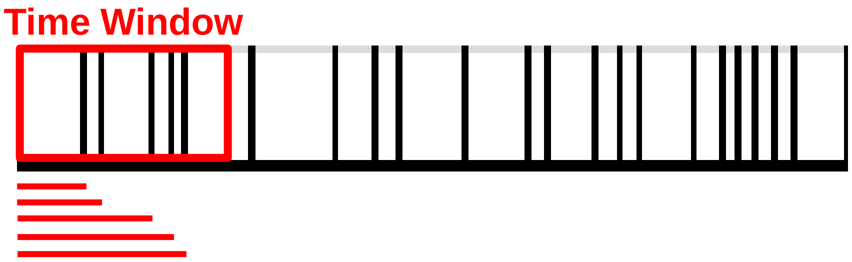
Bonus: Rossi-Alpha Distributions (RAD)

- By measuring the time of detection of neutrons following each trigger, a histogram is created that reflects correlations in the system



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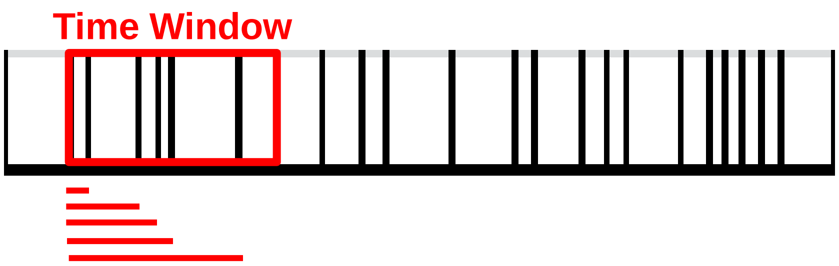
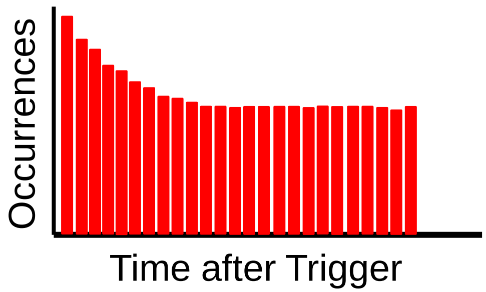


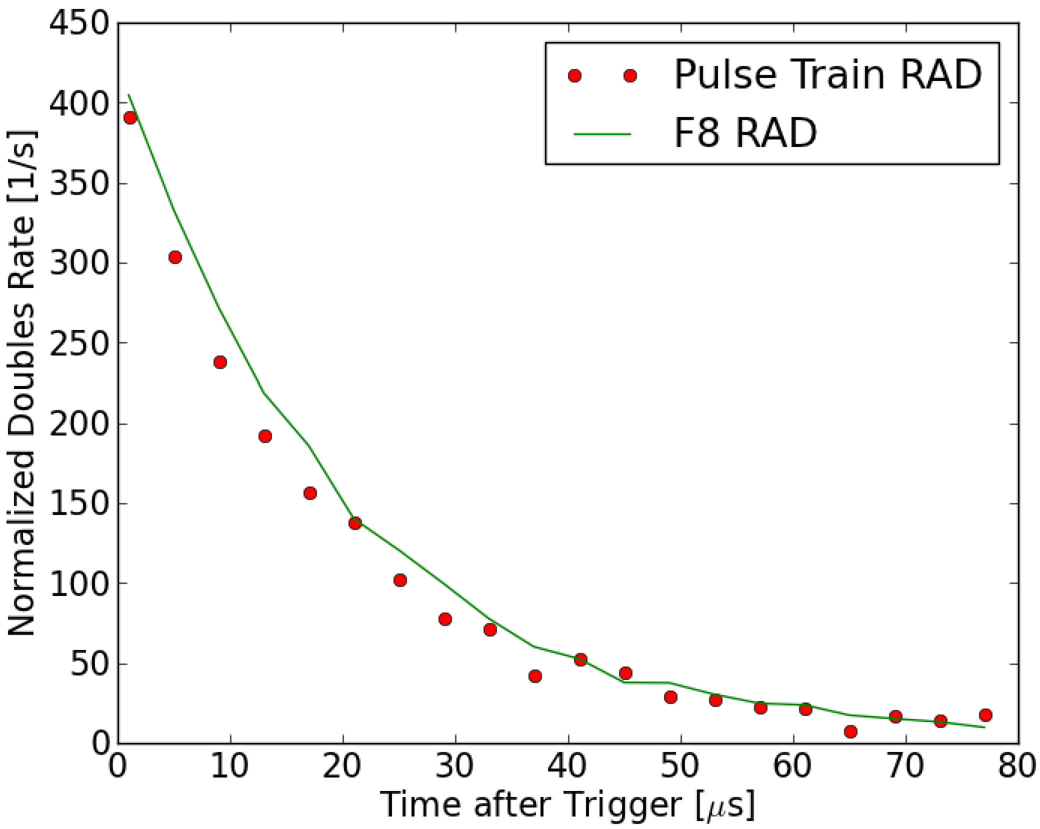


- This process repeats until adequate statistics are obtained
- If the arrival of the pulses is random, a flat distribution is created, but if correlations exist, the familiar shape of a RAD is produced

Bonus: Simulating Rossi-Alpha Distributions

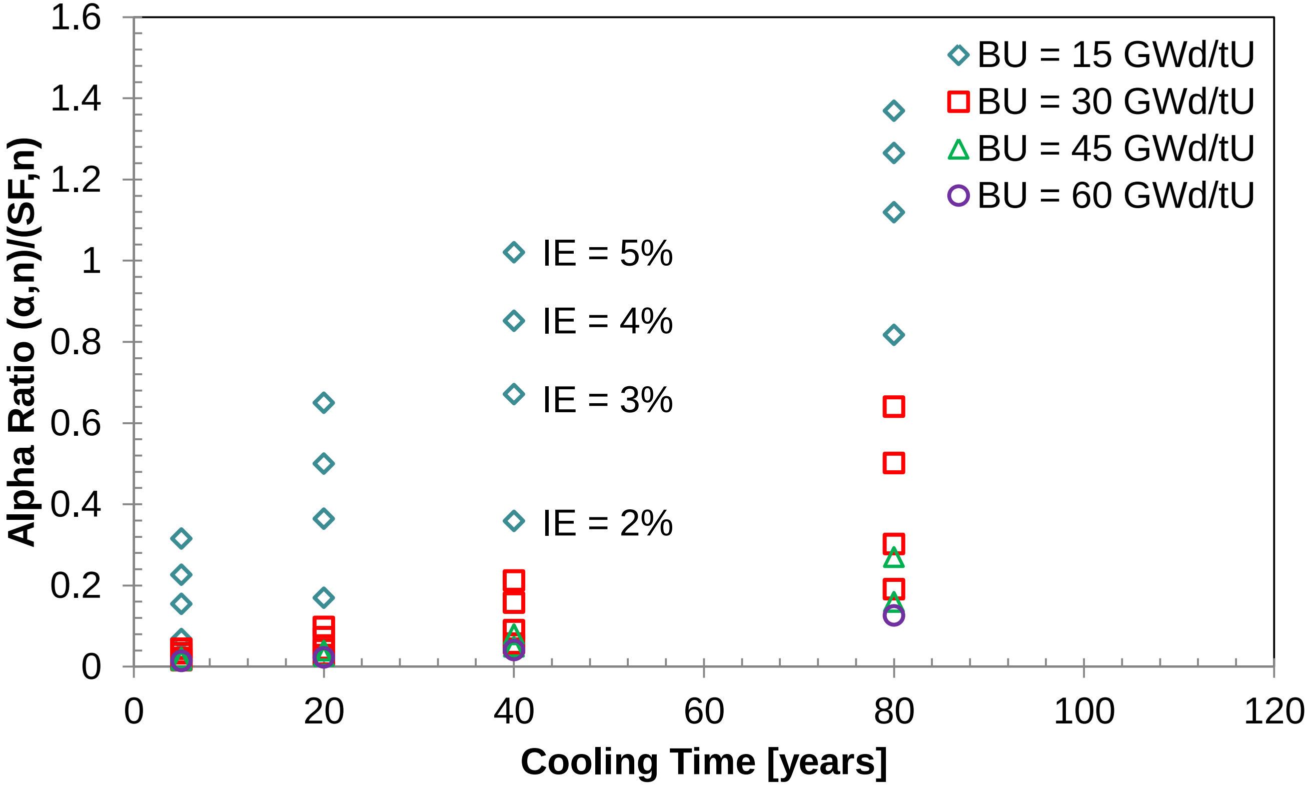
- Rossi-alpha distribution (RAD) is a histogram of times of coincident neutron captures following a trigger neutron capture
- In real life, this is filled with accidentals
- Simulate pulse train with PTRAC or PoliMi to make a RAD with accidentals, dead time, etc…
- Simulate RAD with MCNPX tally of structured, sequential "coincidence" gates that count neutron arrivals at certain times after trigger neutron. One history at a time = no accidentals

Bonus: Simulating Rossi-Alpha Distributions



- Agreement point-by-point is not excellent, die-away agreement is better
- 19.4 µs for F8 tally vs. 19.0 µs for PoliMi pulse train

Bonus: Alpha Ratio for SFL-2a



- Highest alpha ratio observed in cases with long CT, low BU, and high IE
- A.K.A. unusual cases

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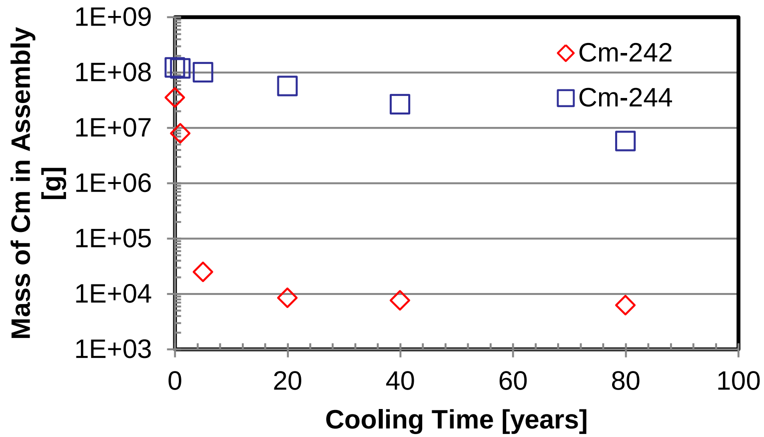
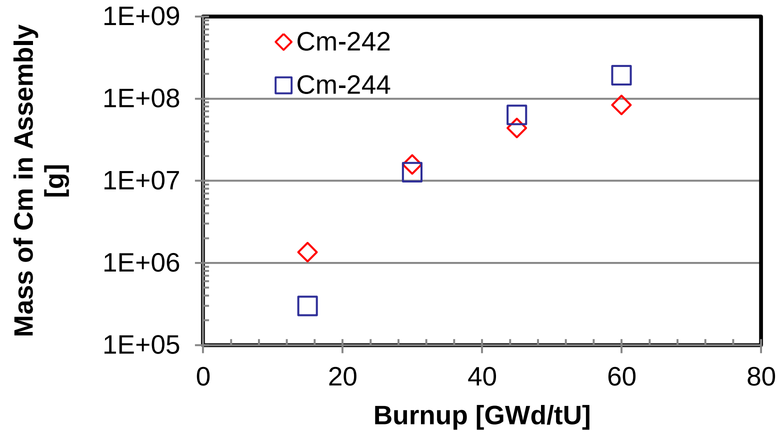
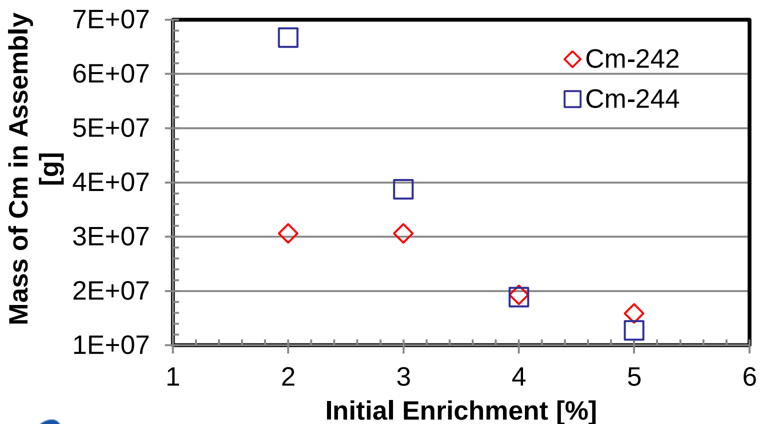
Bonus: Alpha Ratio for SFL-2a

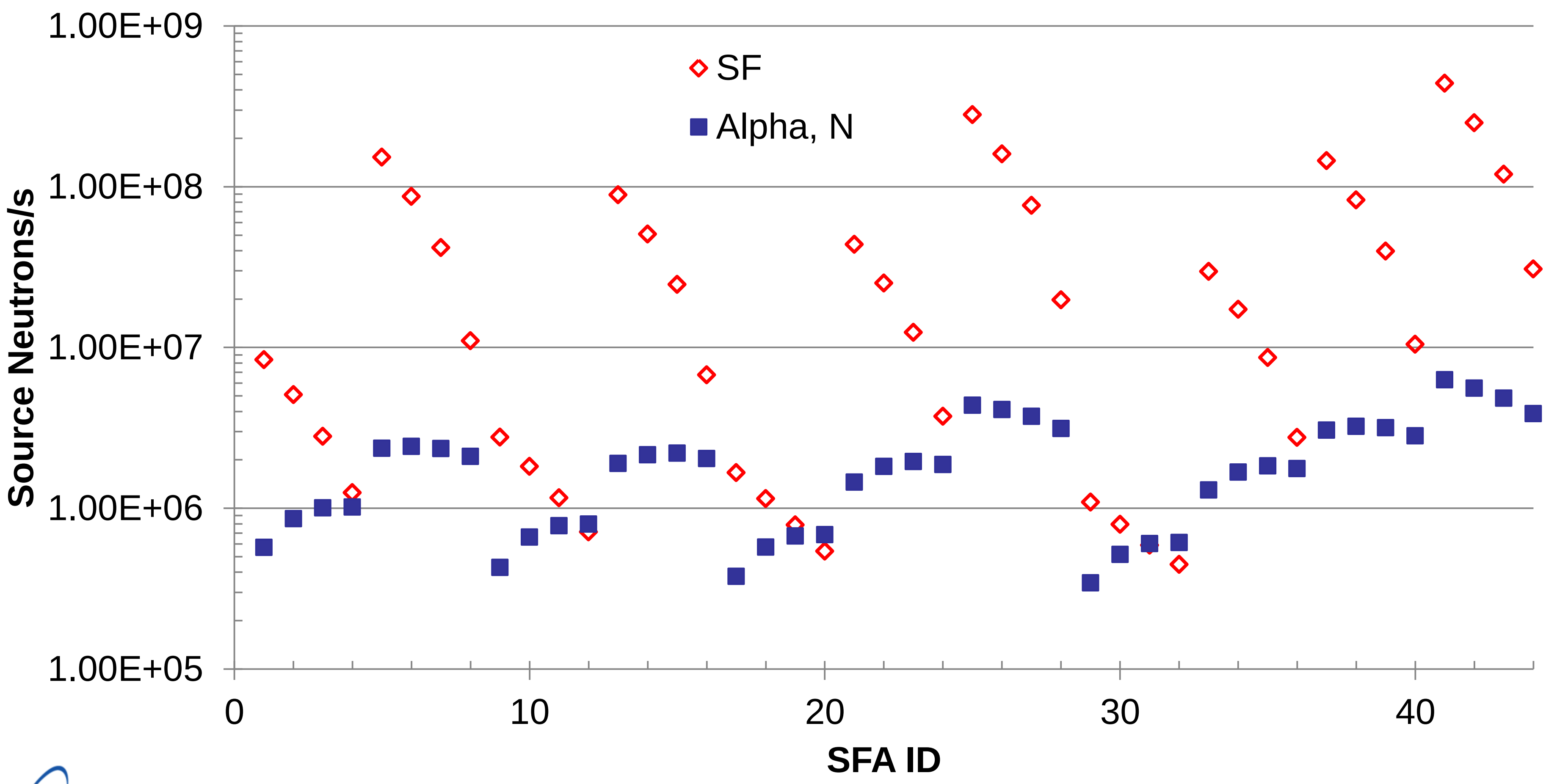




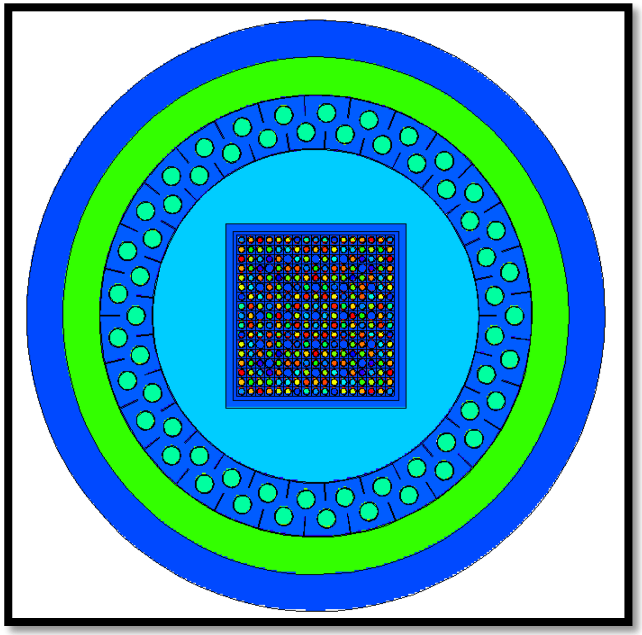


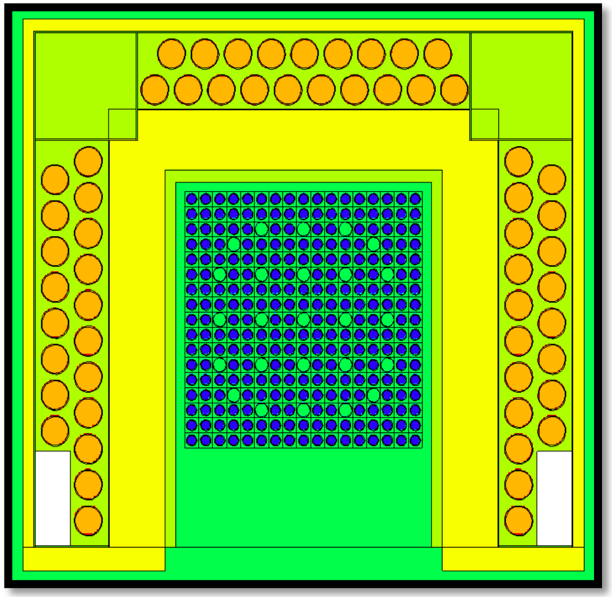
- LEAST Cm in cases with long CT, low BU, and high IE (same unusual cases)

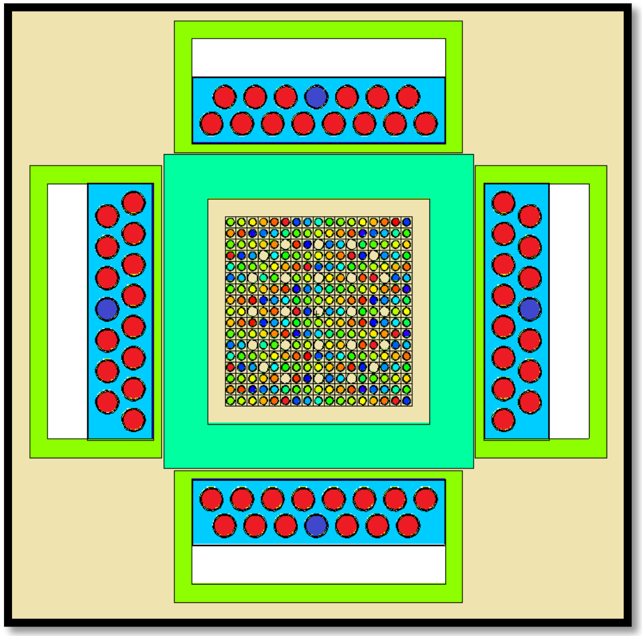
Bonus: Alpha Ratio for SFL-2a



Bonus: Evolution of Design







Bonus: PTRAC Example Output

History	Time [shakes]	Cell	Source	SF	1st fission	2nd fission	3rd fission	Last fission
6	7.25954E+04	1045	3	96244	94239	92235	94239	92238
6	1.40081E+04	1075	3	96244	94239	0	0	94239
33	5.50695E+02	1025	1	96244	0	0	0	96244
73	2.04089E+03	1075	1	96244	94239	0	0	94239
89	1.87530E+04	1045	2	96244	94239	92235	94241	92235
141	6.46086E+03	1075	1	96244	94241	94239	92235	92235
200	3.10552E+03	1005	2	96244	94239	94239	0	94239
239	1.00913E+03	1025	3	96244	0	0	0	96244
244	1.28950E+03	1045	2	96244	94239	0	0	94239
289	3.89959E+02	1025	3	96244	0	0	0	96244
334	2.21057E+04	1045	1	96244	94239	94239	94239	92235
341	5.21562E+04	1005	3	96244	94239	94239	0	94239
385	9.81907E+02	1075	1	96244	0	0	0	96244
396	1.21175E+04	1075	3	96244	92235	92235	94239	94239
396	2.67270E+04	1045	3	96244	92235	92235	92235	92235
396	1.09711E+03	1025	1	96244	94241	0	0	94241
396	8.16233E+02	1025	1	96244	94241	0	0	94241