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# Simulated Performance of the Integrated PNAR and SINRD Detector Designed for Spent Fuel Measurements at the Fugen Reactor in Japan

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# Introduction

- Objective
  - Investigate the use of Passive Neutron Albedo Reactivity (PNAR) and Self-Interrogation Neutron Resonance Densitometry (SINRD) to quantify fissile content in FUGEN spent fuel assemblies (FAs)
- Methodology
  - Detector was designed using fission chambers (FCs)
  - Optimized design via MCNPX simulations
  - Plan to build and field test instrument in FY13
- Significance
  - Improve safeguards verification of spent fuel assemblies in water
  - Increase sensitivity to partial defects

# Passive Neutron Albedo Reactivity (PNAR)

- PNAR uses the cadmium ratio (CR) to quantify the fissile content in the sample by measuring the sample twice:
  1) No Cd liner
  2) With 1 mm thick Cd liner around the sample

$$CR = \frac{Bare\ {}^{235}U\ Fission\ Rate}{Cd\ {}^{235}U\ Fission\ Rate}$$

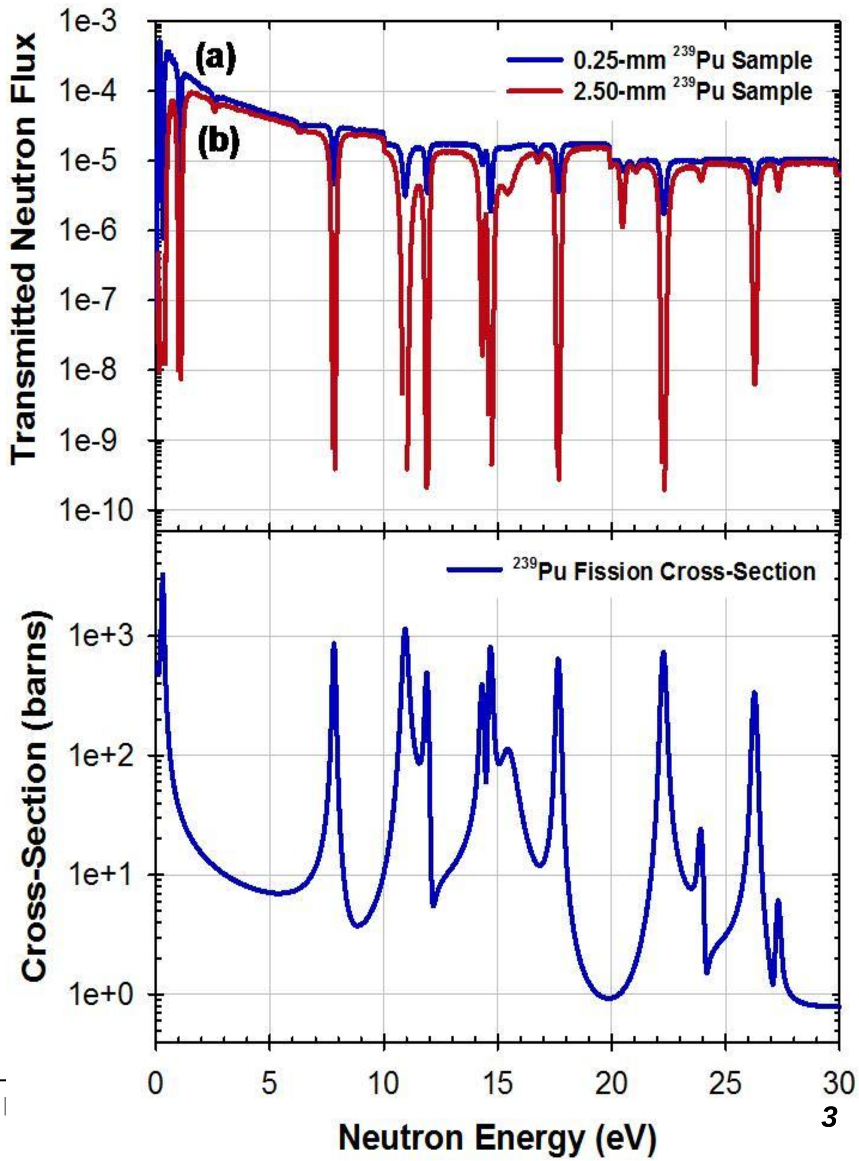
- $^{239}$Pu effective mass was used to relate the CR to fissile mass in the Fugen spent MOX FAs:

$$^{239}Pu_{eff} = C_1 \cdot {}^{235}U + {}^{239}Pu + C_2 \cdot {}^{241}Pu$$

  – where constants $C_1$ and $C_2$ weight the contributions of $^{235}$U and $^{241}$Pu in the measured signal respective to the amount of $^{239}$Pu

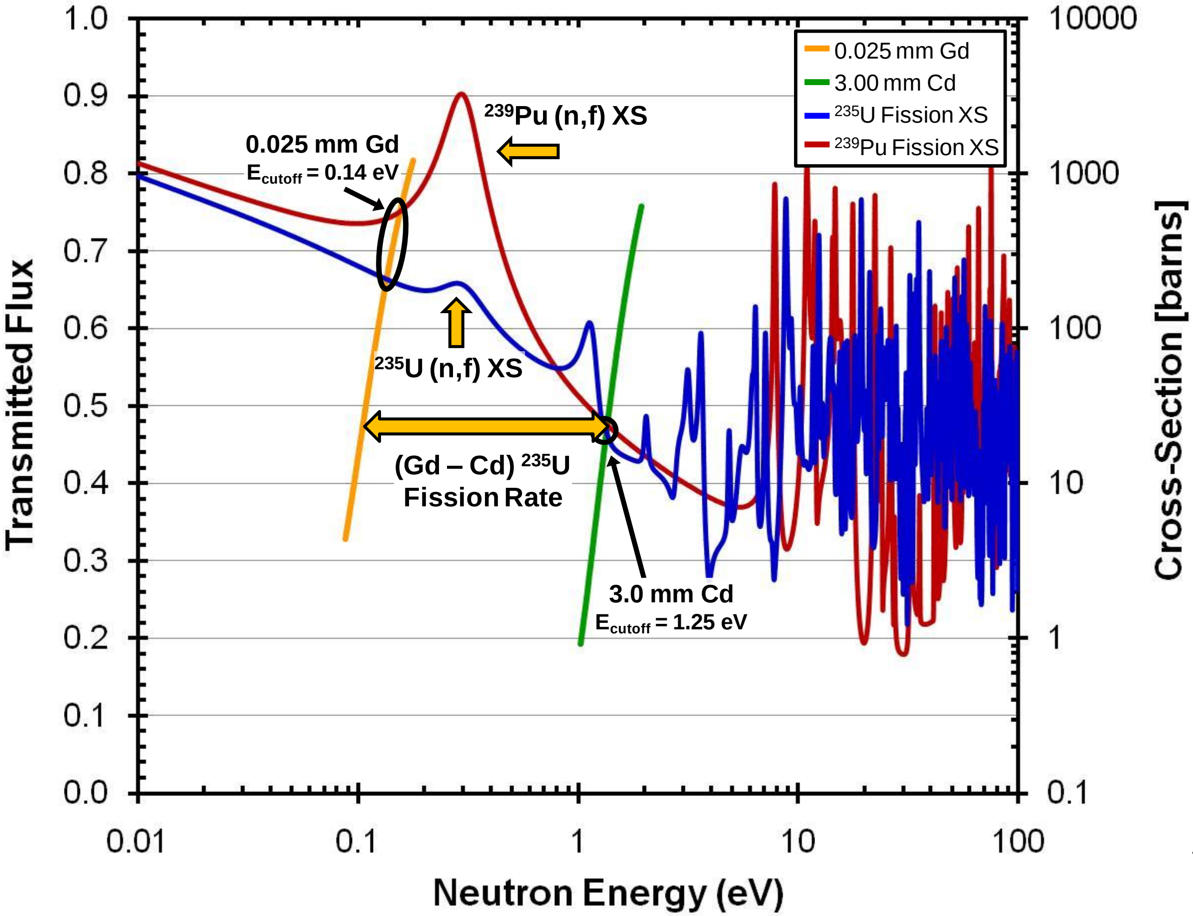
# Self-Interrogation Neutron Resonance Densitometry (SINRD)

- SINRD utilizes the unique resonance structure in fission cross-section of different fissile isotopes
- Sensitivity is based on using the same fissile materials in the FCs as are in the sample
  - Resonance absorption lines in transmitted flux are amplified by the corresponding (n,f) reaction peaks in the FCs



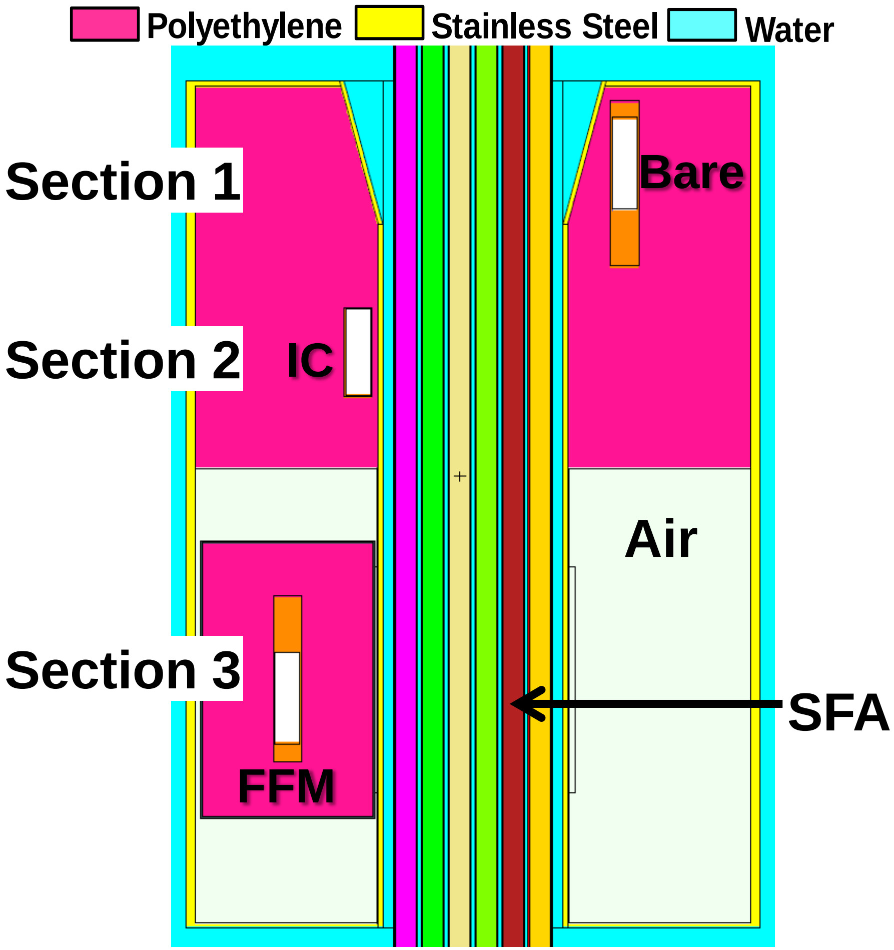
# Filters for SINRD Detectors

- Transmitted flux through Gd & Cd filters vs neutron energy
  - Thick Cd absorbs majority of neutrons in low energy $^{239}$Pu resonance region
  - Thin Gd transmits a significant portion of these lower energy neutrons



# Fugen Detector Design (Y-Z view)

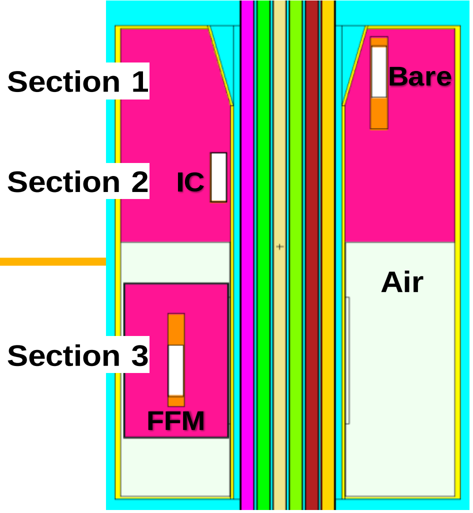
- Total of 15 detectors in SINRD+PNAR instrument:
  - 12 Fission Chambers (FCs) and 3 Ion Chambers

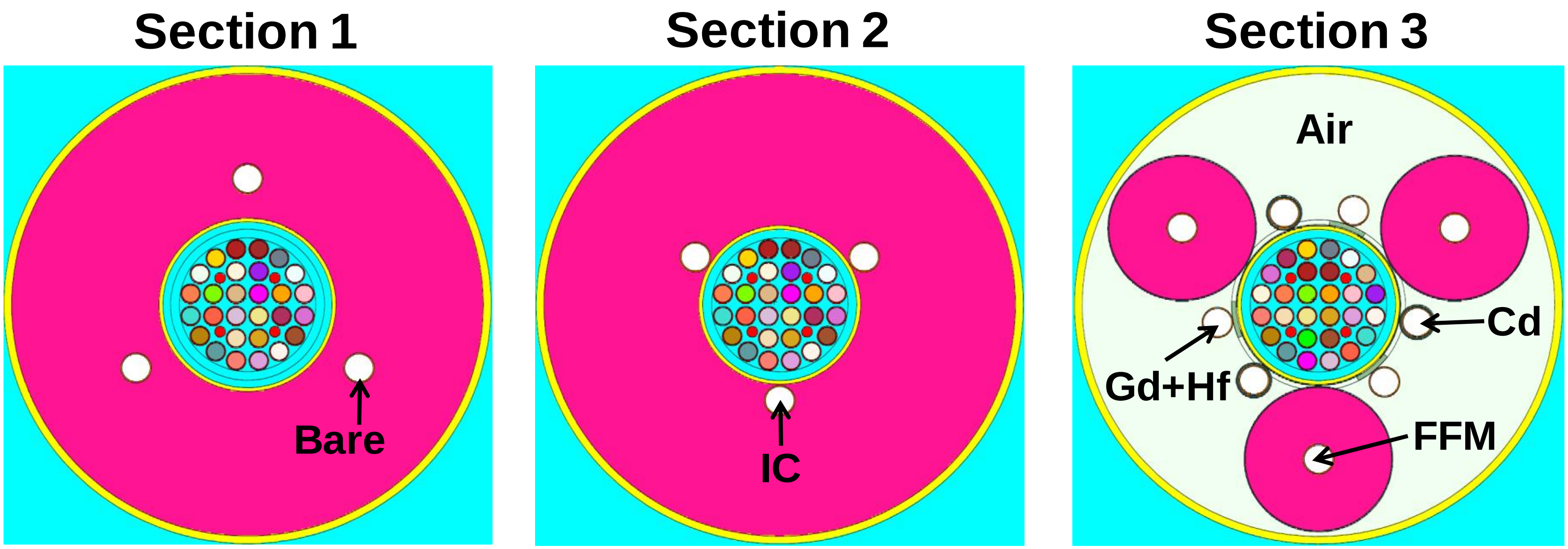



| Dimensions | |
|---|---|
| SFA Outer Diameter | 11.2 cm |
| Water Gap | 1.5 cm |
| Detector Inner Diameter | 12.7 cm |
| Detector Outer Diameter | 48 cm |
| Detector Height | 59 cm |
| Cd Liner* Height | 32 cm |

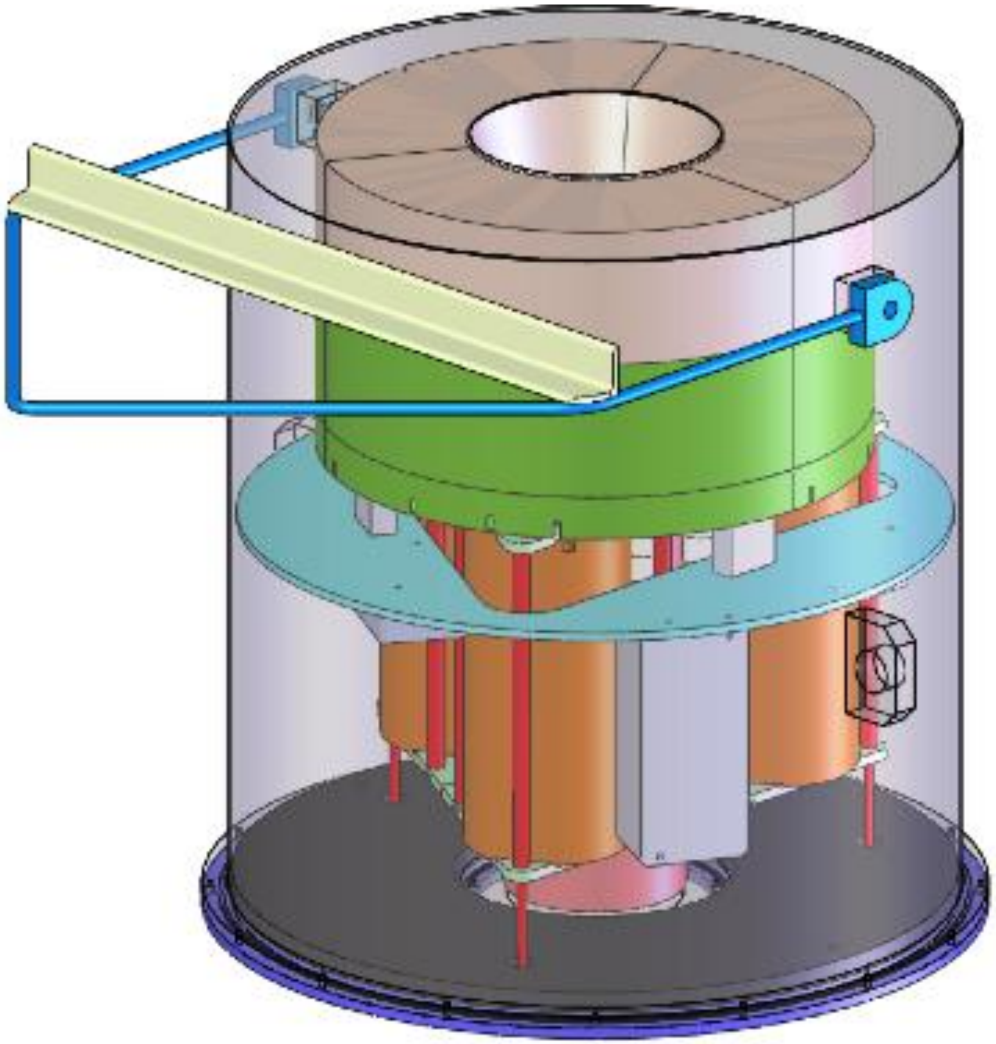
** Cd liner is 1 mm thick*

# Detector Design (X-Y view)



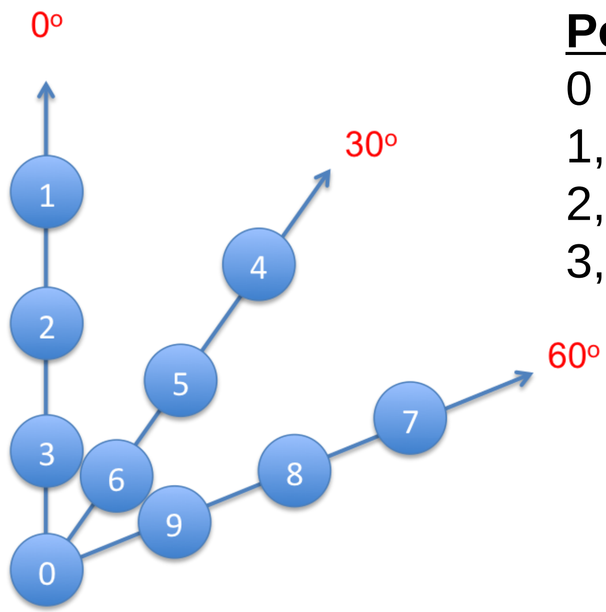




# Fugen Detector Design: 3-D Rendering



# Variable Fuel Assembly Positioning

- Total of 10 positions:
  - 3 relative angles – relative to y-axis, aligned with FFM in sec.1 & 3
  - 4 radial offsets from centered (position 0) to 0.7 cm from center (positions 1, 4, 7)

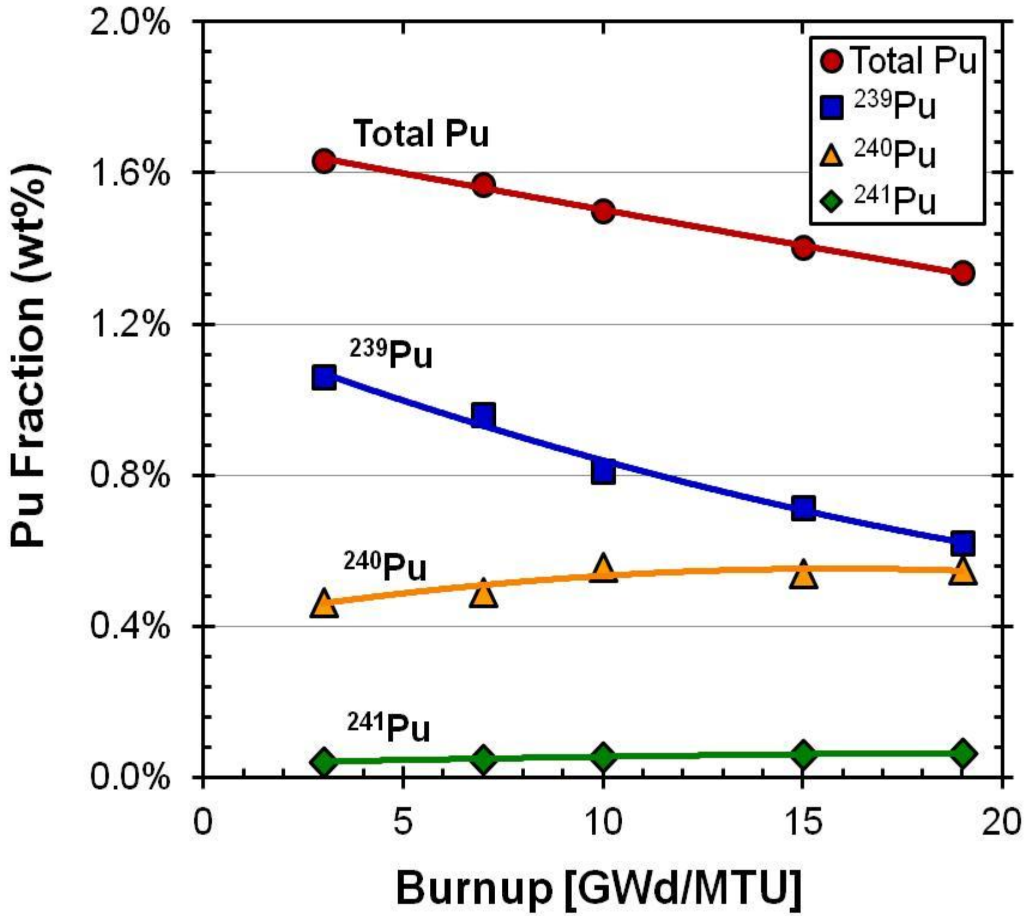



**Positions:**

0 = centered in the detector
1, 4, 7 = 0.7 cm from center (*nearest detector wall*)
2, 5, 8 = 0.4 cm from center
3, 6, 9 = 0.2 cm from center

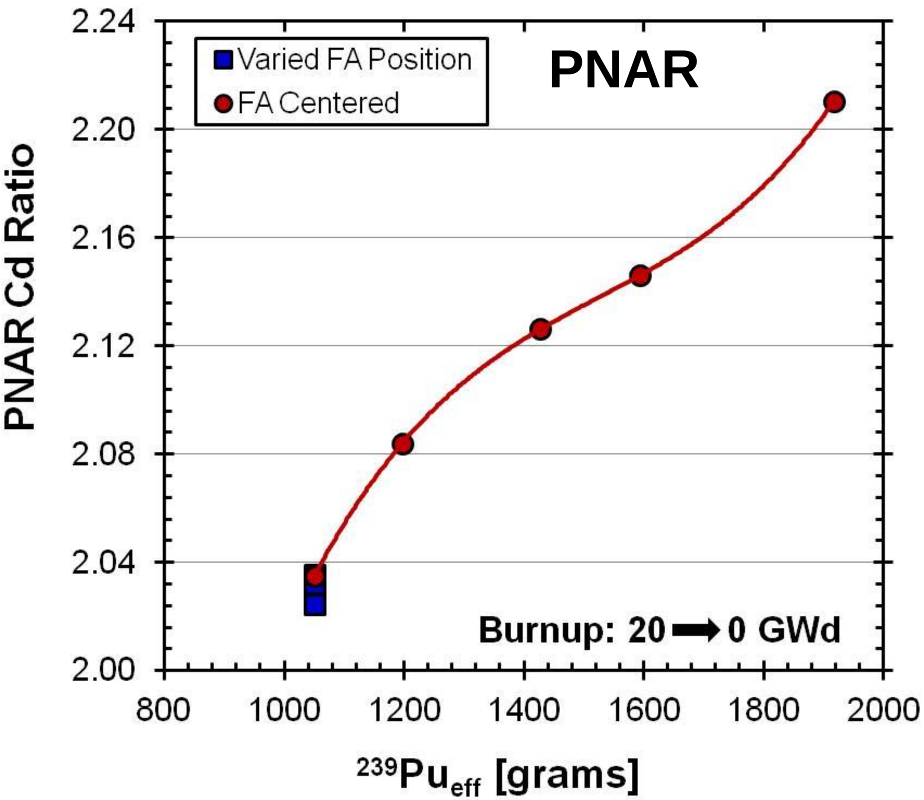
# MOX Fuel: Pu Isotopics versus Burnup

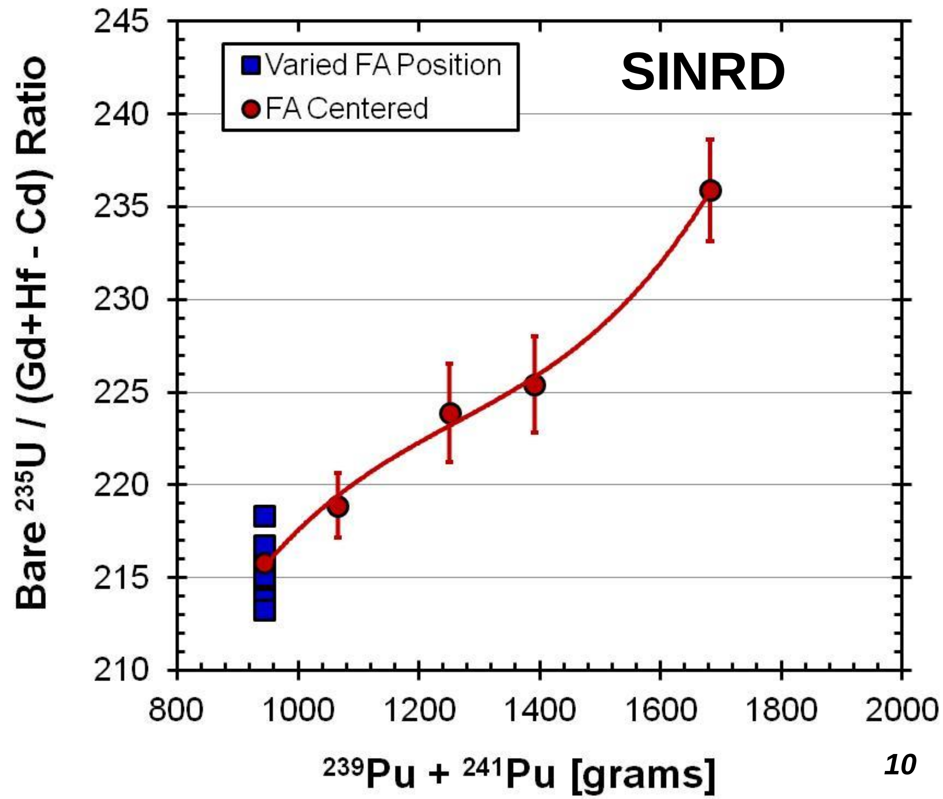
- Simulated the response of SINRD+PNAR detector to Fugen spent MOX FAs
  - Burnup = 3 to 19 GWd/MTU
  - $^{244}$Cm spontaneous fission neutrons were used to self-interrogate the spent fuel pins in MCNPX



# MCNPX Results

- Both PNAR and SINRD ratios are sensitive to Pu fissile mass over burnup range of 3 to 19 GWd/MTU
  - 7.9% change in PNAR ratio & 0.5% change from FA positioning
  - 8.5% change in SINRD ratio & 1.2% change from FA positioning



# Summary and Conclusions

- MCNPX simulations were performed to optimize the design of the SINRD+PNAR detector
  - PNAR ratio was less sensitive to FA positioning than SINRD
  - SINRD ratio was more sensitive to Pu fissile mass than PNAR
- Significance:
  - Integration of these techniques can be used to improve verification of spent fuel assemblies in water
- Future Work:
  - Build and field test instrument on actual spent fuel in FY13
  - Quantify the sensitivity of PNAR and SINRD ratios to pin diversions
  - Investigate the use of the neutron to gamma ratio to better determine the FA position within the detector

# Acknowledgements

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