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Title: Neutron Collar Evolution and Fresh PWR Assembly Measurements with a New Fast Neutron Passive Collar

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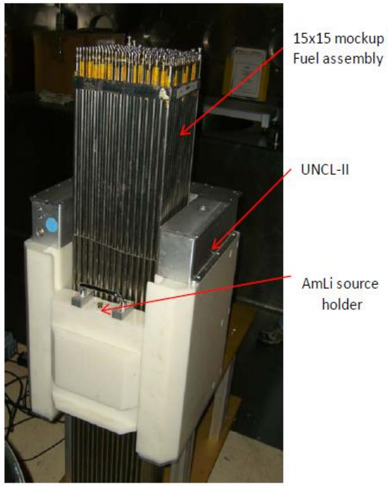
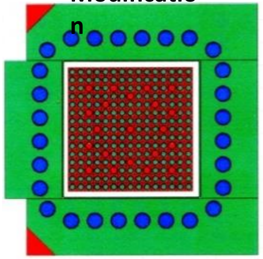
Neutron Collar Evolution and Fresh PWR Assembly Measurements with a New Fast Neutron Passive Collar



Passive UNCL Modification



H. O. Menlove, A. P. Belian, W. C. Geist, M. Root, and C. D. Rael

Los Alamos National Laboratory

Topics - Yesterday to Tomorrow

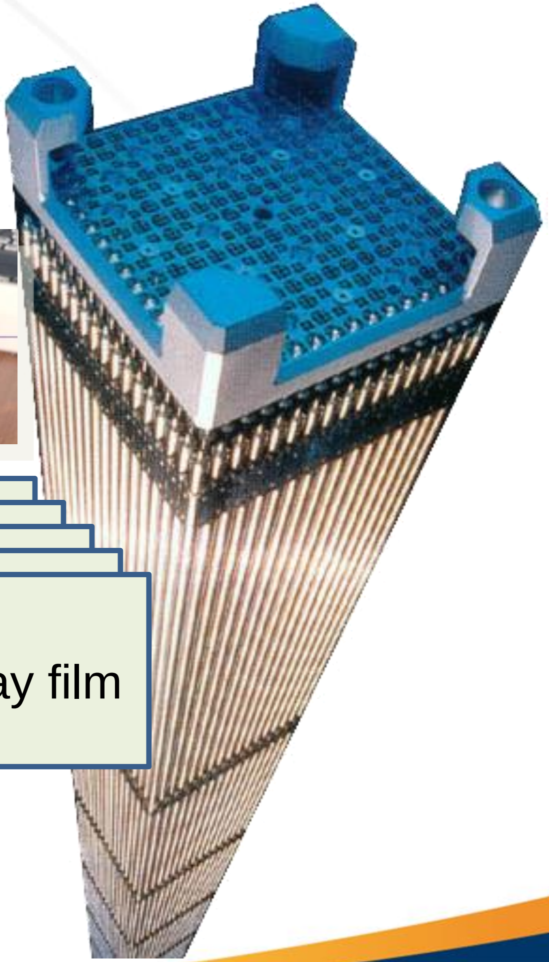
- Evolution of the measurement approaches for fresh LWR fuel assemblies (~ 40y)
- Fast-neutron interrogation and fast or thermal neutron detection
- Passive neutron method
  - Fast-neutron interrogation (hard spectrum)
  - Thermal-neutron detectors

IAEA 1977 Status for LWR Fuel Assembly Verification

A. Keddar IAEA 1978

Enrichment Meter
for surface
+
X-ray film for interior

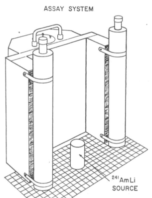
HM-5 current IAEA enrichment

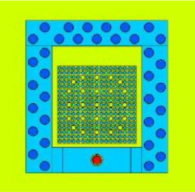


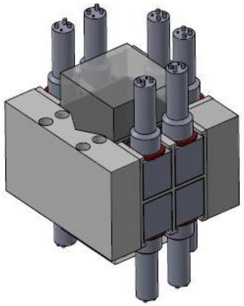
X-ray film

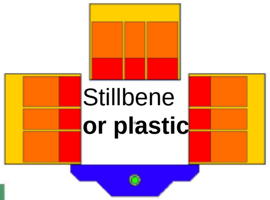
UNCL System Evolution (40y)

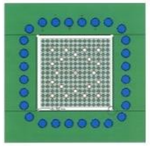
- 1978 ^{4}He gas (18 bar) fast-neutron detector
- 1979 UNCL coincidence using AmLi neutron source
- 1990 UNCL-II higher efficiency model (12%)
- 2012 IAEA fast-neutron (Cd) high pressure ^{3}He
- 2014 IAEA fast-neutron liquid scintillator detector
  - Uses 2 or 4 AmLi sources (Levitas and T.H. Lee)
- 2015 EFC EURATOM fast-neutron ^{3}He 10 bar
  - Uses 1 AmLi source (Cd lined)
- 2016 Neutron Collar Rodeo several scintillator based systems modeled with MCNP using AmLi (5 labs)
- 2017 Fast Neutron Passive Collar (FNPC) (no AmLi)





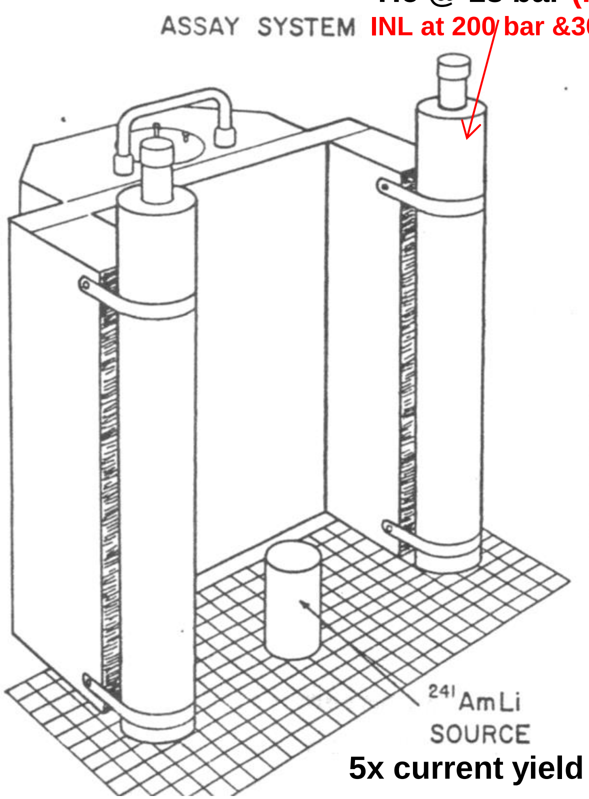






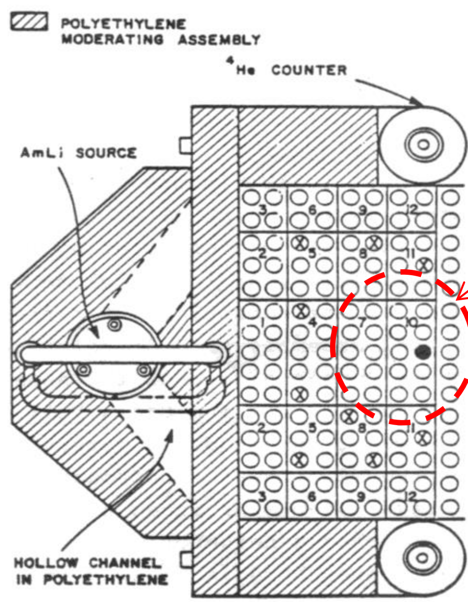
1978 Portable Active Neutron Interrogation Sysytem for LWR Fuel Assemblies
Brandenberger and Menlove, LA-7528-M

Fast-neutron detectors
^{4}He @ 18 bar (no Cd)
INL at 200 bar &30 tubes

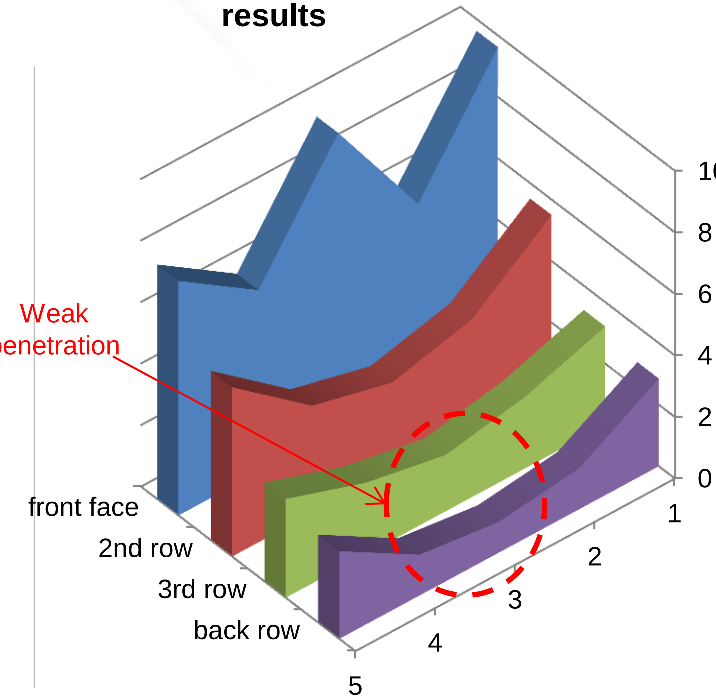


5x current yield

Penetration measurements

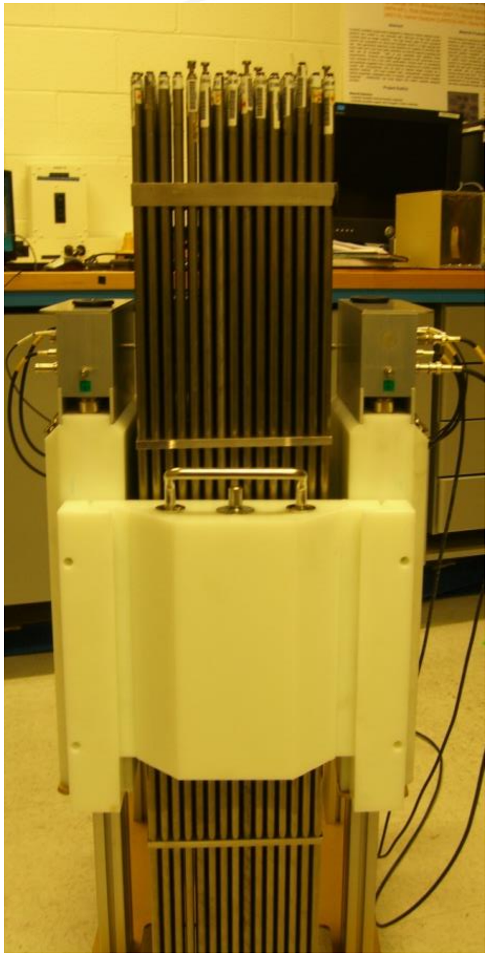


Penetration results



- *Problems of high AmLi strength and poor penetrability (one unit delivered to IAEA – still at IAEA)*

1980 UNCL-1 used by IAEA



UNCL-1

- 1st active neutron coincidence mode
- Based on AWCC detector physics
- 18 3He tubes at 4 bar pressure
- Efficiency ~ 9-10%
- Introduced prior to poison rod use
- Exrensive penetration studies

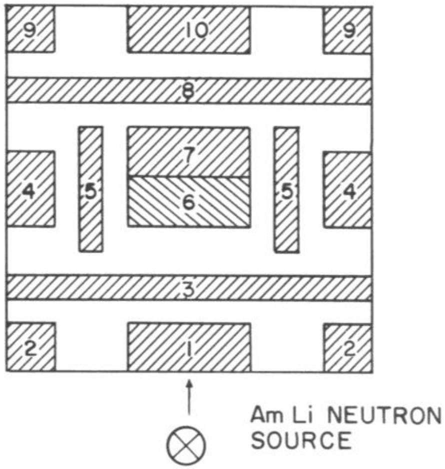
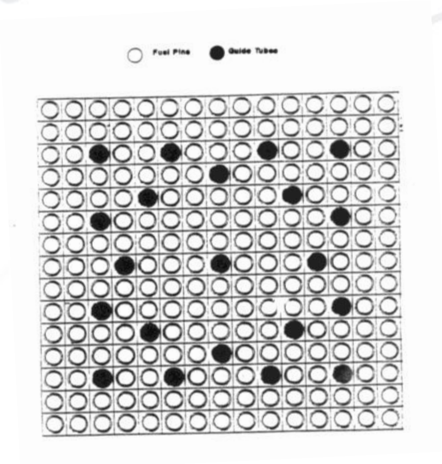


TABLE A-1. Rod Substitution Sensitivity

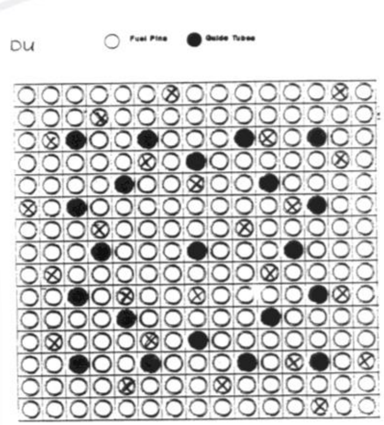
Substitution Location	Empty Rod (%/rod)	Iron Rod (%/rod)	DU Rod (%/rod)
1	0.35	1.68	0.40
2	0.64	1.25	0.46
3	0.41	0.71	0.34
4	0.41	0.62	0.32
5	0.54	0.53	0.21
6	0.57	0.51	0.20
7	0.53	0.44	0.20
8	0.36	0.32	0.21
9	0.48	0.60	0.25
10	0.46	0.47	0.36
Av	0.48	0.71	0.30

1989 SP-1 report, ISPO No. 301, IAEA Task No. A.154
(for center sensitivity for DU pins – Required by IAEA)

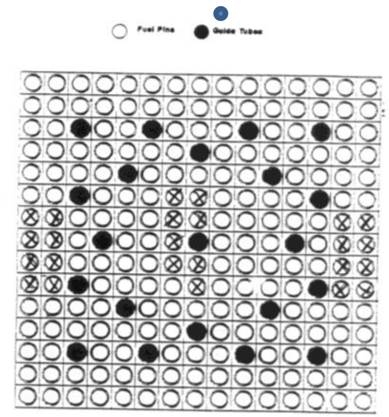
$D \sim Qe^2M^2$



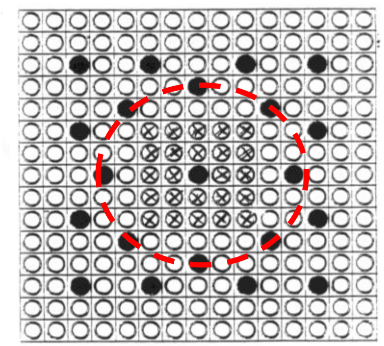
100% LEU @ 3.2%



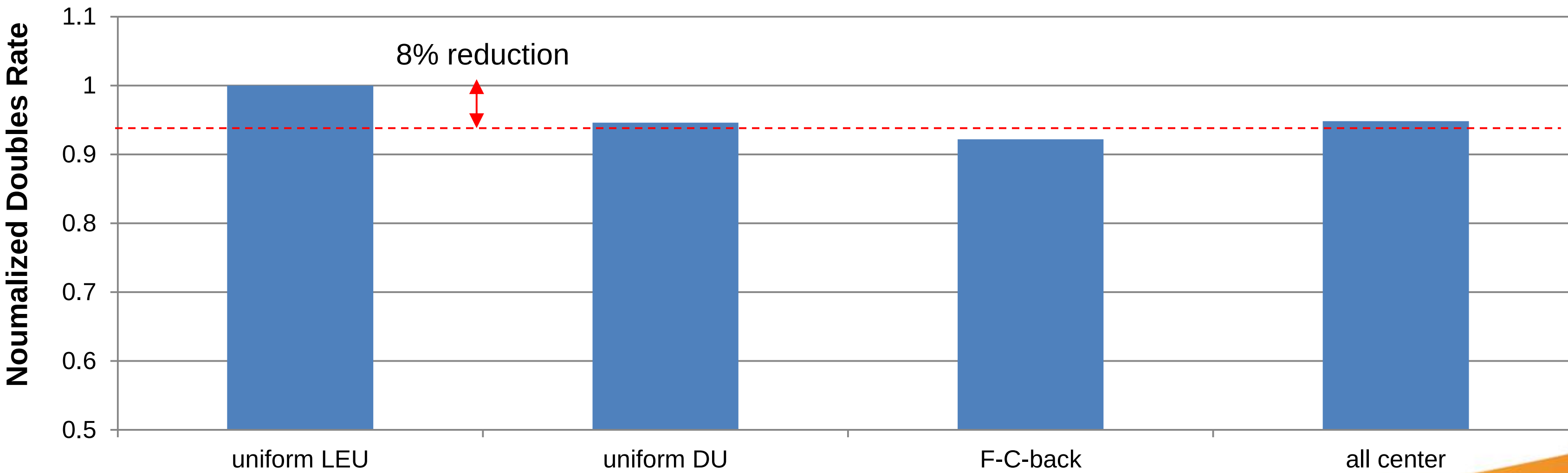
12% DU pins (24)



12% DU pins



12% DU pins



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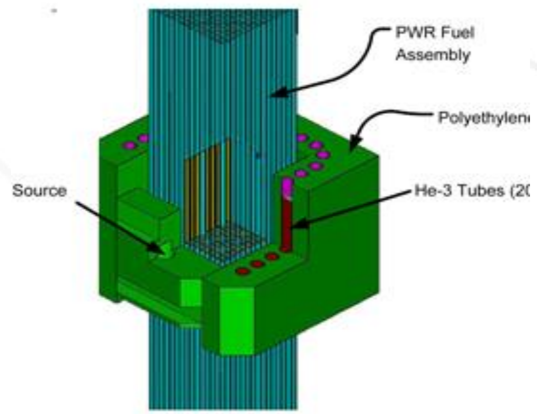
Fresh LWR Measurement UNCL-1 Background



- Over 25 years of successful collar measurements
- AmLi source used to induce fission in ^{235}U, with prompt fission neutrons measured with neutron coincidences.
- In "thermal mode," thermal neutrons pass from polyethylene and cause fission. This gives a short measurement time but is sensitive to thermal neutron poisons – correction uses operator information

PWR in plastic bag

Full length scan

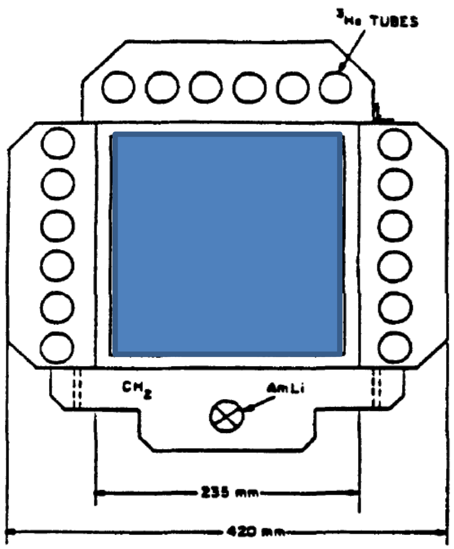
Resende Braz 1982

Fresh LWR Measurement - continued

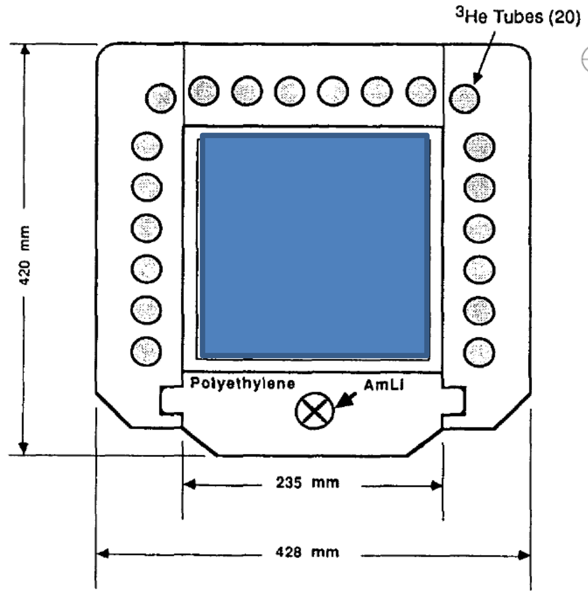
- Fast mode using cadmium liners uses only epi-cadmium neutrons and so is less sensitive to thermal neutron poisons but measurement time is ~ 1 hour with current detectors – too long for inspections
- Newer fuel designs have more neutron poison, so problem is increasingly important
- New detector designs being considered
- Passive neutron interrogation collar slides to follow

Thermal-neutron Detector Design Evolution

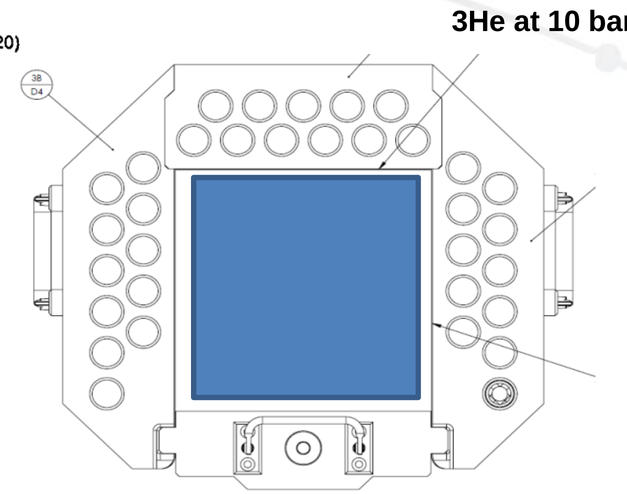
UNCL-I

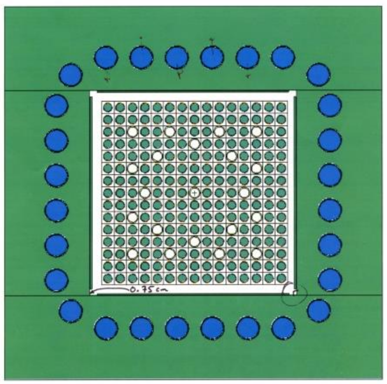


UNCL-II

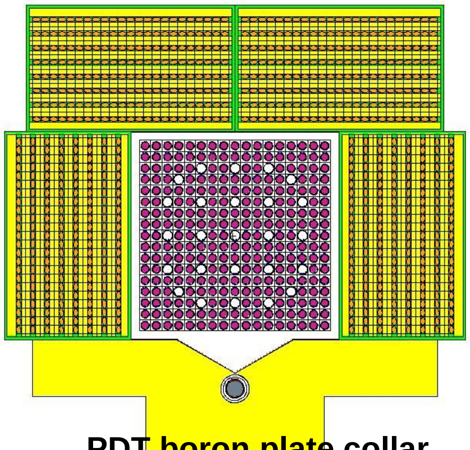


EFC

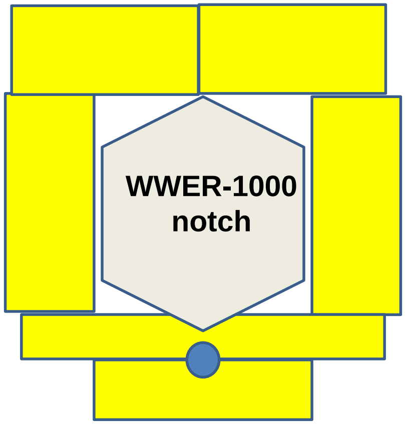




Passive neutron collar (16% efficiency)



PDT boron plate collar (from the Rodeo)

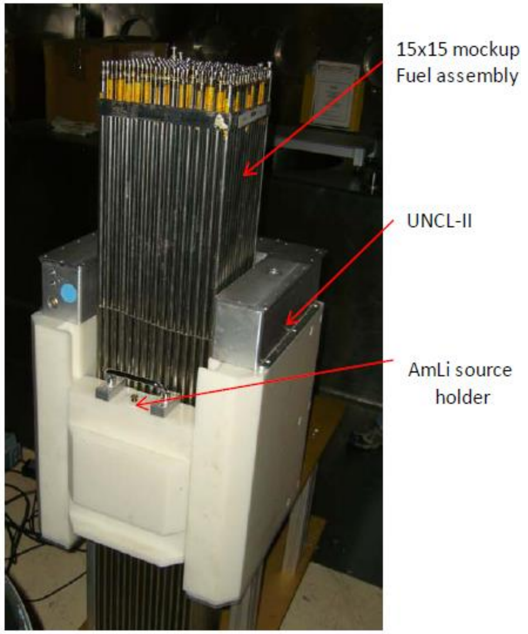


WWER-100- notch concept

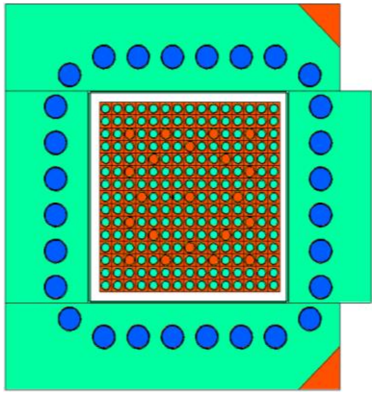
Fast Neutron Passive Collar (FNPC) Approach

(2017-18 funded by SGTech)

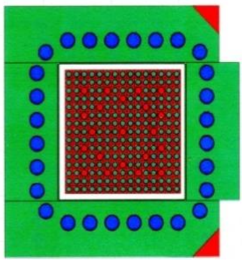
- Self-interrogation using the spontaneous fission neutrons from ^{238}U to interrogate the ^{235}U
- No AmLi source
- No correction for Gd pins needed
- Negligible accidental pileup rate
- Hard neutron spectrum interrogation and thermal-neutron detection
- Detector optimized for passive mode operation with high efficiency (~ 28%)



MCNP simulation

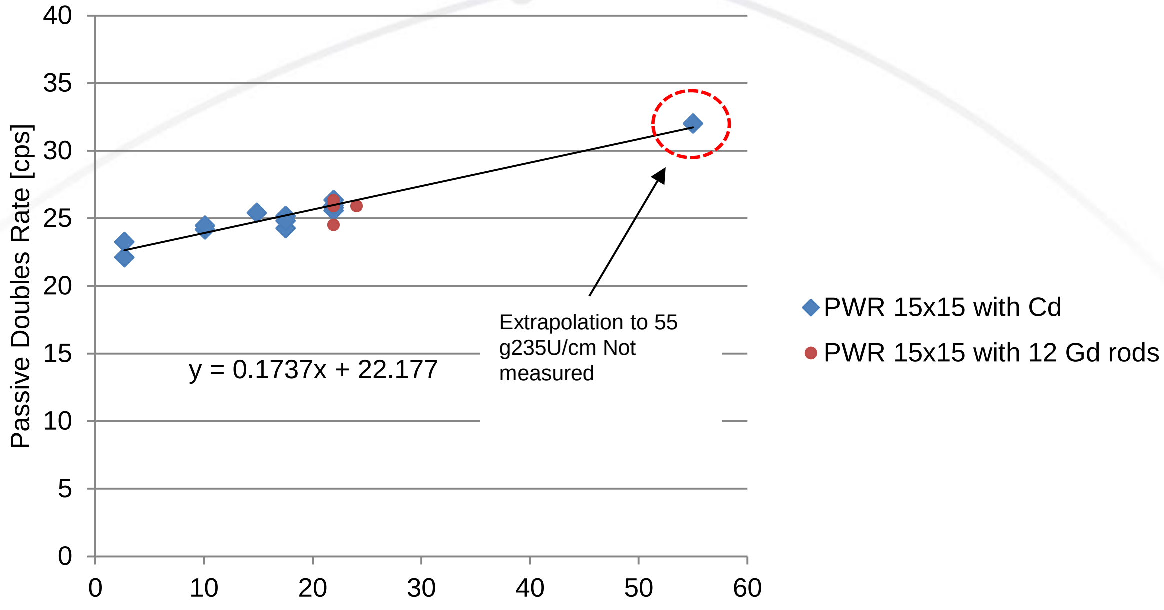


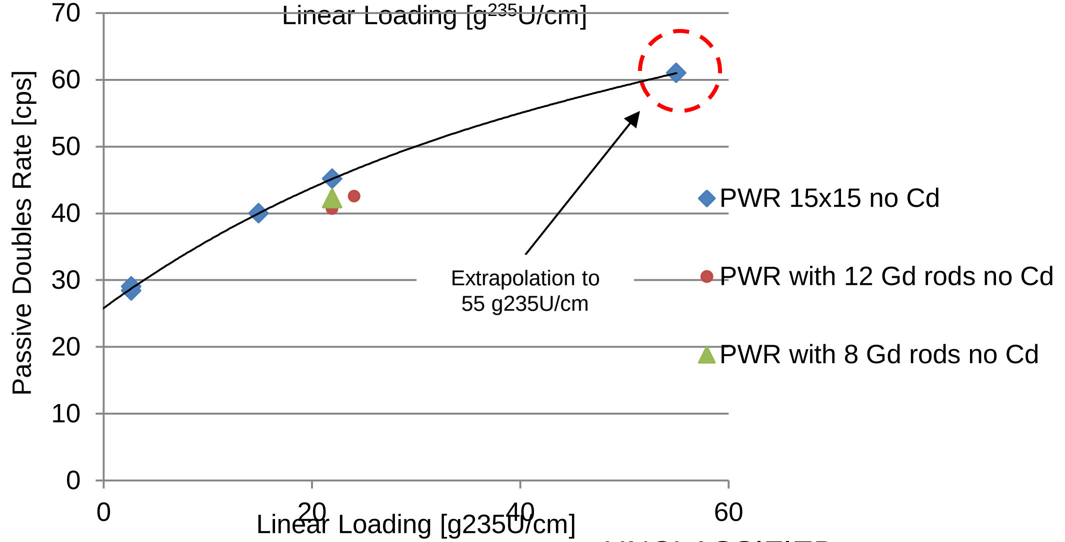
2017 Proof of Principle Measurements at LANL using 15x15 PWR mockup



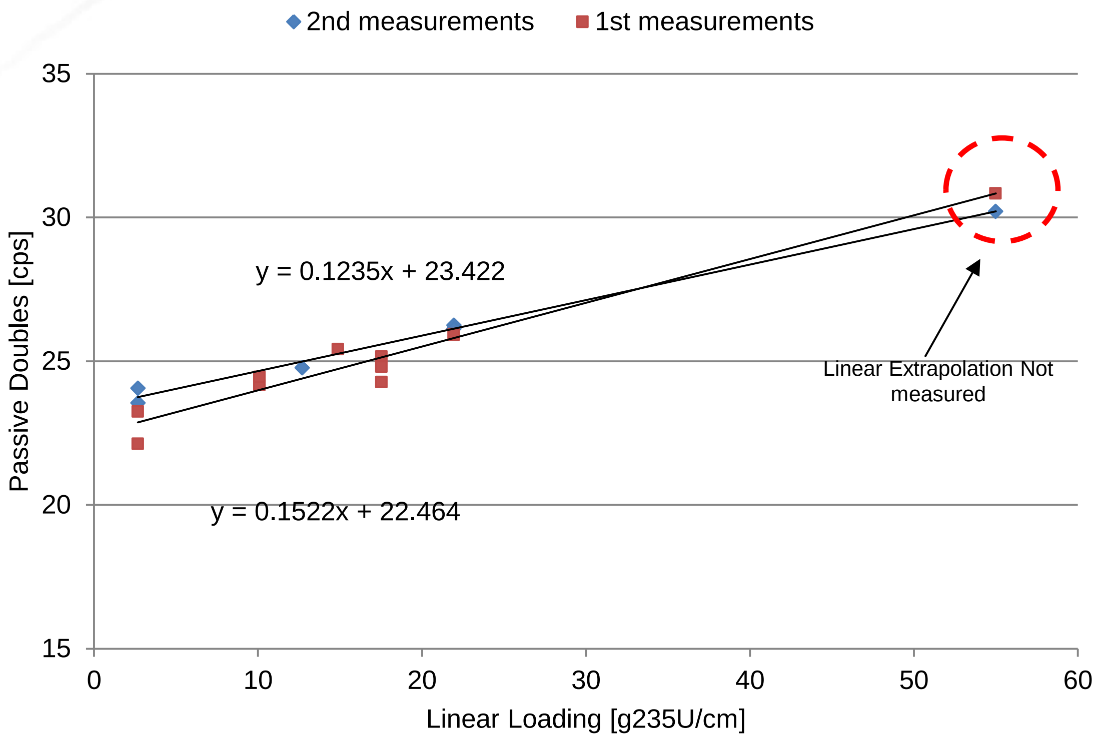
The passive
4th side used a slab
from a mod-1 collar
To give 15.5% efficiency

2017 Preliminary Fuel Assembly Measurements





Repeat Fuel Assembly Measurements with High Precision

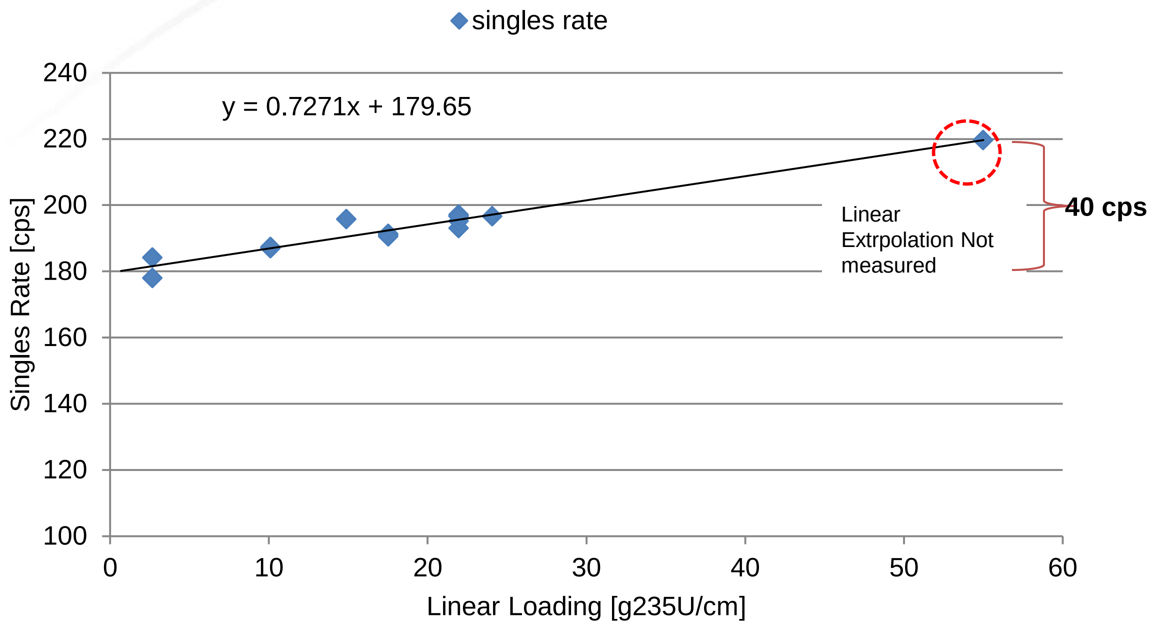


Statistical doubles error for 900s measurement was 3.0% for the ^{235}U mass at 55 g/cm loading

Singles Rate Analysis

^{234}U contribution

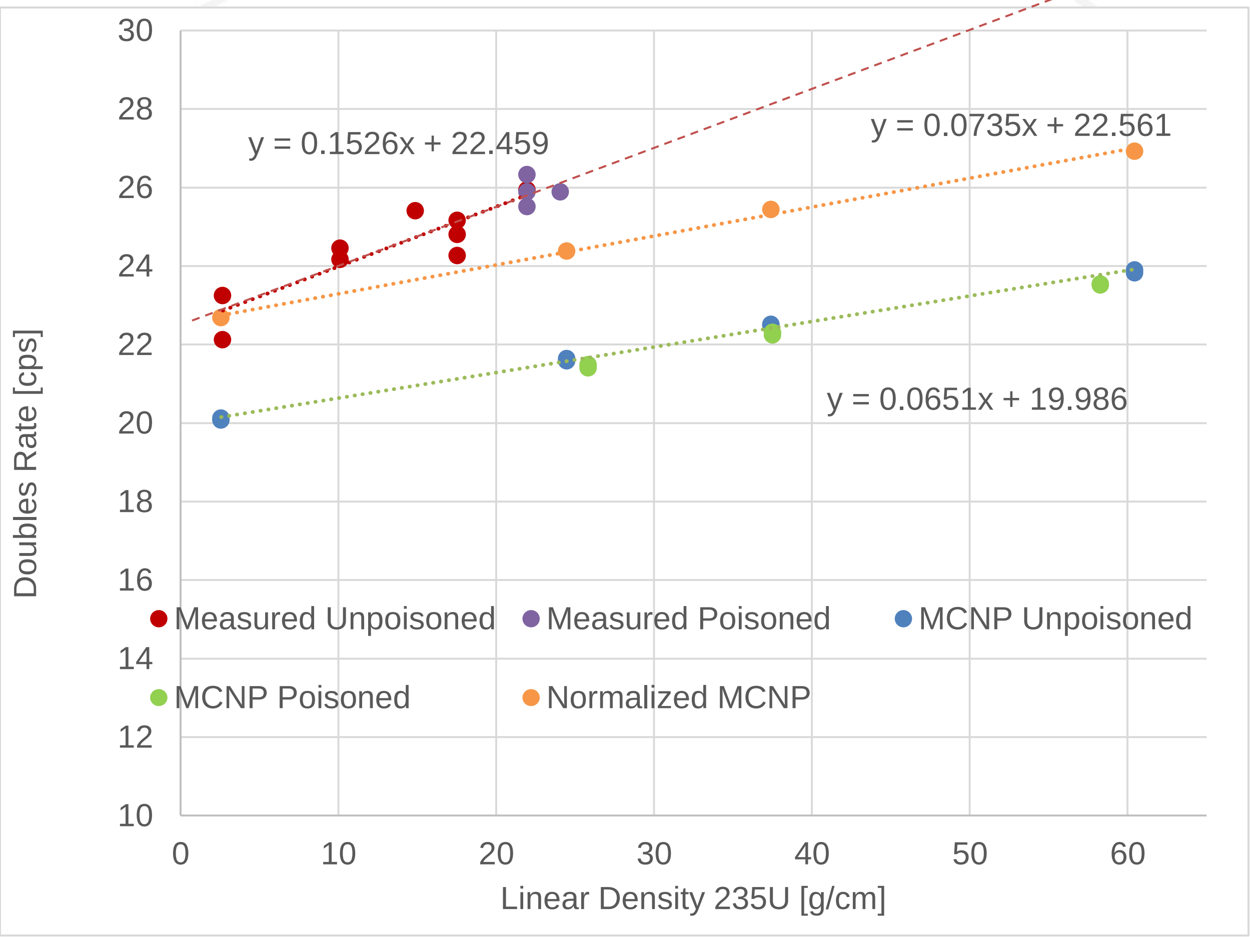
S ~ ^{238}UY M(1+α)
D ~ ^{238}UY M^2 {   }



- Singles rates show that the ^{234}U fraction in the LEU contributes to the neutron rate.
- The MCNP6 calculations indicated that ~ 6.8% of the doubles rate was from the ^{234}U neutron IF reaction

Leakage multiplication alone would be ~ 10-20 cps net at 55g235U/cm
The 40 cps net includes ^{234}U alpha,n neutrons

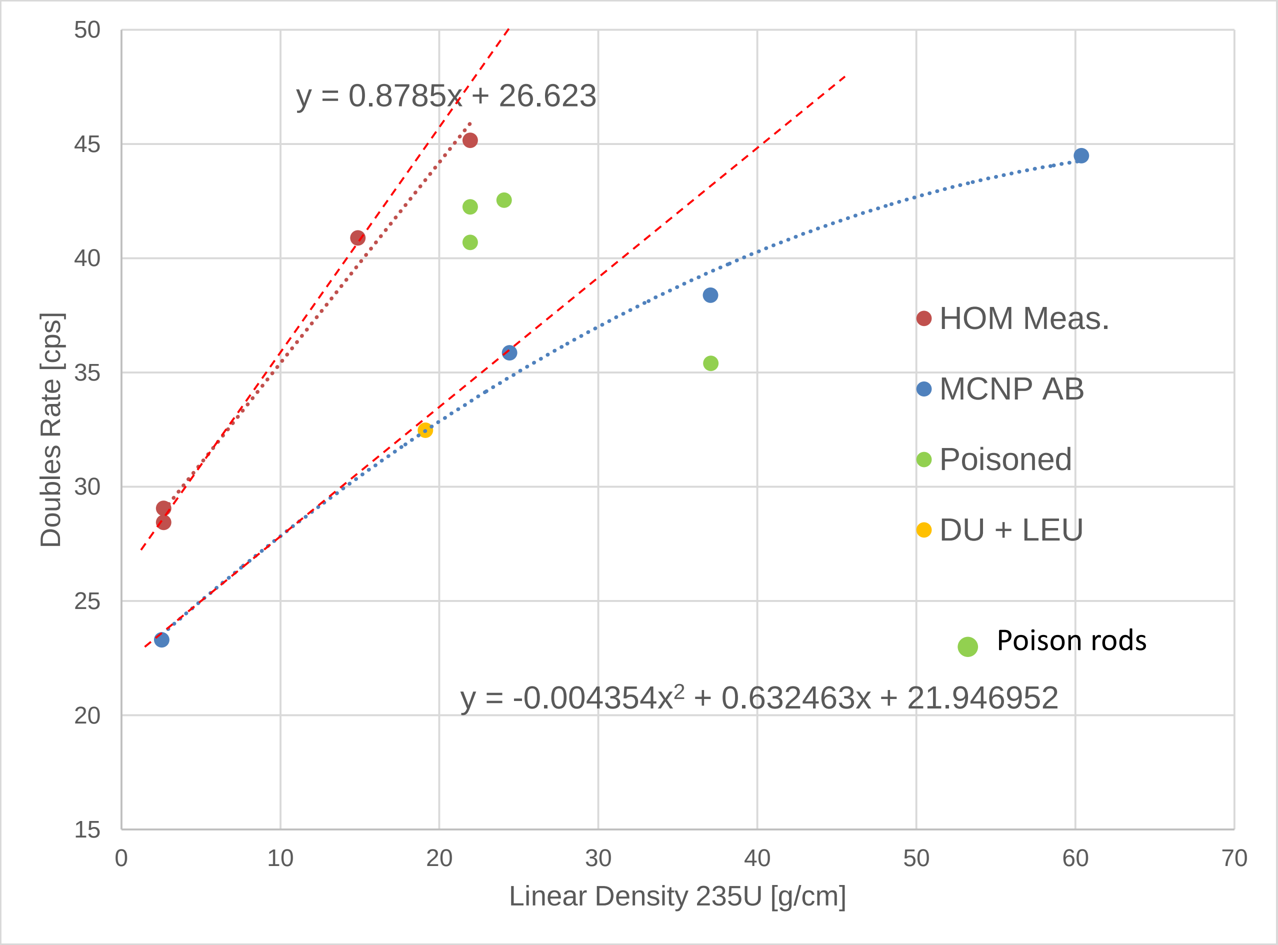
MCNP Analysis for Fast Neutron Interrogation



MCNP shows

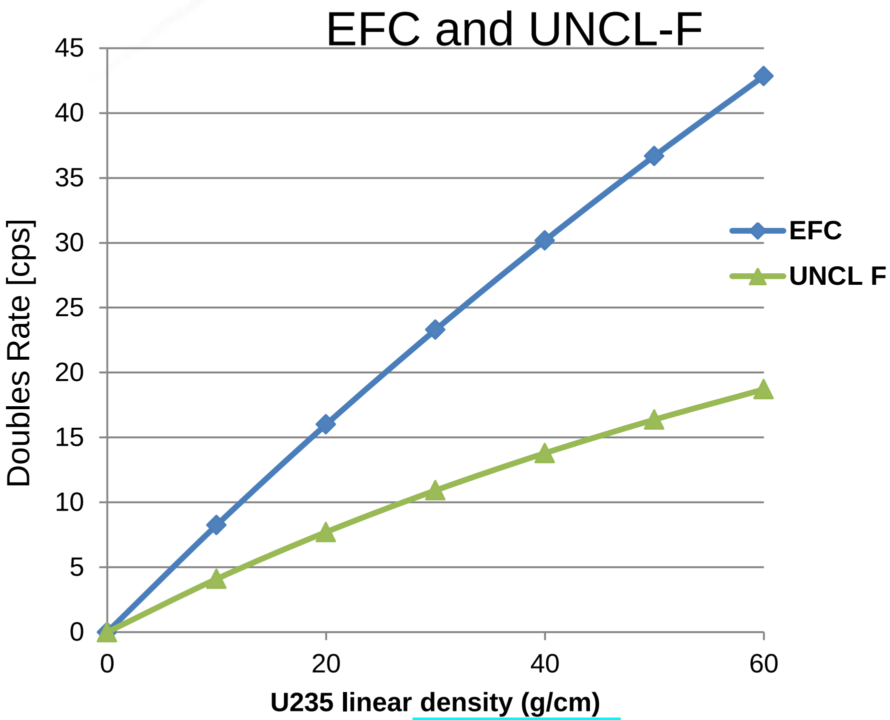
- **Linear doubles curve**
- **Small Gd perturbation (< 1%)**
- **Less slope than measurements (0.074 v. 0.15)**

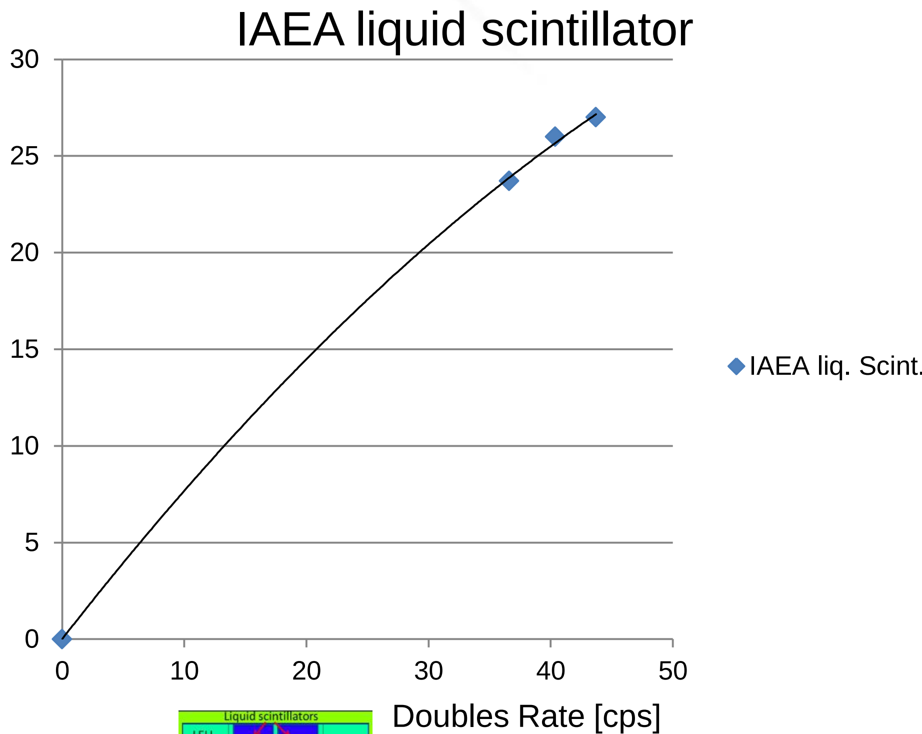
MCNP Analysis for Thermal Neutrons

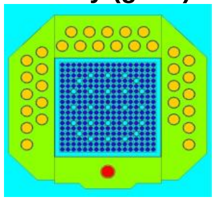


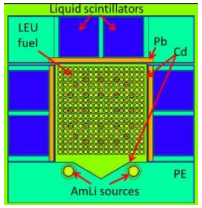
AmLi Fast Neutron Systems (i.e. Cd liner)

Non-linear doubles curves caused by epi-Cd neutron absorption

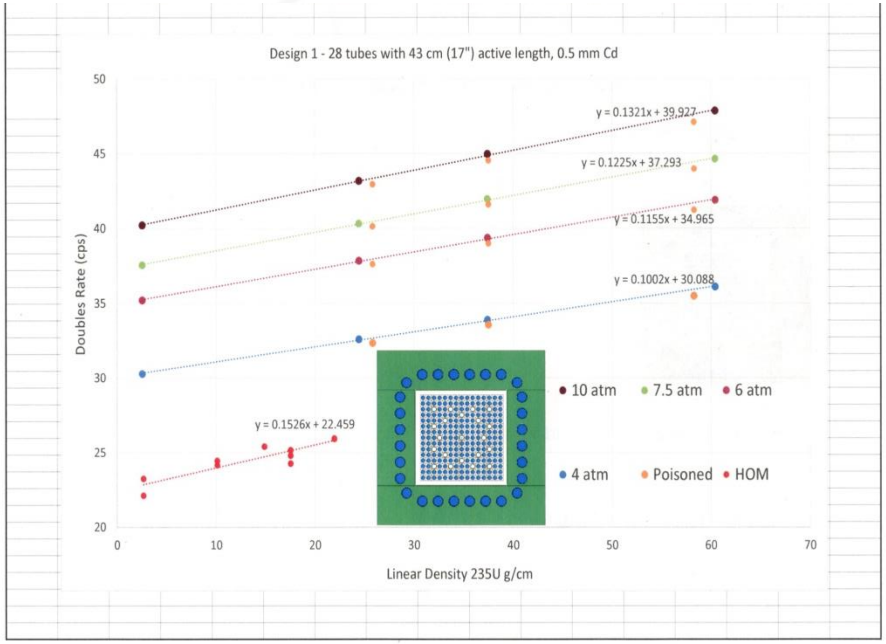


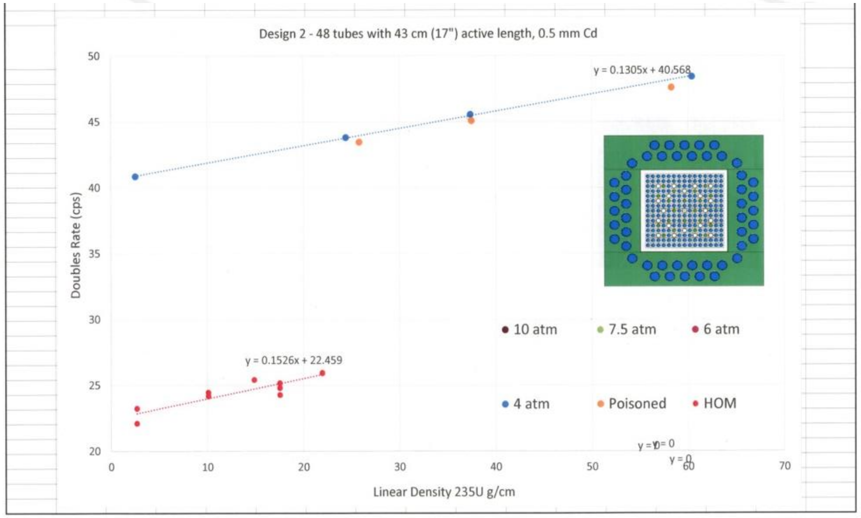


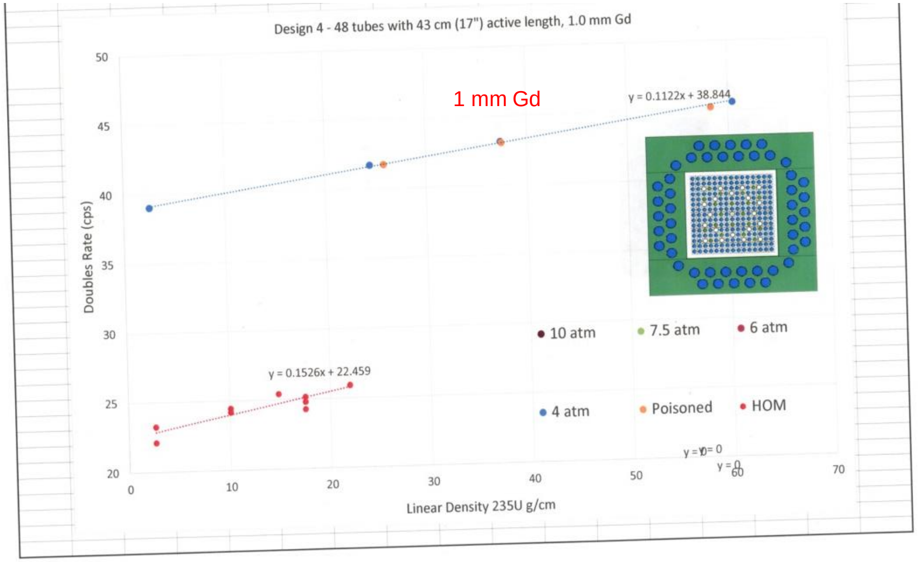




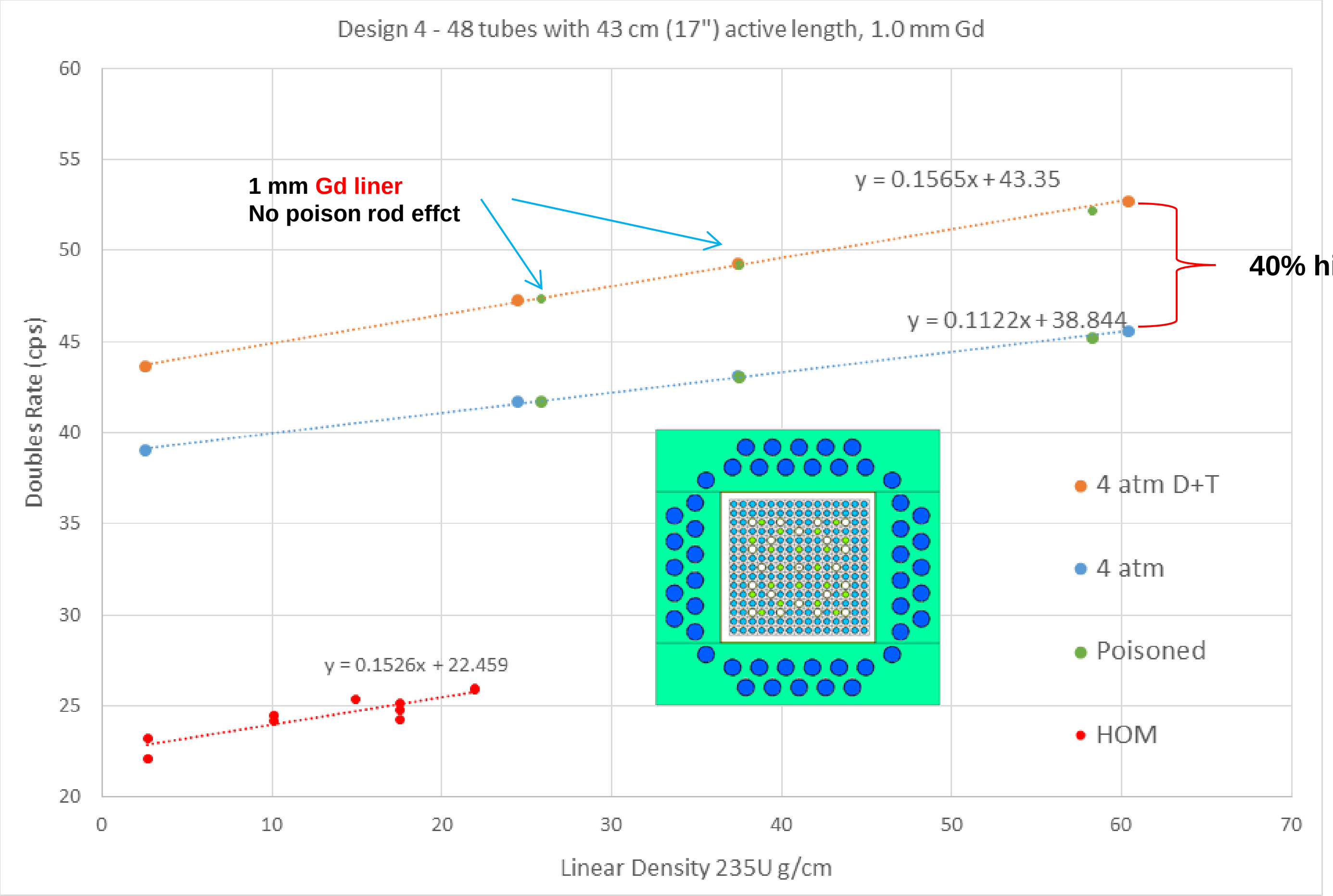
MCNP Analysis for Different Gas Pressure and Detector Efficiency







MCNP Calculations for Doubles plus Triples Rates (advanced analysis future option)



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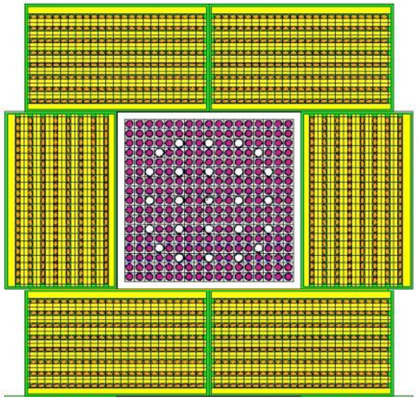
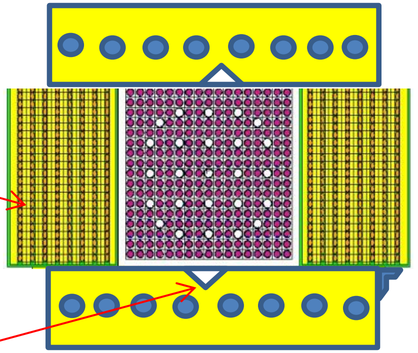
Design Concept for Hybrid 3He Tube and PDT ^{10}B Plate Combination

Hybrid Purpose

- Use less ^{3}He
- Obtain perfomance info for ^{10}B
- Reduce cost for commercial system



Full ^{10}B plate detector



Hybrid ^{10}B plate ^{3}He tube detector

Side slabs adjust by 2cm for VVER-1000

notches for VVER-1000 assemblies.

Summary

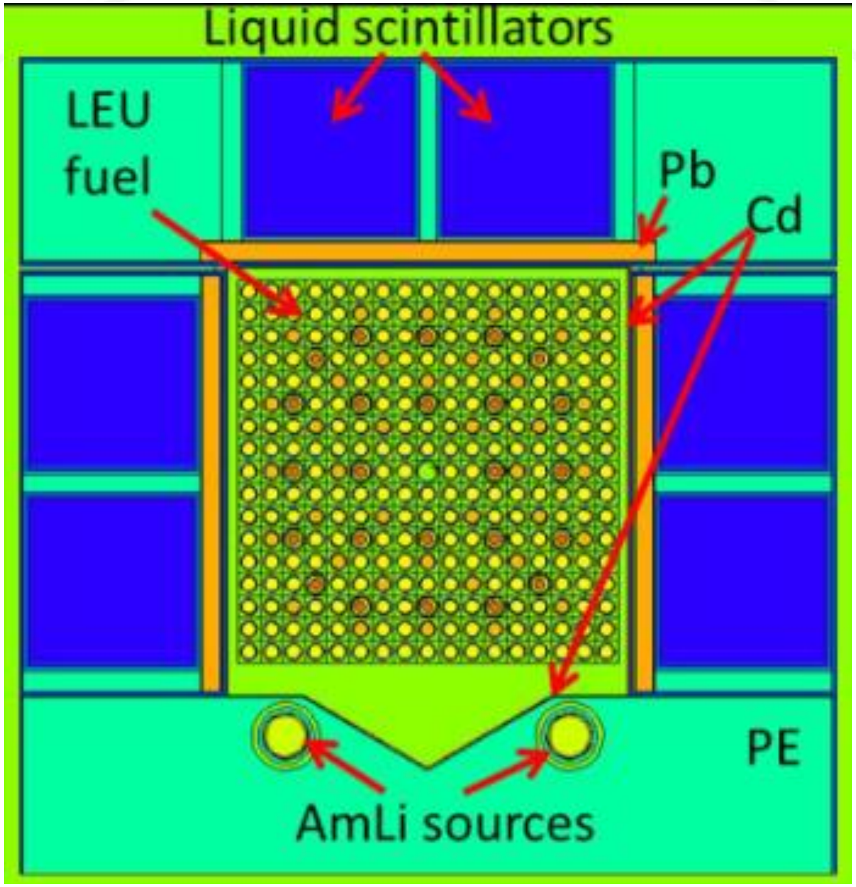
- The passive neutron collar approach removes the effect of poison rods when using a 1mm Gd liner
- No AmLi sources are required (no hazardous shipment)
- The doubles rate calibration curve is linear so there is less error in determining the ^{235}U mass compared to AmLi neutron source interrogation (non-linear)
- The ^{238}U SF neutrons are higher energy than AmLi (0.3 MeV); thus, better penetration
- The accidental rate pile-up is almost negligible (thus, long gates)
- The thermal-neutron mode detectors provide penetrability to the center of the assembly
- The passive mode system is well suited for unattended mode operation
- Challenges
  - BWR fuel assemblies have less mass and less neutron multiplication than PWR
  - Effective removal of cosmic-ray spallation neutron bursts needed via QC tests

Acknowledgements

The authors would like to acknowledge the Department of Energy National Nuclear Security Administration's Office of Nonproliferation and International Security NNSA/NA-241 for their support in this research.

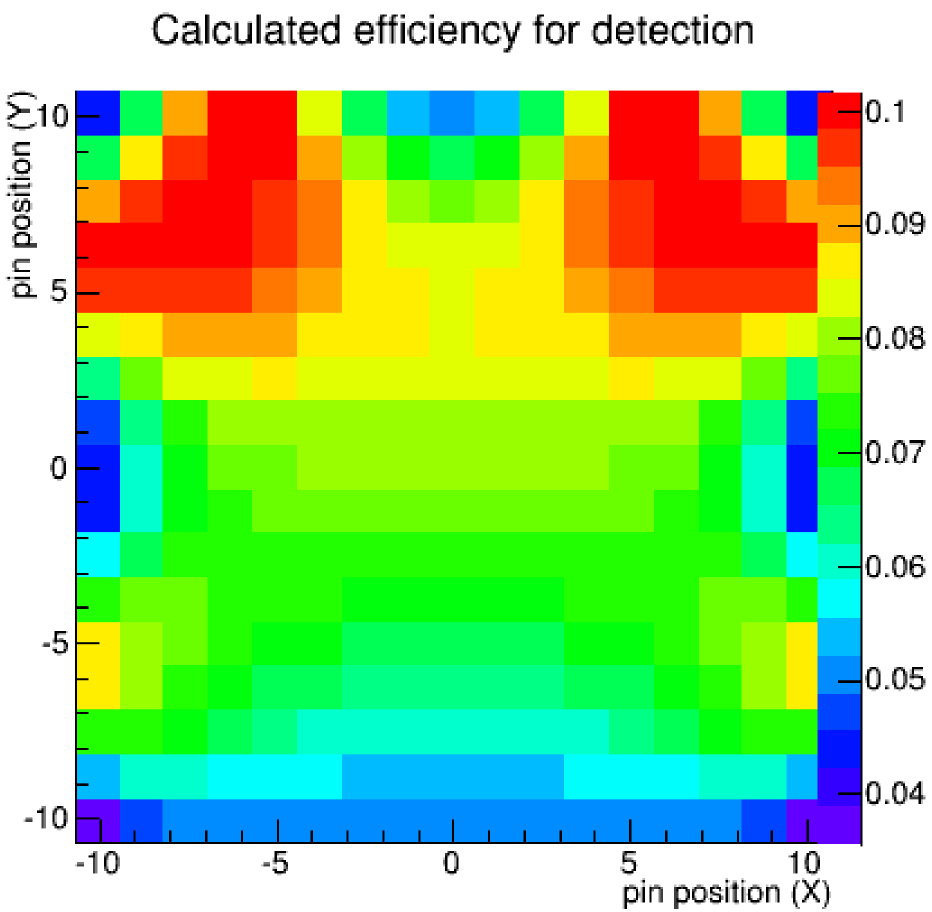
- *FY18 PWP24.1.3.1 Measurement Technology - Passive Neutron Collar*

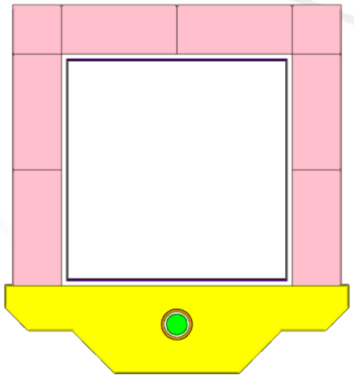
Extra slide for IAEA Fast Neutron Collar



Via T. H. Hoon IAEA, Santa Fe ANS meeting Sept 2016

Extra slide for SNL Calculated position Sensitivity

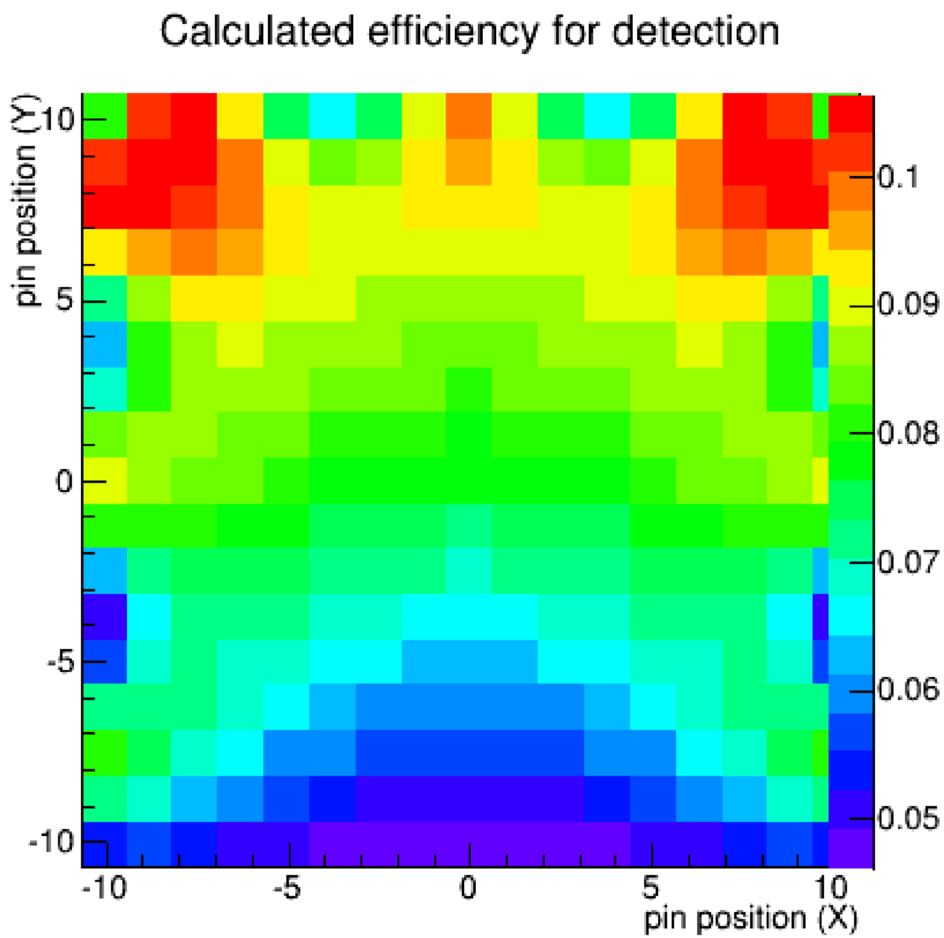


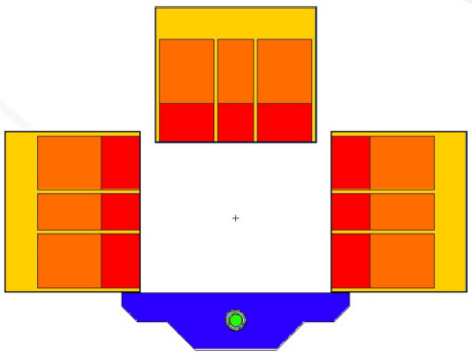


PSD Plastic
10 cm on a side
15% efficiency

- **From Peter Marleau - SNL**

Extra slide for SNL Calculated position Sensitivity





Stilbene
7.5 cm on a side
15% efficiency

- **Copy from Peter Marleau – SNL Rodeo Wrapup meeting Santa Fe Sept 2016**