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Title: COMPARISON OF 252CF TIME CORRELATED INDUCED FISSION WITH AmLi INDUCED FISSION ON FRESH MTR RESEARCH REACTOR FUEL

Author(s): Joshi, Jay Prakash

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COMPARISON OF ^{252}CF TIME CORRELATED INDUCED FISSION WITH AmLi INDUCED FISSION ON FRESH MTR RESEARCH REACTOR FUEL

Presented by Jay P Joshi
MS in Nuclear Engineering
Committee Members: Dr. Shoaib Usman, Advisor
Dr. Alexis C Trahan, LANL Mentor
Dr. Ayodeji Babatunde Alajo

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OUTLINE

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OBJECTIVES

- To calibrate Advanced Experimental Fuel Counter (AEFC)
  - ^{252}Cf in instead of traditional AmLi source
- To benchmark MCNP simulations using experimental results
- To investigate the effects of change in fuel assembly geometry to the count rates
- Finally, to show the boost in doubles count rates (coincidence rates) with ^{252}Cf active source due to the time correlated induced fission (TCIF) effect

MOTIVATION

- MTRs around the world
  - With both highly enriched uranium (HEU) and low enriched uranium (LEU) fuel
  - ^{235}U can be separated directly from HEU fuel and diverted to the weapons program
  - Countries where MTRs are installed were committed to non-proliferation and their commitment needed verification
- Difficulties to obtain AmLi source in the US
- Better doubles rates obtained with ^{252}Cf compared to AmLi in the past field trail in Uzbekistan in 2012 and 2014

INTRODUCTION

- The effective application of international safeguards to research reactors requires verification of spent fuel as well as fresh fuel.
- To accomplish this goal various nondestructive and destructive assay techniques have been developed in the US and around the world.
- The Advanced Experimental Fuel Counter (AEFC) is a nondestructive assay (NDA) system developed at Los Alamos National Laboratory (LANL). [1]

INTRODUCTION (CONTINUED)

- Both neutron and gamma measurement capabilities
- Spent fuel assemblies are stored in water
  - The system designed to be watertight to facilitate underwater measurements by inspectors. [1]

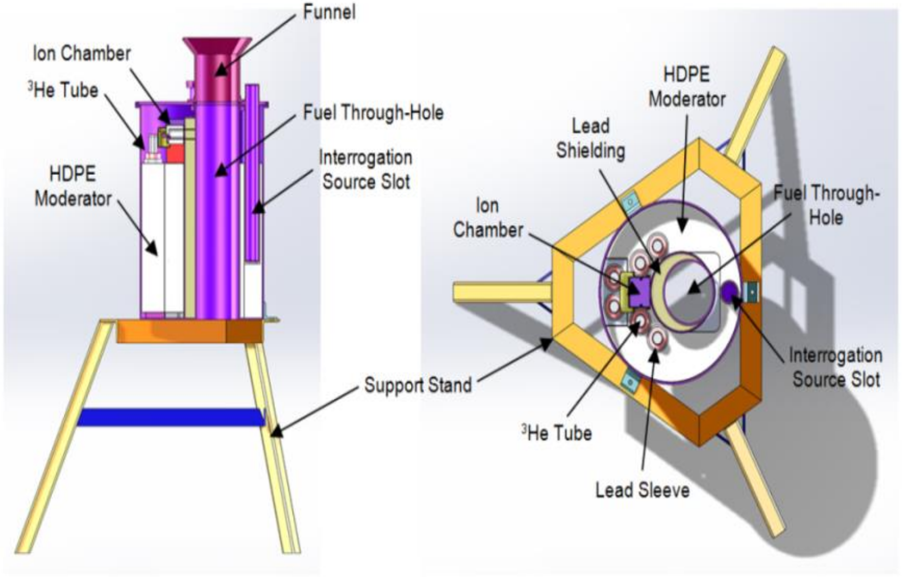

Figure 1: Mechanical design of the AEFC [1]

INTRODUCTION (CONTINUED)

- Six ^{3}He neutron detectors and one ion chamber for gross gamma measurement
- Detectors are shielded with lead for high gamma doses
- Collimator for ion chamber
- Neutrons are moderated by HDPE and water
- Both active and passive neutron interrogation capabilities
- Active neutron measurement provides information about residual fissile mass
- Passive neutron measurement provides BU, IE, and CT [1]

INTRODUCTION (CONTINUED)

- Passive gross gamma results provide information about BU, IE, and CT.
- In the past, active interrogation mostly used AmLi.
- In 2014 during the Uzbekistan field trail, AEFC was calibrated by ^{252}Cf.
- Results showed better doubles count rates with ^{252}Cf than AmLi. [2]
- Why would ^{252}Cf give better <u>coincidence</u> results?
- ^{252}Cf was supposed to be complex due to its time correlated SF neutrons.

INTRODUCTION (CONTINUED)

Neutron Coincidence Counting

- In the AEFC, two or more neutrons are coincident if they are detected by any of the six ^{3}He detectors within the specified gate window.
  - In this case, the gate window is 128 μsec.

No. of Neutrons	1	2	3	4	n
No. of Coincidences	0	1	3	6	n(n-1)/2

- The coincidences measured can come from accidentals from background and active source. [6]

INTRODUCTION (CONTINUED)

- Accidentals can be separated from the real coincidences from fuel.
- The process of separation is explained by the Rossi-Alpha distribution.

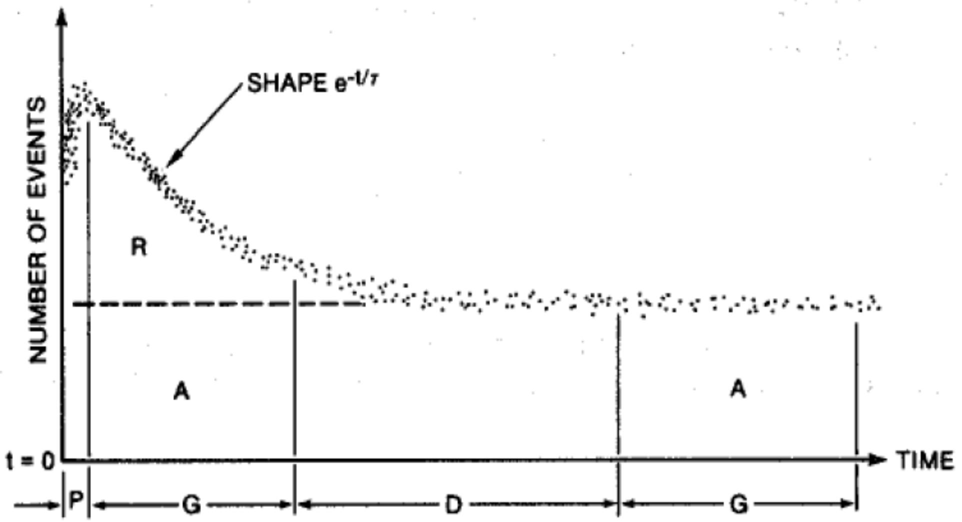

Figure 2: Rossi-Alpha distribution [5]

INTRODUCTION (CONTINUED)

- P is a pre-delay, G is a gate length, and D is a long delay gate[5]
- First neutron detected inside any of six ^{3}He detectors acts as a trigger and opens a time window.
- All neutrons detected within that specified time window are time correlated coincidences to the initial triggering neutron. [6]
- Subsequently, each neutron after the first triggering, neutron triggers its own window of equal time length and thus a distribution is produced. [6]

INTRODUCTION (CONTINUED)

- If a random source (AmLi) is measured, a flat distribution will be obtained.
- If a source that emits time correlated neutron (^{252}Cf) is measured, the distribution obtained will look like an exponential function given by

$$S(t) = A + Re^{-t/\tau}$$

- Where A is accidental coincidence and R is real coincidence [5]

INTRODUCTION (CONTINUED)

- Initially, coincidence counting concept was
  - source would produce random neutron
  - fuel would produce correlated neutron
  - net correlated neutrons from fuel itself
- However in the asymmetric system such as AEFC, ^{252}Cf gives better results. [2]
  - Very small source-detector efficiency
  - Negligible contribution from the background (active source)
- Experimental - The source-detector is over moderated and efficiency is less than 1%
  - Fuel gets in the source-detector line of sight
  - The efficiency reduces even more

INTRODUCTION (CONTINUED)

- MCNP - Fuel-detector efficiency is approximately 5%
- Effect of time correlated SF neutron background from ^{252}Cf is negligible.
- Average energy of Amli neutron 0.3 MeV is much lower than average energy of ^{252}Cf of 2.3 MeV.
- AmLi neutrons are thermalized much faster than ^{252}Cf neutrons.
- Probability of inducing fission in the fuel is much higher with AmLi.
- Once again, AmLi seems to be favorable to produce better coincidence results.

INTRODUCTION (CONTINUED)

- The reason why ^{252}Cf gives better coincidence results is

INTRODUCTION (CONTINUED)

Time Correlated Induced Fission (TCIF) Effect

INTRODUCTION (CONTINUED)

- Term was brought up by Dr. Howard Menlove at the LANL.
- Related to the neutrons emitted in IF event from the fuel assembly coupled to the neutrons produced in a precursor fission event in an active interrogation source
- SF neutron from active source are time correlated with the IF neutron from the fuel.
- Combined multiplicity is higher with ^{252}Cf.
- Only one IF event is possible per random (α,n)reaction with AmLi.

INTRODUCTION (CONTINUED)

- More than one IF per SF event with ^{252}Cf
- Boost in doubles rate is due to the boost in combined multiplicity due to the TCIF effect of ^{252}Cf.

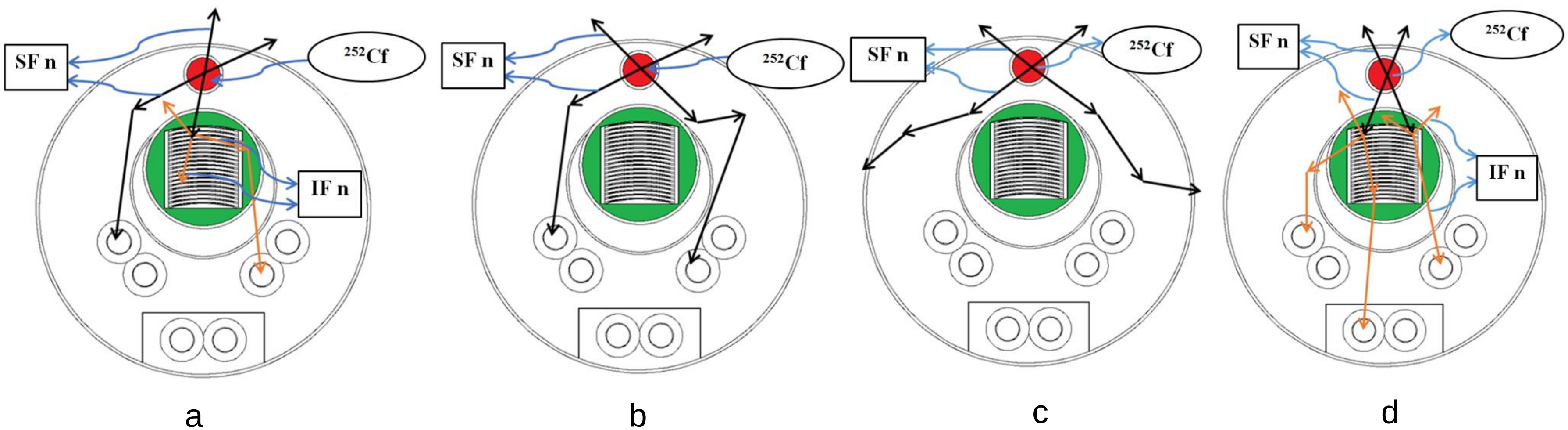

Figure 3: Possible neutron detection scenarios with ^{252}Cf active sources

MATERIALS USED

- Clean AEFC system
- Water tank
- Crane to move AEFC and fuel assembly
- JSR-15 Shift Register
  - HV: 1680 V
  - Pre-delay: 4.5 µsec
  - R+A or A Gate: 128 µsec
- Laptop with INCC
- L-108 and O-187R, MTR type fresh fuel assemblies
- ^{252}Cf (A7866)- 45,670 n/s
- ^{252}Cf (A7869)- 170,695 n/s
- AmLi (N-165) – 37,940 n/s

MATERIALS USED (CONTINUED)

- Key Dimensions
  - Full Assembly (FA) L-108:108 cm long , while 60 cm active fuel meat
  - Partial Assembly (PA) O-187R: 90 cm long, while 60 cm active fuel meat
  - AEFC
    - Height: 112 cm
    - Axial center of ^{3}He detectors at 67.67 cm above the base of the tank
    - Fuel through hole diameter: 12 cm
    - Length of ^{3}He detectors: 25 cm

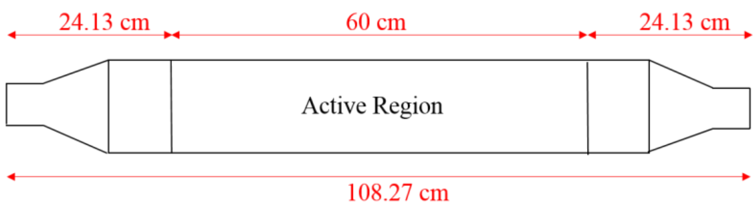

Figure 4: MTR fuel assembly

MATERIALS USED (CONTINUED)

- Water Tank Dimensions

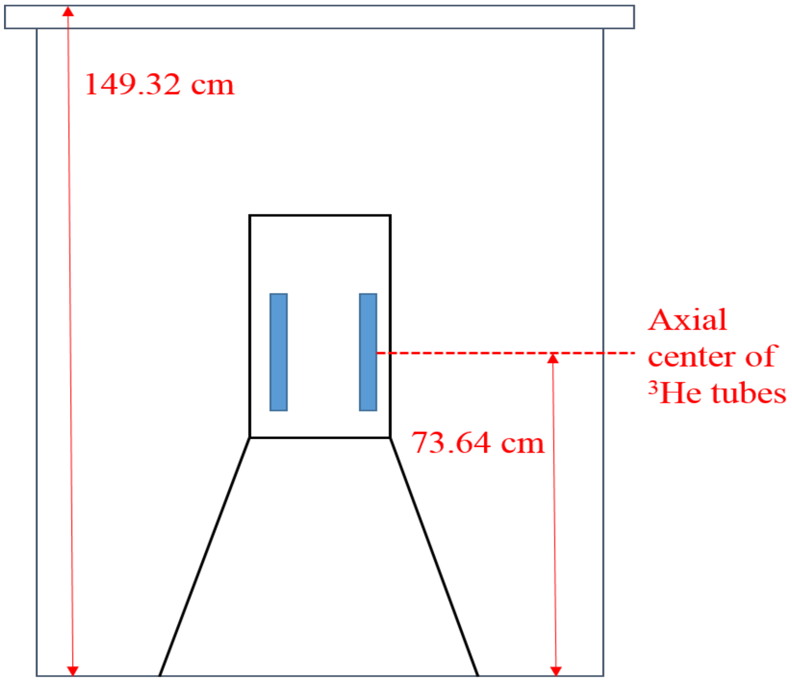

Figure 5: AEFC inside poly water tank

MATERIALS USED (CONTINUED)

Figure 6: AEFC outside the water tank

Figure 7: AEFC + MTR inside water [4]

Figure 8: O-187R MTR fuel assembly

METHODOLOGY

Experimental Measurement Procedure

- FA-^{252}Cf measurements :
  - Completely lowered to the base of the water tank
  - 23 point measurements:3 cm increment axially upward each time
  - Mid point measurement (13.67 cm above the base of the water tank)
  - Mid point measurement: fuel assembly rotated 90 degree
  - Bottom point measurement: 18 cm below the mid point measurement configuration
- FA-AmLi Measurements:
  - Mid point measurement: AmLi

METHODOLOGY (CONTINUED)

- PA-^{252}Cf measurements :
  - Mid point measurement (31.32 cm above the base of the water tank)
  - Mid point measurement: fuel assembly rotated 90 degree
  - Top and Bottom point measurement: 18 cm above and below the mid point measurement configuration
- PA-AmLi Measurements:
  - Mid point measurement: AmLi

METHODOLOGY (CONTINUED)

- MTR fuel plates in fabricated fuel holder:
  - Mid point measurement: varying fuel plates with ^{252}Cf(A7869)
  - With 1, 8, and 9 plates

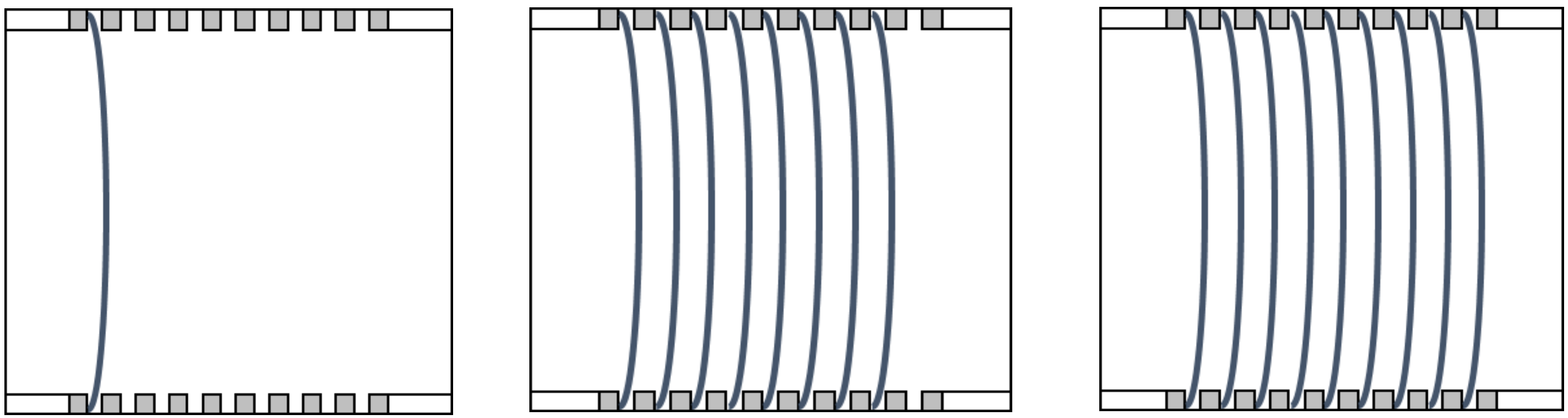

Figure 9: Varying Fuel plates in a fuel holder

METHODOLOGY (CONTINUED)

MCNP Simulation Procedure

- Replicated experiments
- Additional simulations
  - Varying fuel plates: 4, 6, 8,10,….18, 19 plates
  - Varying enrichment: 20% to 93.5%

RESULTS AND ANALYSIS

- Count rates normalized to ^{252}Cf(A7866)
- FA Benchmarking
  - Singles (S): within 5% up to 30 cm
  - Doubles (D): within 4% up to 30 cm
  - S and D diverging after 30 cm
  - $3 * \sigma$ error bars

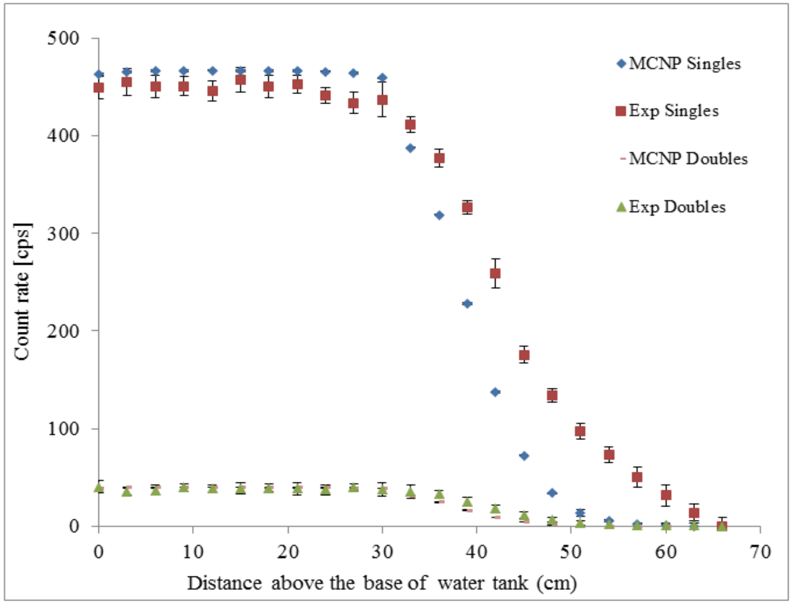

Figure 10: L-108 scan with ^{252}Cf SF source

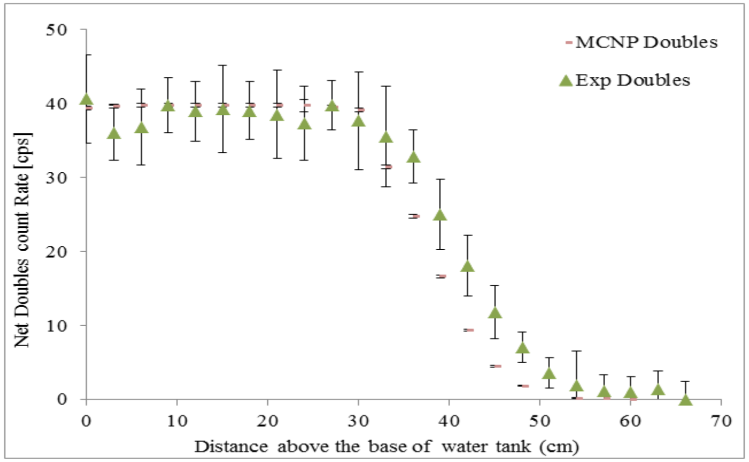

Figure 11: L-108 net doubles count rates

RESULTS AND ANALYSIS (CONTINUED)

- PA Benchmarking
  - Singles within 25%
  - Doubles within 3%
  - $3 * \sigma$ error bars

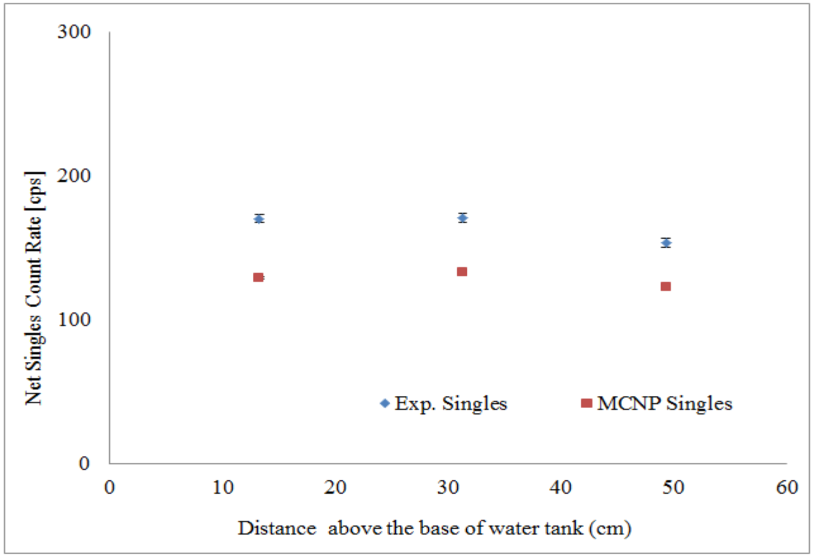

Figure 12: Three-point scan singles count rates

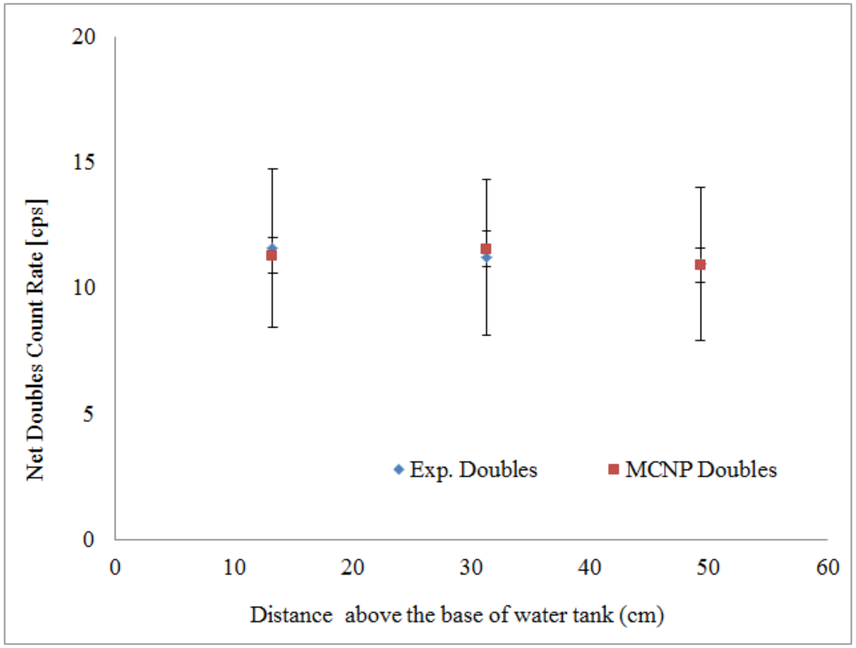

Figure 13: Three-point scan doubles count rates

RESULTS AND ANALYSIS (CONTINUED)

- AECF Calibration
  - S and D count rates vs residual fissile mass
  - Linear fit: Exp. varying plates singles and MCNP varying plate singles
  - 2nd degree poly – concave down: MCNP varying enrichment singles
  - Linear fit: Exp. varying plate doubles and MCNP varying plates doubles
  - 2nd degree poly – concave down: MCNP varying enrichment doubles

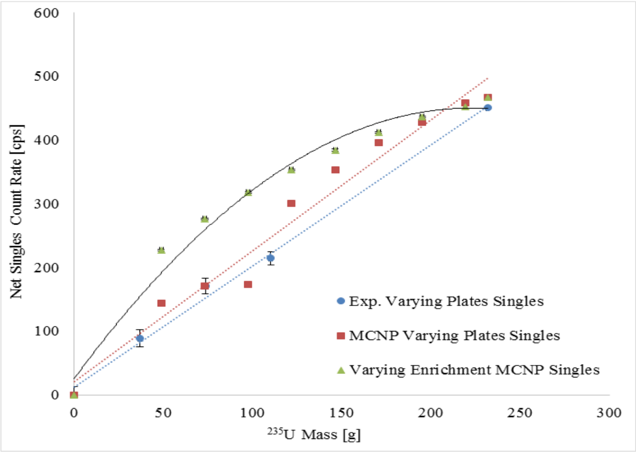

Figure 14: Singles count rate calibration

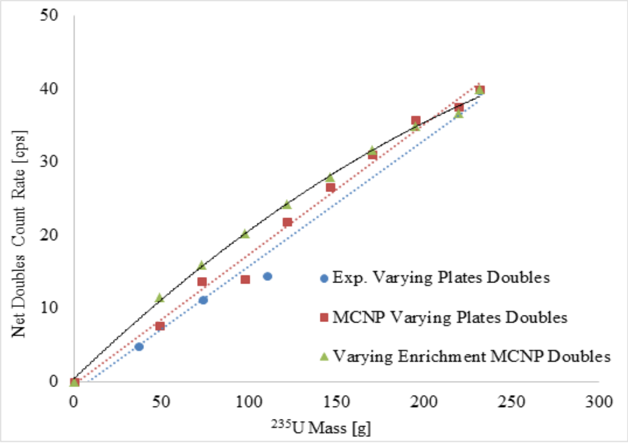

Figure 15: Doubles count rates calibration

RESULTS AND ANALYSIS (CONTINUED)

- AECF Calibration
  - Singles, varying fuel plates Exp. and MCNP results, agree within 5%
  - Doubles within 20%
  - Higher count rates with varying enrichment in the middle
    - Higher ^{238}U content
    - ^{235}U self shielding higher than ^{238}U

RESULTS AND ANALYSIS (CONTINUED)

- AECF singles calibration with ^{252}Cf vs AmLi- MCNP Results
  - Comparison of top, middle, bottom, and average singles
  - All agree within 5% with average
  - Homogenous distribution of ^{235}U in fresh fuel
  - In burned fuel, ^{235}U content is lowest in the middle compared to top and bottom
  - Helps distinguish fresh and used fuel
  - Normalized net singles: 31% higher with AmLi

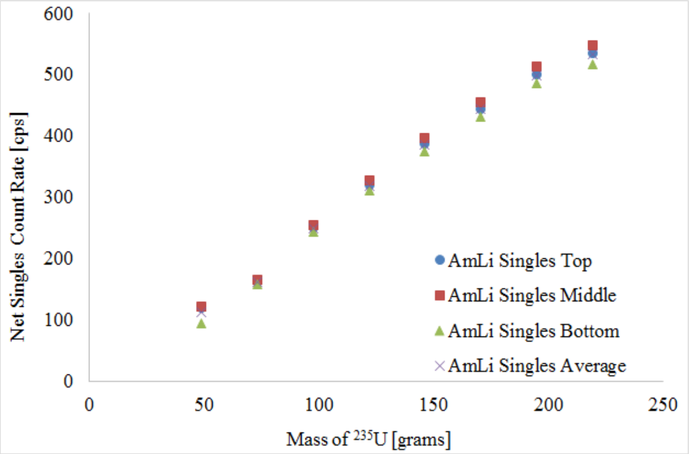

Figure 16: Singles calibration with AmLi source

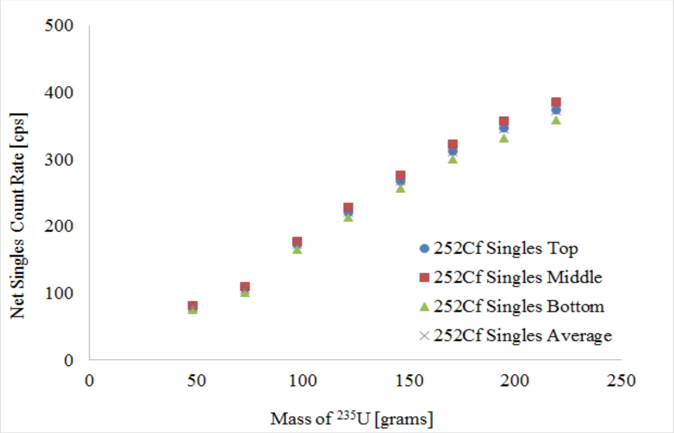

Figure 17: Singles calibration with ^{252}Cf source

RESULTS AND ANALYSIS (CONTINUED)

- AECF doubles calibration with ^{252}Cf vs AmLi- MCNP Results
  - Comparison of top, middle, bottom, and average doubles
  - All agree within 4% with average
  - Normalized net doubles: 22 higher with ^{252}Cf

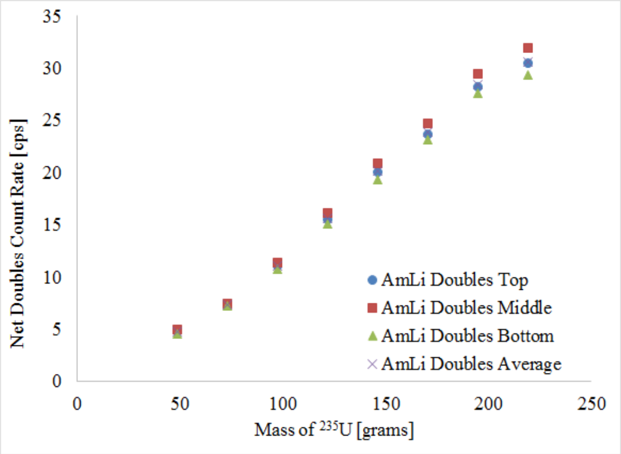

Figure 18: Doubles calibration with ^{252}Cf source

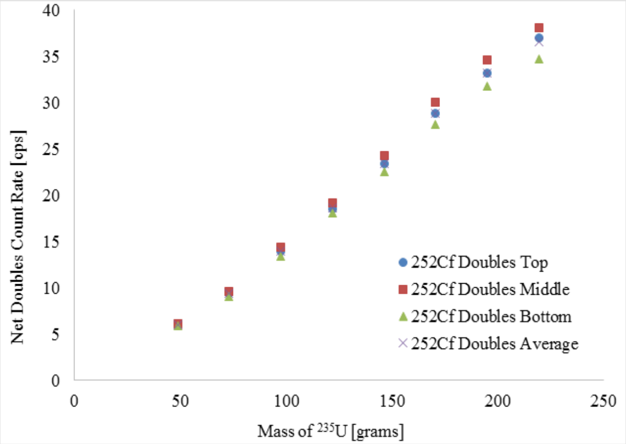

Figure 19: Doubles calibration with ^{252}Cf source

RESULTS AND ANALYSIS (CONTINUED)

	Singles	Doubles
Exp Original Configuration (FA)	450.71±3.41	39.78±1.34
Exp 90 deg rotated Configuration (FA)	427.35±1.95	38.38±0.69
Exp Original Configuration (PA)	170.54±1.025	11.21±0.334
Exp 90 deg rotated Configuration (PA)	154.07±1.621	10.99±0.424

- Comparison of count rates when geometry of fuel assembly is changed
  - FA: 5.18% fewer singles and 3.52% fewer doubles when rotated
  - Approximately $7 * \sigma$ for singles and $2 * \sigma$ for doubles
  - PA: 9.7% fewer singles and 1.96% fewer doubles when rotated
  - Approximately $16 * \sigma$ for singles and $1 * \sigma$ for doubles
  - More data is needed for confirmation
  - Bigger change in singles rate, while marginal change in doubles
  - The change needs to be accounted in verification measurements

RESULTS AND ANALYSIS (CONTINUED)

- Experimental

	AmLi, N-165	^{252}Cf, A7-866
Singles IF/Source	1.19E-02	9.70E-03
Doubles IF/Source	7.18E-04	8.36E-04

Source	Doubles IF/Singles IF
AmLi, N-165	6.03E-02
^{252}Cf, A7-866	8.62E-02

- MCNP

	AmLi, N-165	^{252}Cf, A7-866
Singles IF/Source	1.14E-02	9.88E-03
Doubles IF/Source	6.91E-04	1.01E-03

Source	Doubles IF/Singles IF
AmLi, N-165	6.02E-02
^{252}Cf, A7-866	1.01E-01

CONCLUSION

- The singles and doubles rates in MCNP benchmarking agreed mostly within 5% and 4% respectively
- Calibration showed experimental and MCNP varying fuel plate singles agreed within 5% and doubles agree within 20%
- The varying enrichment curve showed higher count rates due to the lower self shielding of ^{238}U compared to ^{235}U and larges effects of water
- Singles and doubles of top, middle, and bottom measurements agree within 5% and 4% respectively with the average
- Measurements with 90 deg rotated assembly showed singles count rates as a function of geometry
- Normalized AmLi singles 1.23 times higher than singles from ^{252}Cf
- Normalized AmLi doubles 1.18 times lower than doubles from ^{252}Cf

CONCLUSION (CONTINUED)

- Although ^{252}Cf produced roughly 20% less singles than AmLi, there were more correlated neutrons within those single to result 17% higher doubles rates.
- The boost in the doubles count rates with ^{252}Cf due to the boost in induced fission event due to the TCIF effect
- For future work, an experimental calibration of the AEFC with the fresh fuel containing higher percentage of ^{238}U on average and varying ^{235}U enrichment could be performed.
- The AEFC could be calibrated with fresh fuel rods containing various concentrations of GdO_3 poison rods to simulate fission product absorption.

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Questions ?