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# Nondestructive Measurements of Fissile Material Using Self-Indication Neutron Resonance Absorption Densitometry (SINRAD)

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# Introduction

- **Motivation**
  - Need for direct measurement of the fissile content in spent fuel by IAEA
    - Implement effective international safeguards
    - Recover continuity of knowledge
    - Detect the diversion of fuel for proliferation purposes
- **Purpose**
  - Develop the use self-indication neutron resonance absorption densitometry (SINRAD) to measure the concentration of fissile materials in spent fuel
  - Improve nuclear safeguards and material accountability

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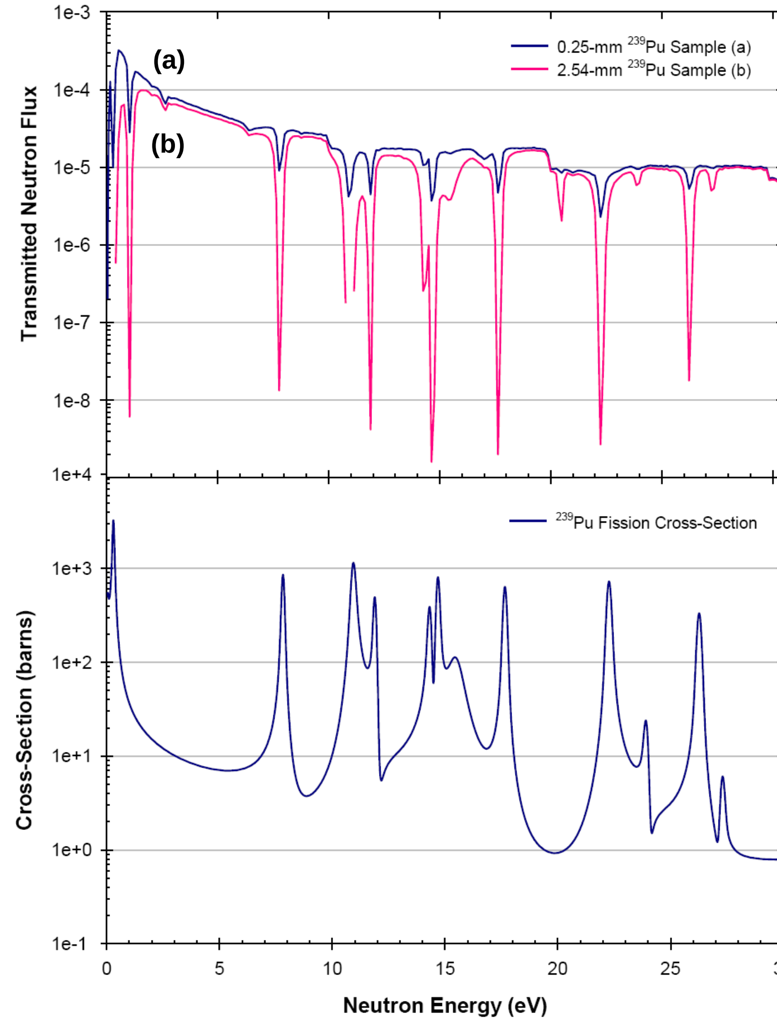
# Self-Indication Neutron Resonance Absorption Densitometry (SINRAD)

- **Utilizes unique resonance structure in the fission cross-section of different fissile isotopes**
  - The epithermal neutron flux is measured after transmission through a fissile sample using a set of fission chambers.
- **Sensitivity of this technique is based on using the same fissile materials in the sample and fission chamber**
  - Resonance absorption lines in the transmitted flux are amplified by the corresponding (n,f) reaction peaks in fission chamber



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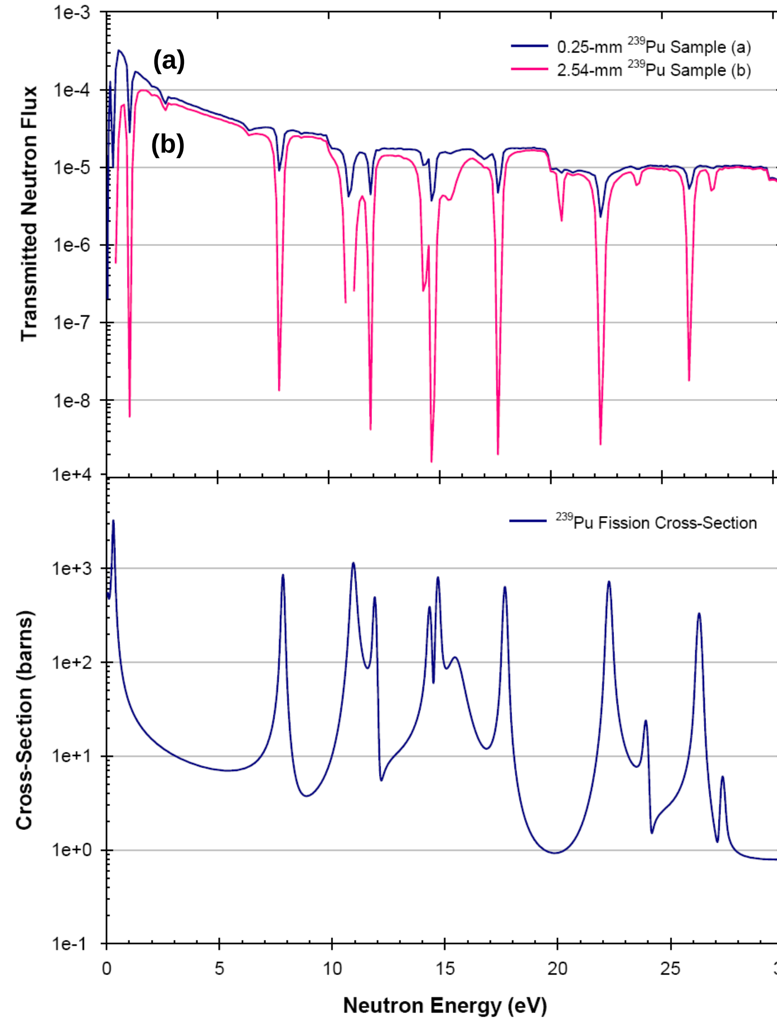
# Transmitted Flux vs. $^{239}$Pu Fission Cross-Section

- **Comparison of $^{239}$Pu fission XS (bottom) to absorption lines in transmitted flux (top)**
  - Curve (a) :  0.25-mm $^{239}$Pu sample
  - Curve (b) :  2.54-mm $^{239}$Pu sample
  - A 0.114-mm Gd filter was used to remove thermal neutrons

- **As sample thickness increases, the self-indication effect decreases**
  - Due to self-shielding effects occurring from the saturation of the larger resonances



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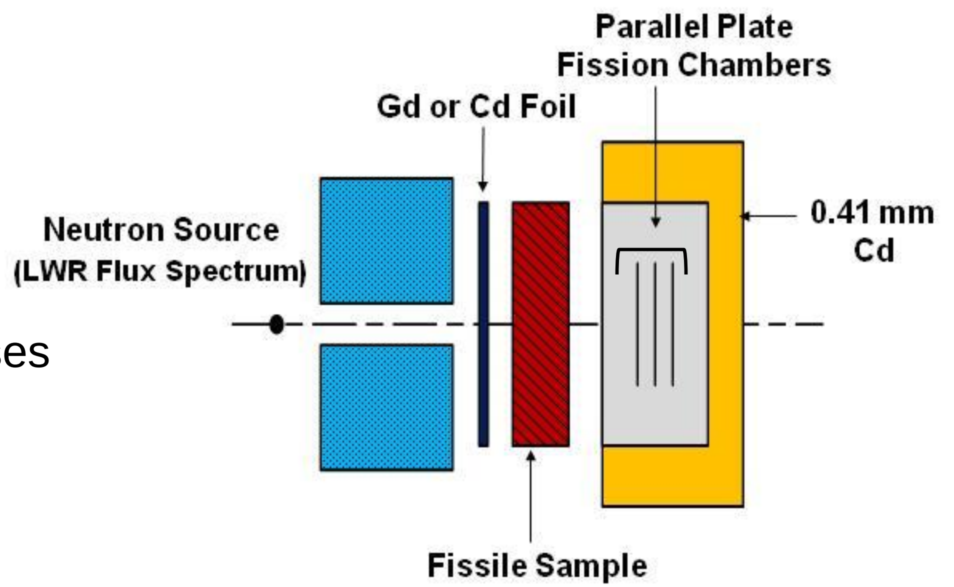
# Primary Research Objectives

- **Develop and assess the sensitivity of using SINRAD for nuclear safeguards measurements**
- **Experimental benchmark approach**
  - Simulate SINRAD to measure the concentration of fissile materials in MCNPX
  - Benchmark results against 1968 and 1969 experimental measurements
- **Importance of benchmarking experimental results**
  - Validate use of MCNPX as computational tool
  - Assess the accuracy of the MCNPX models used
  - Enables models of SINRAD to be applied to more complex geometries
    - e.g. LWR fuel assemblies and pyroprocessing materials

# Fissile Metal Plates – 1968 Experimental Setup

- **Neutron Source**
  - Collimated neutron beam from LASL Water Boiler reactor
- **Gd or Cd Foil**
  - Used to remove thermal neutrons
  - Varied thickness of foils to determine the effect of neutron cutoff energy on detector responses
- **Fissile Samples**
  - 5.0-cm diam. metallic disks
    - 93.0 w/o $^{235}U$
    - 94.2 w/o $^{239}Pu$
  - thicknesses ranged from 0.24 to 3.35-mm



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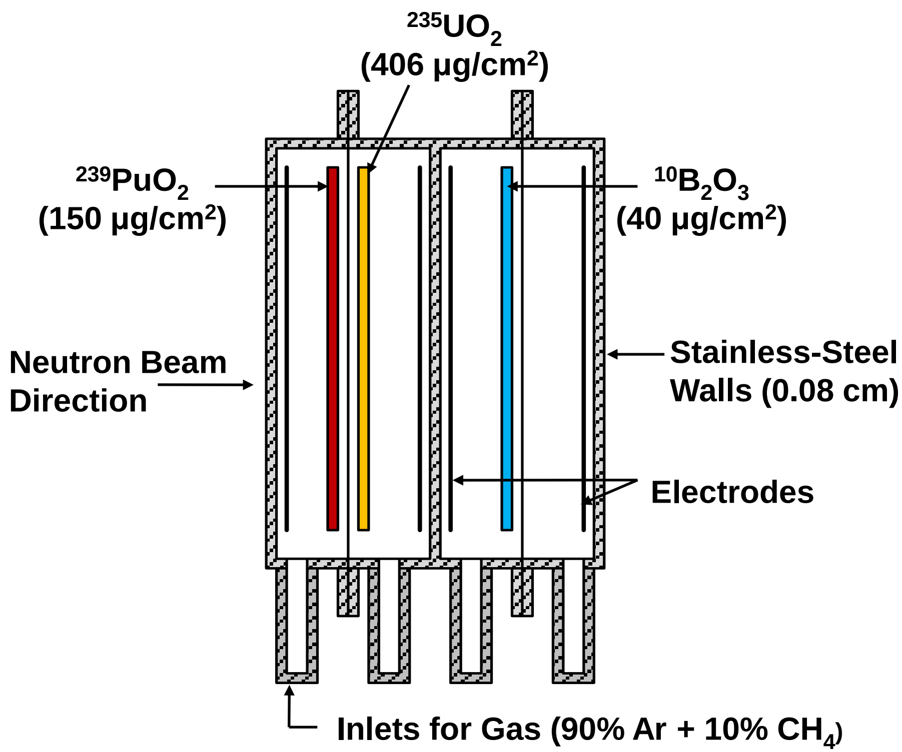
# Fissile Metal Plates – Parallel-Plate Detectors

- **Parallel-Plate Fission Chambers**
  - Three fission chambers containing deposits of $^{239}$Pu, $^{235}$U, and $^{10}$B
  - Attenuation of neutron flux between parallel-plate fission chambers was small



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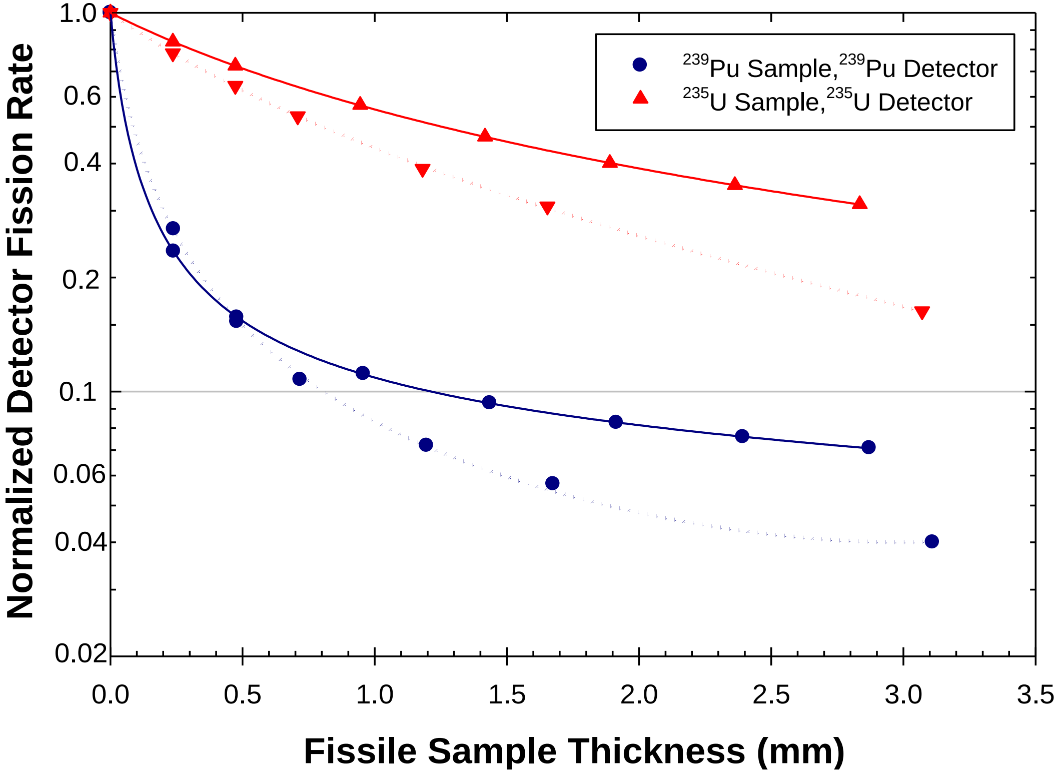
# Fissile Metal Plates – Detector Fission Rate versus Fissile Sample Thickness

- **Dashed lines - 1968 measurements**
  - All results normalized to zero sample thickness
  - Results obtained using a 0.114-mm Gd filter
- **Self-indication effect is larger for $^{239}$Pu sample**
  - $^{239}$Pu has a large resonance at 0.3-Ev



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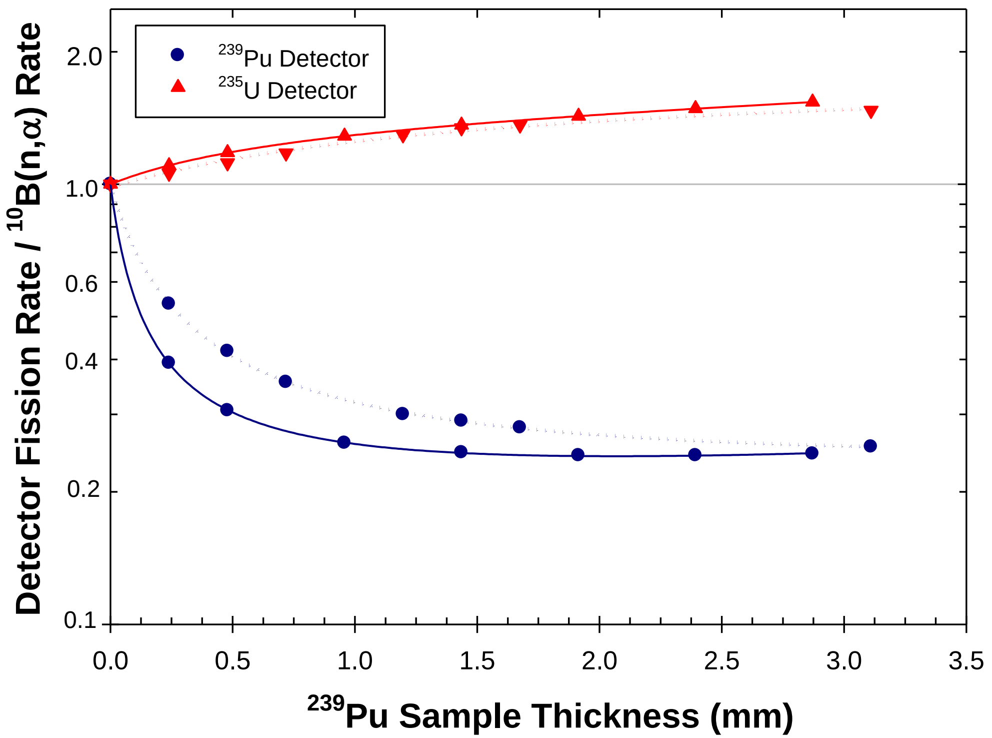
# Fissile Metal Plates – Detector Fission Rate to $^{10}B$ (n,α) Rate versus $^{239}Pu$ Sample Thickness

- **Dashed lines - 1968 measurements**
  - Results obtained using a 0.076-mm Gd filter
- **Ratio of detectors:**
  - greatly reduces the sensitivity of the measured response to extraneous material in fissile sample mixture
- **Self-shielding effects:**
  - due to saturation of the large $^{239}Pu$ resonance
  - occur for sample thicknesses greater than 1.0-mm



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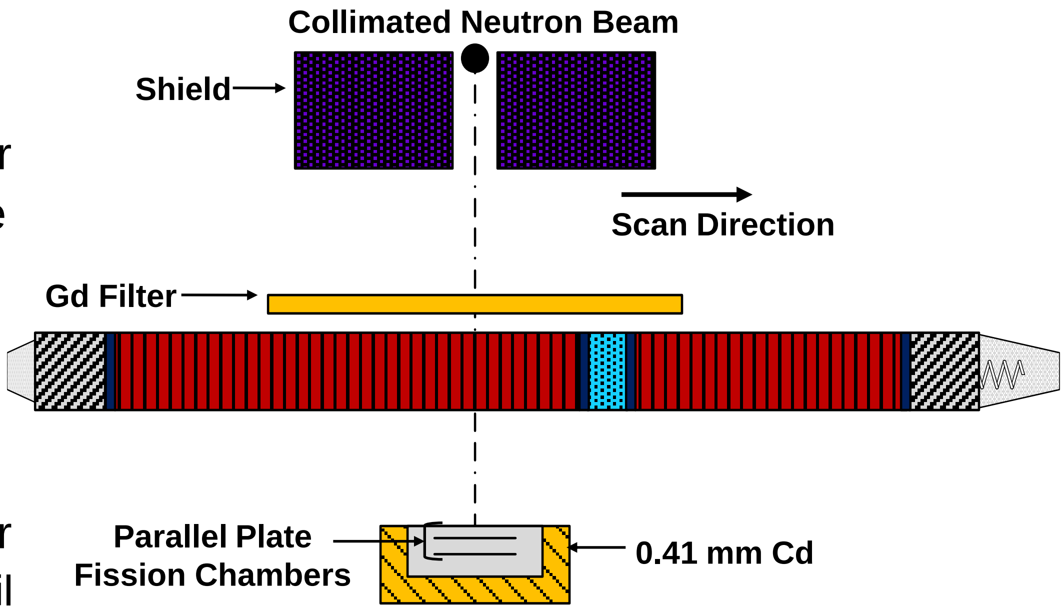
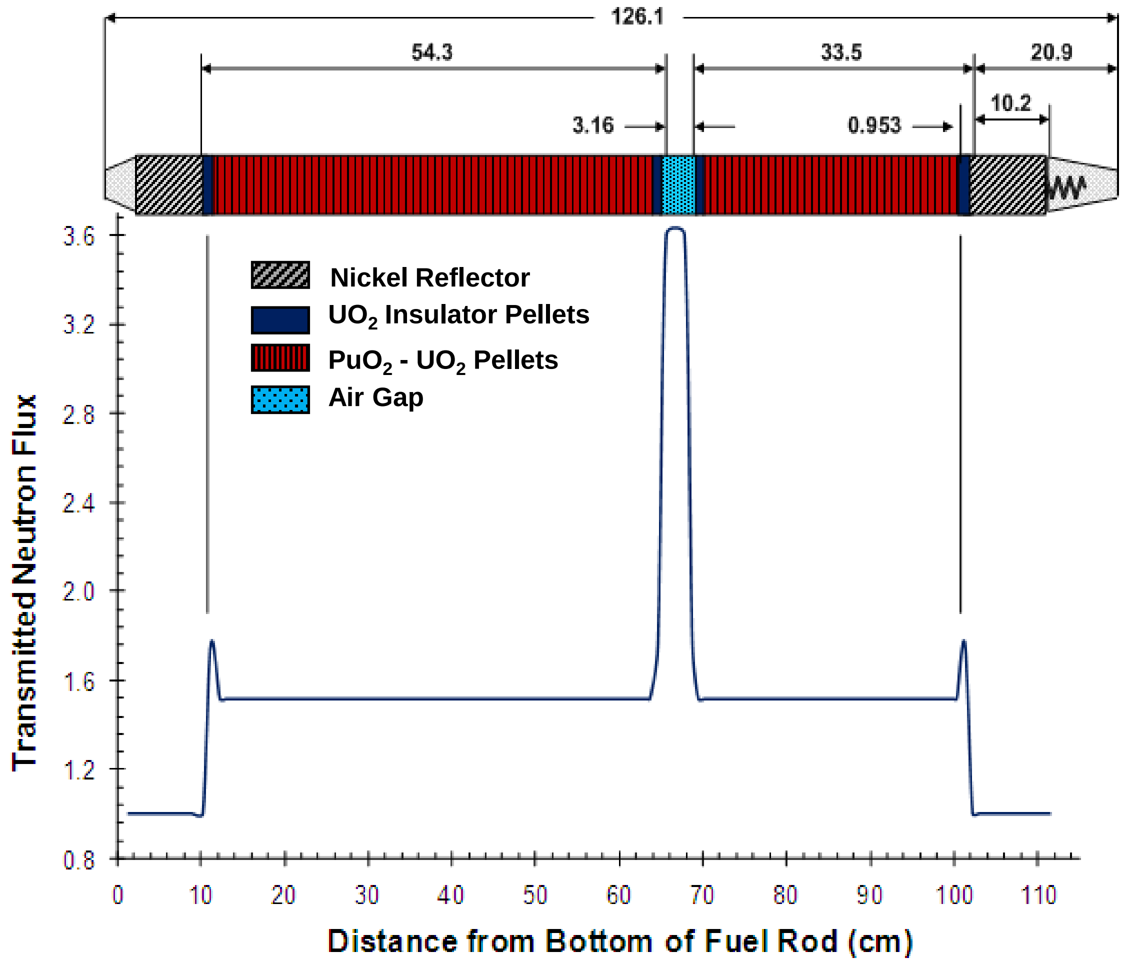
# MOX Fuel Rods – 1969 Experiment

- **South East Fast Oxide Reactor (SEFOR) fuel rods**
  - Reactivity measurements indicated that some pellets contained 5% - 40% less Pu than specified by manufacturer
  - SINRAD was used to measure the pellet-to-pellet Pu distribution in MOX rods
- **1969 experimental setup**
  - Collimated neutron beam from the LASL Water Boiler Reactor
    - Filtered by 0.025-mm Gd foil
  - MOX fuel rod was advanced across neutron beam path in 0.76-cm increments



# Schematic of the SEFOR Fuel Element

- **MOX Fuel composition and dimensions**
  - MOX fuel was 12 – 27 w/o $PuO_2$-$UO_2$ (depleted) mixture
  - Cylindrical pellets: 2.3-cm diameter and 1.6-cm high
- **Profile of neutron transmission data**
  - $^{238}U$ pellets are clearly distinguishable from MOX fuel segments
  - Eliminates the possibility of a rod containing only $^{238}U$ pellets



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# Nondestructive Assay Results for MOX Fuel Rods

- **Delayed neutron yield technique was used for measurements**
  - Amount of Pu in 4 irradiated rods is significantly less than the amount of Pu in the two standard rods
- **Results were used to calculate initial composition of MOX pellets in MCNPX model of 1969 experiment**

| | Rod Number | U + Pu (g) | $^{239}$Pu + $^{241}$Pu (g) | Pu / (U + Pu) |
|---|---|---|---|---|
| Standard Rods | A13 | 2949 | 738 | 27.3% |
| | 473 | 2930 | 549 | 20.5% |
| Irradiated Rods | 873 | 2956 ± 30 | 339 ± 9 | 12.5% |
| | 878 | 2926 ± 29 | 484 ± 12 | 18.1% |
| | 919 | 2862 ± 29 | 458 ± 11 | 17.5% |
| | 920 | 2900 ± 29 | 445 ± 11 | 16.8% |

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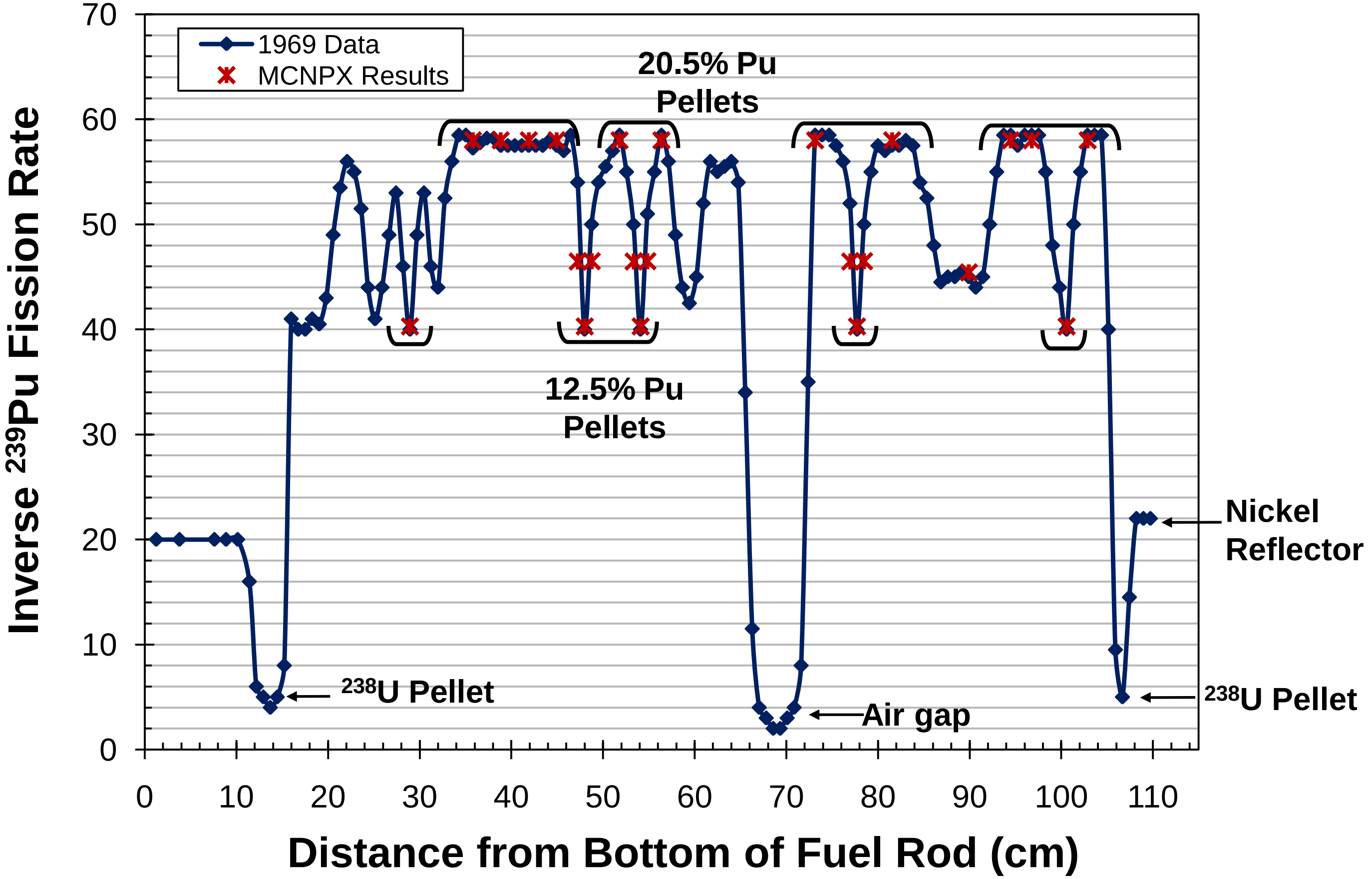
# MOX Fuel Rods - Benchmark Results (1)

- **Axial Pu distribution in SEFOR fuel rod 878 obtained from the self-indication neutron scan**



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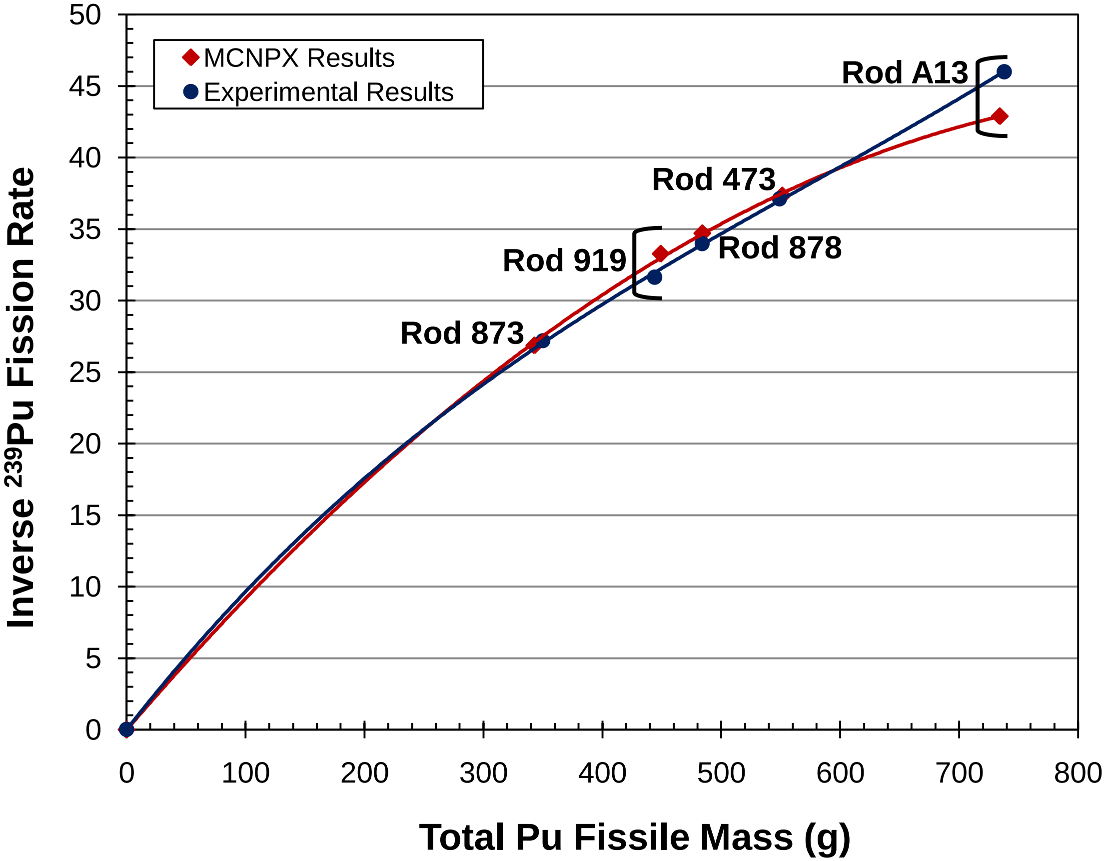
# MOX Fuel Rods - Benchmark Results (2)

- **Integral along the length of the rod of the inverse $^{239}$Pu fission rate as function of total fissile plutonium mass**



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# Conclusions

- **MCNPX Simulations**
  - Agreement of MCNPX results with 1968 and 1969 experimental measurements confirms the accuracy of MCNPX models used
  - Fissile Metal Plates: use of detectors ratios reduces sensitivity of measured response to extraneous material present in the fissile sample mixture
  - MOX Fuel Rods: SINRAD measurements were able to see through entire pellet and identify the Pu enrichment of misplaced pellets with high accuracy
- **Significance**
  - Application of SINRAD as verification method for spent fuel from FBR and LWR reactors
  - Enables MCNPX models of SINRAD to be applied to more complex geometries (e.g. LWR fuel assembly)
- **Future Work**
  - Develop and assess the sensitivity of using SINRAD to measure the $^{235}U$ and $^{239}Pu$ content in LWR spent fuel assemblies and pyroprocessing materials

# Acknowledgements

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# Notes