# Redux Analysis of $D_2O$ Reflected Plutonium Foils at Low Temperature

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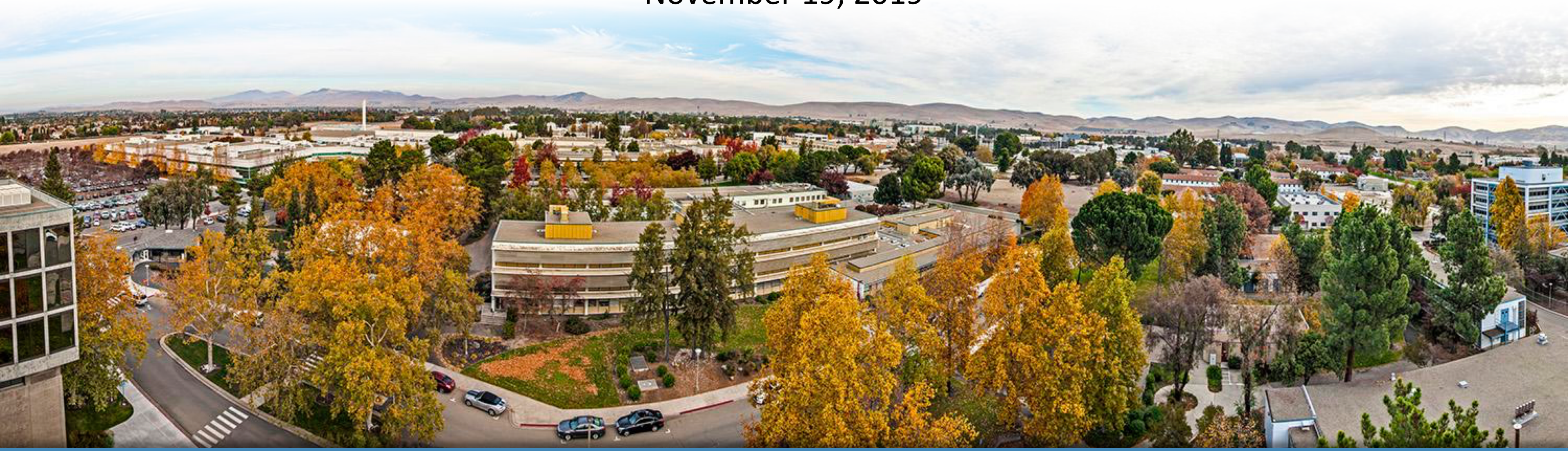

LLNL-PRES-######
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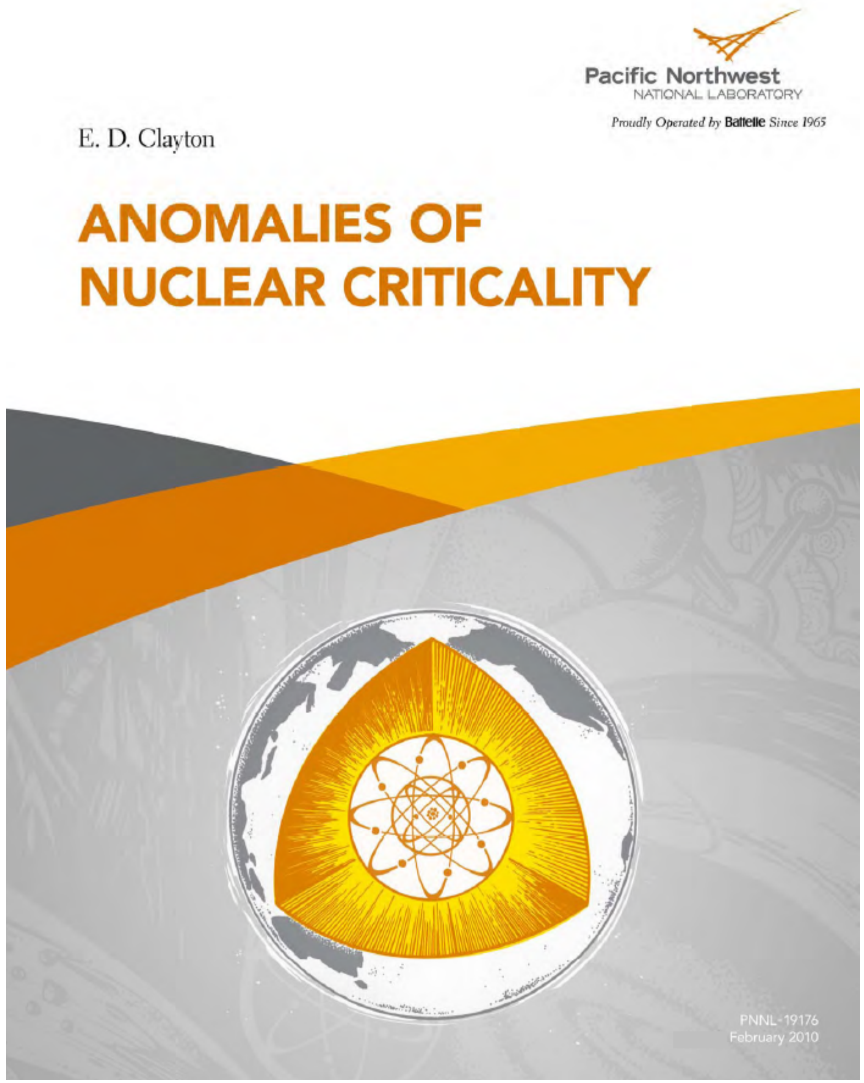
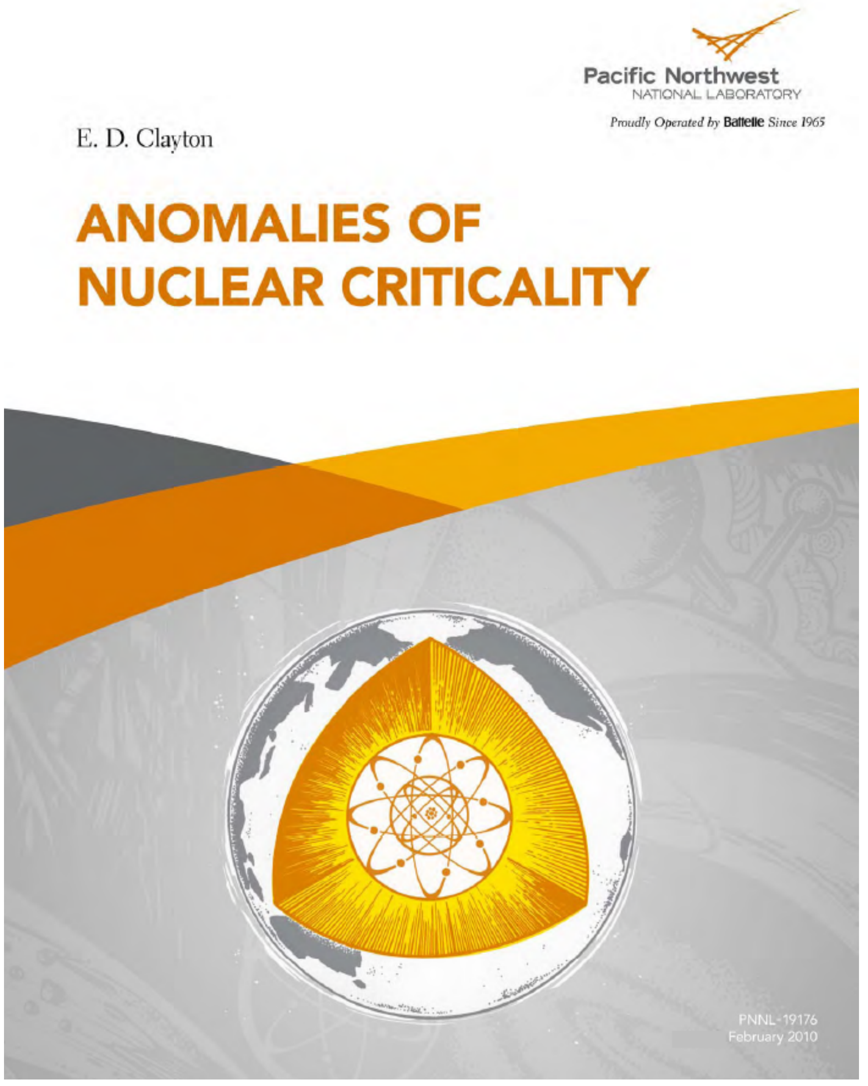
# Introduction

- “Small critical mass” concepts
  - Thin foils
  - Non-absorbing low temperature moderating reflectors



# Introduction

- Jarvis and Mills performed experiments at Los Alamos in the **1960s**
  - Results indicated that critical masses of **290-384 grams** could be achieved with **$^{235}$U (93%)**, polyethylene sheets, and beryllium reflector blocks in a cubic array
  - Experiments performed on the Comet vertical lift machine



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  - Experiments performed on the Comet vertical lift machine
  - They also performed calculations showing that the critical mass could be as low as **250 grams** if the $^{235}$**U** fuel were redistributed

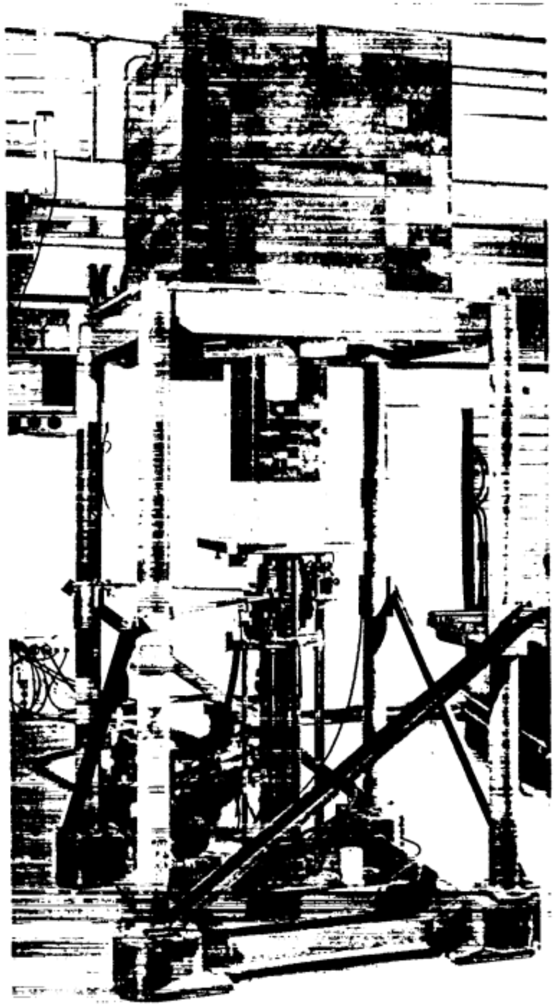
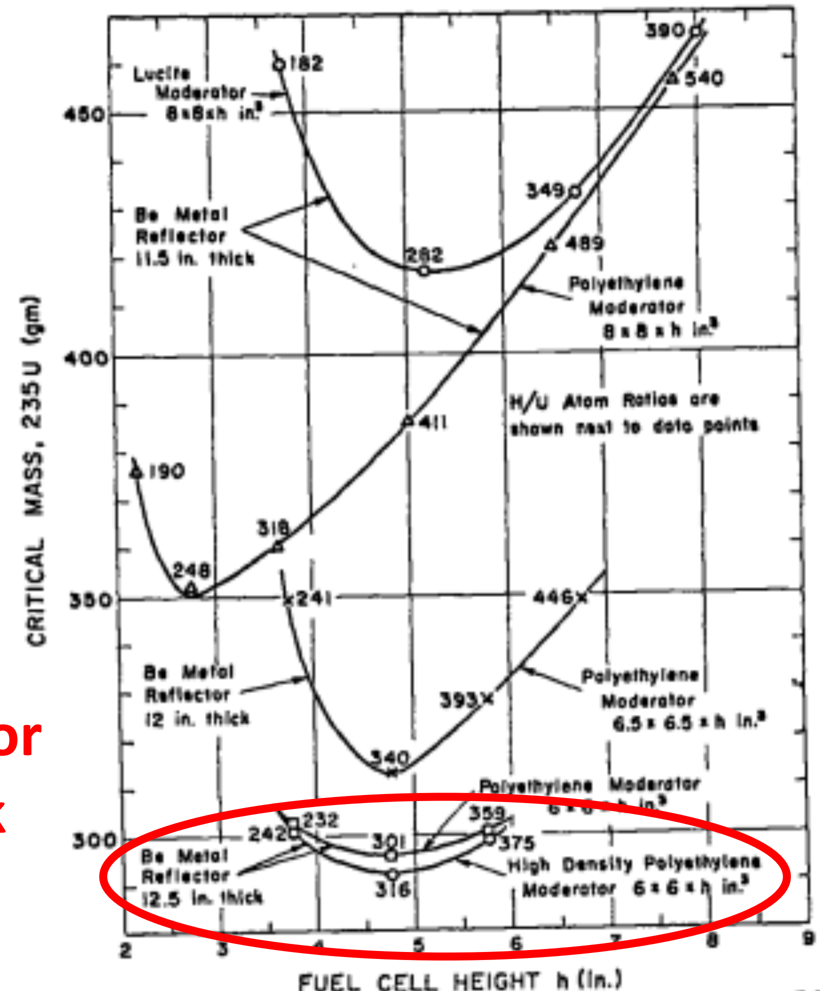


Fig. 4. The Comet critical assembly machine showing the minimum critical mass experiment with the core in the disassembled position.

# Introduction




Be metal reflector 12.5 inches thick

High Density Polyethylene Moderator

Fig. 5. Critical conditions for a polyethylene and $^{235}$U foil core in a beryllium reflector.

# Introduction

Table I. Critical Conditions for a Hydrogenous Core in a Thick Beryllium Reflector

| Moderator Material | Fuel Cell Cross Section (In.) | Fuel Cell Height (In.) | Beryllium* Reflector Thickness (In.) | Weight of Core Moderator Material (kg) | Average Moderator Thickness Between Foils (In.) | Critical Mass $^{235}U$ (grams) | Atomic Ratio $H/^{235}U$ |
|---|---|---|---|---|---|---|---|
| Polyethylene Density = 0.961 g/cc | 6.0 x 6.125 | 5.75 | 12.5 | 3.327 | 0.271** | 299 | 375 |
| | " | 4.75 | " | 2.749 | 0.224** | 292 | 316 |
| | " | 3.75 | " | 2.170 | 0.167** | 301 | 242 |
| Polyethylene Density = 0.928 g/cc | 6.0 x 6.125 | 5.75 | 12.5 | 3.215 | 0.256** | 301 | 359 |
| | " | 4.75 | " | 2.656 | 0.211** | 296 | 301 |
| | " | 3.75 | " | 2.097 | 0.167** | 303 | 232 |
| Polyethylene Density = 0.947 g/cc | 6.5 x 6.625 | 6.75 | 12.0 | 4.506 | 0.257 | 349 | 446 |
| | " | 5.75 | " | 3.839 | 0.230 | 328 | 393 |
| | " | 4.75 | " | 3.171 | 0.200 | 313 | 340 |
| | " | 3.75 | " | 2.504 | 0.200 | 349 | 241 |
| Polyethylene Density = 0.888 g/cc | 8.0 x 8.125 | 7.75 | 11.5 | 7.331 | 0.625 | 456 | 540 |
| | " | 6.50 | " | 6.148 | 0.520 | 422 | 489 |
| | " | 5.00 | " | 4.729 | 0.500 | 386 | 411 |
| | " | 3.63 | " | 3.429 | 0.322 | 360 | 318 |
| | " | 2.75 | " | 2.601 | 0.275 | 352 | 248 |
| | " | 2.25 | " | 2.128 | 0.225 | 376 | 190 |
| Lucite Density = 1.132 g/cc | 8.0 x 8.125 | 8.00 | 11.5 | 9.670 | 0.625 | 466 | 390 |
| | " | 6.56 | " | 8.034 | 0.540 | 433 | 349 |
| | " | 5.20 | " | 6.248 | 0.420 | 417 | 282 |
| | | 3.76 | " | 4.463 | 0.342 | 460 | 182 |

**These six stackings had uranium foil on all six sides of the fuel cell.

# Introduction

- Olson and Robkin published a paper **1970** called "A New Small Mass Critical Configuration" in the *ANS Transactions*
  - Modeled a sheet of $^{235}U$ or $^{239}Pu$ surrounded by $D_2O$
  - Temperature of core and moderator was lowered to 4K (boiling point of $^4He$)
  - With and without edge reflection around $D_2O$

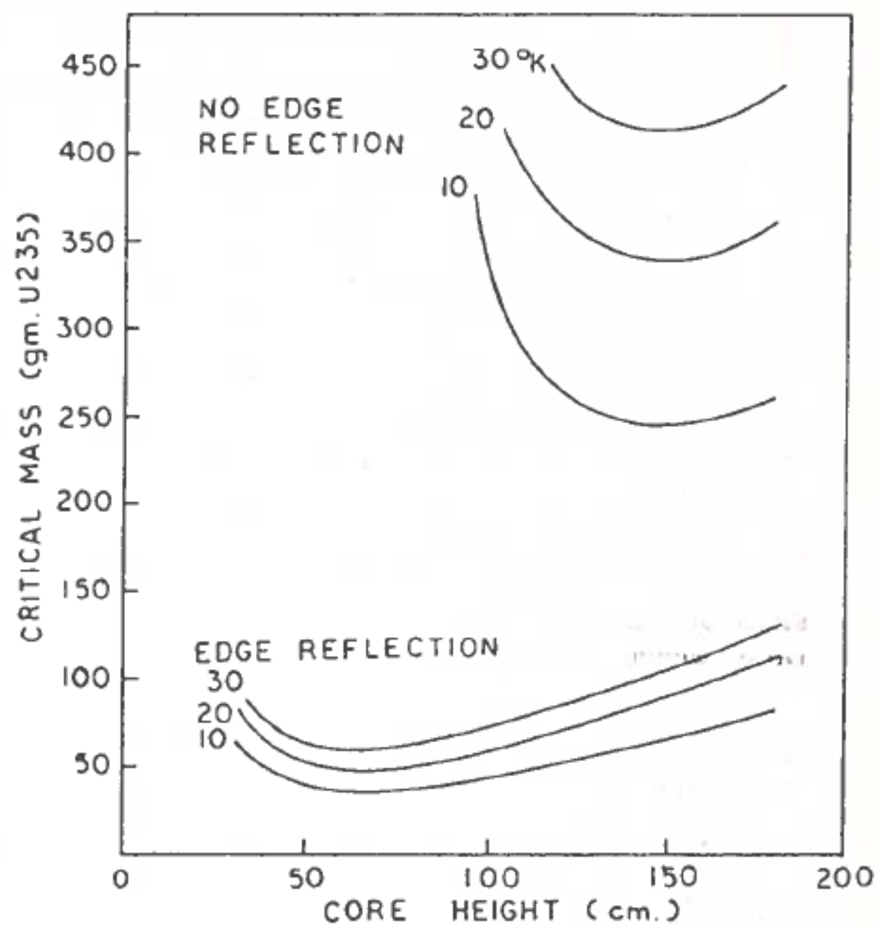



Fig. 1. Critical mass of $^{235}U$ as a function of core height for assumed core neutron temperatures of 10, 20, and 30°K.

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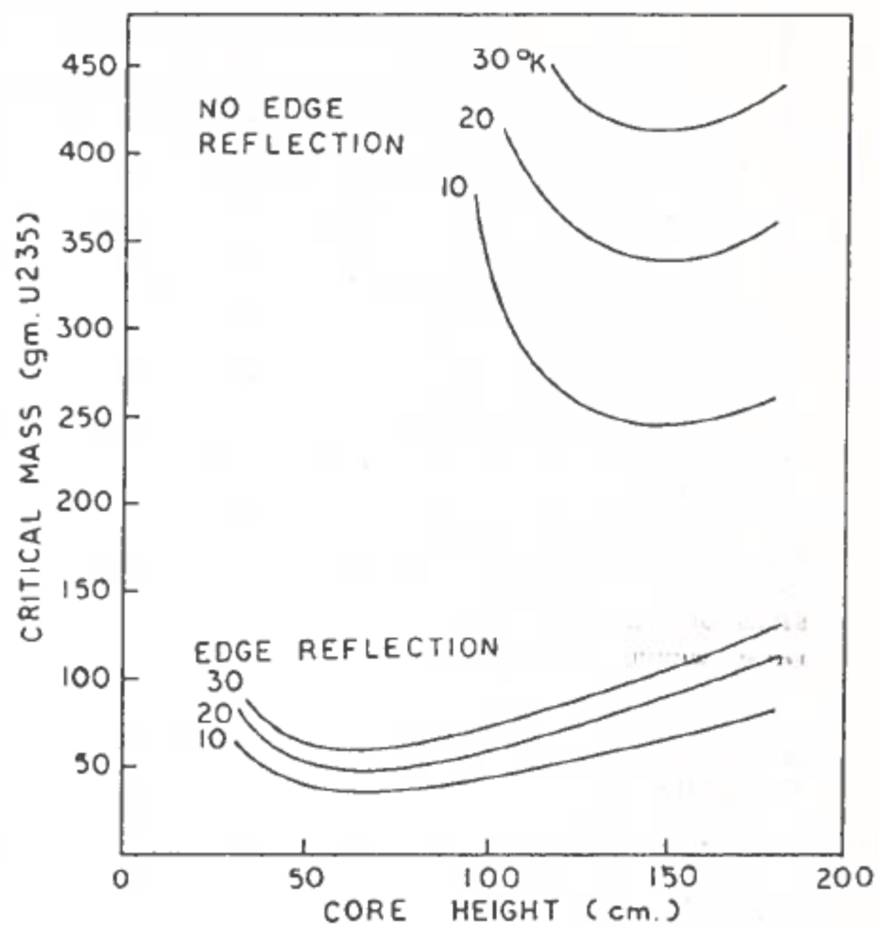
- In **1977**, Yates published a paper, citing Olson and Robkin's paper.
  - Modeled spherical shells of $^{235}U$ and $^{239}Pu$ instead of thin sheets
  - Did not use edge reflectors
  - Did not model the system at low temperature

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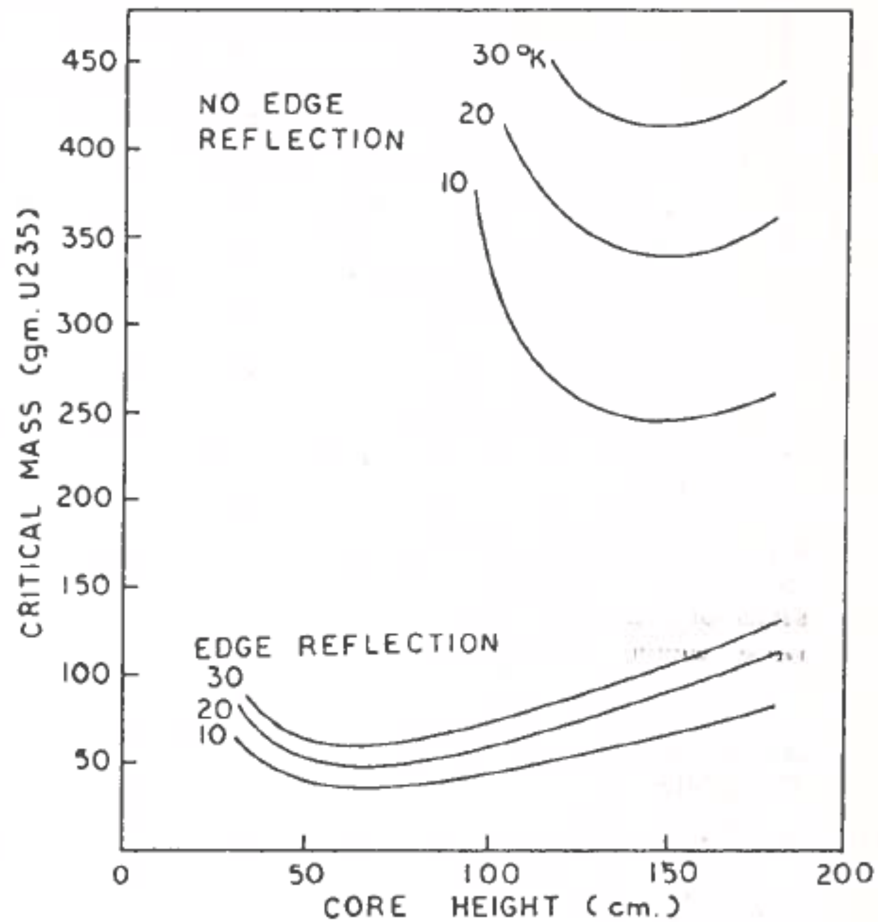


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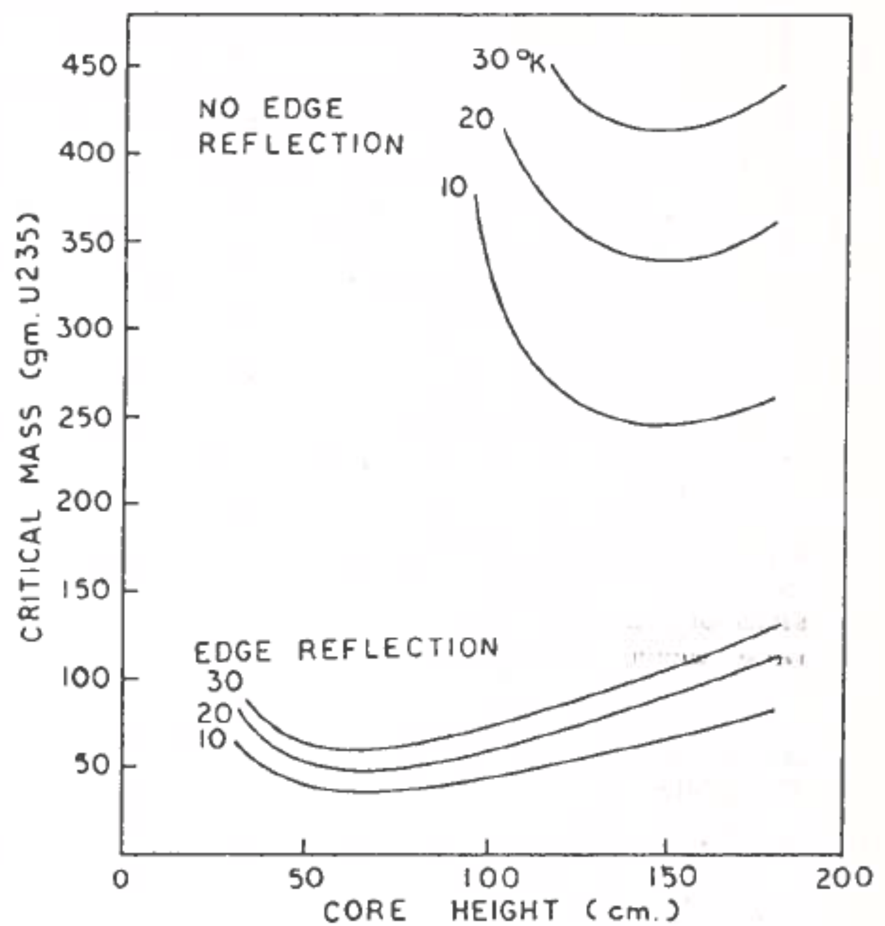
  - "Critical masses" were slightly lower than Olson and Robkin's results at room temperature
  - Performed a hand calculation to determine the "critical mass" at 4K

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- Jarvis and Mills critical masses (1967)
  - **290-384 grams with $^{235}U$, polyethylene, and beryllium blocks**
  - Experimentally validated results
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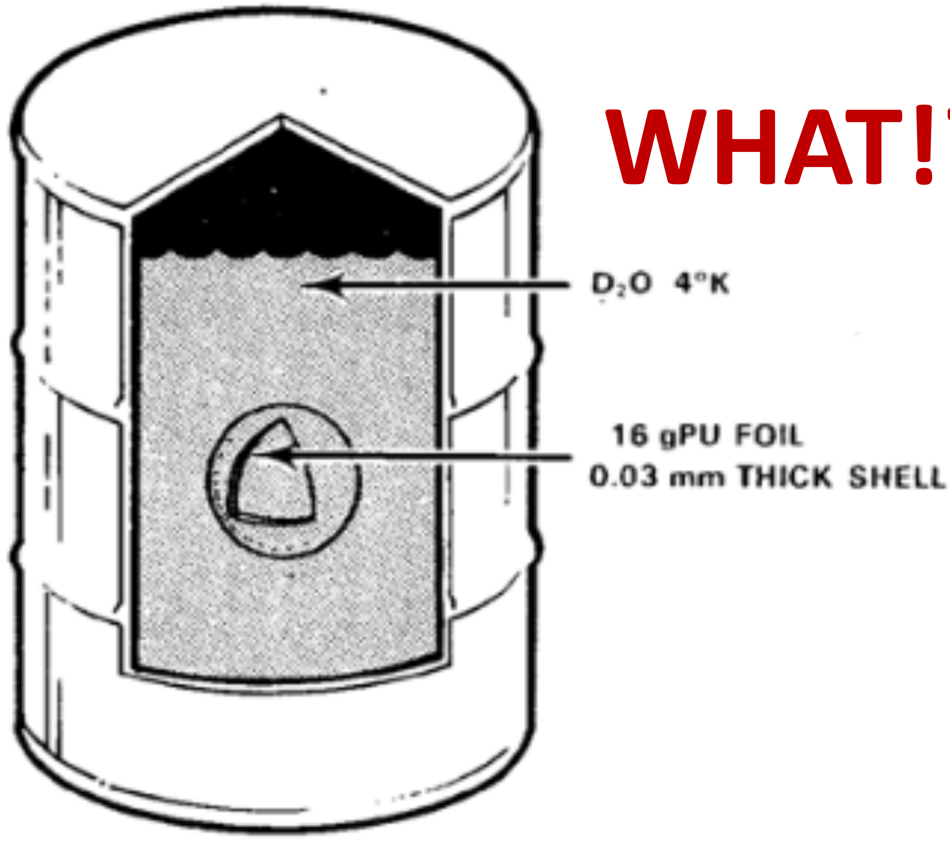
- Yates "critical mass" (1977)
  - **15.6 grams with $^{239}Pu$ at 4K (220-240 cm box of $D_2O$)**
  - Models only
  - No low temperature calculations

# Introduction

- Anomalies of Nuclear Criticality
  - **16 grams of $^{239}$Pu inside of a 55-gallon drum filled with $D_2O$ at 4K**

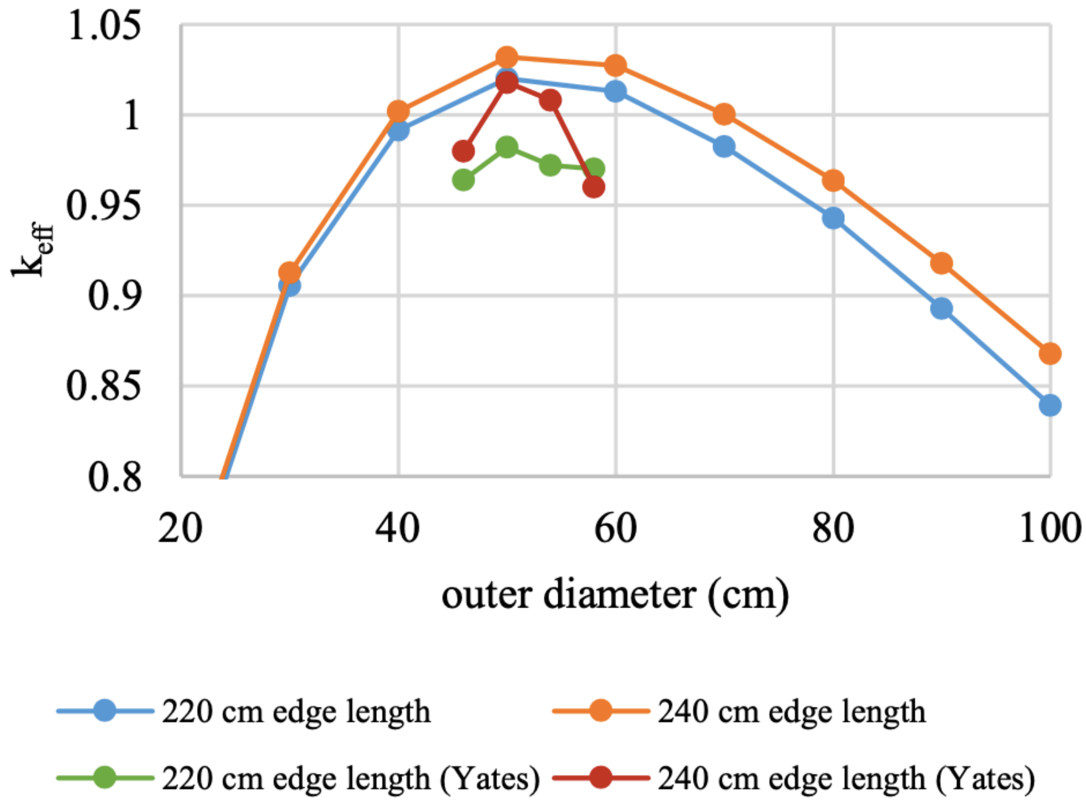



WHAT!?!

# Redux Analysis

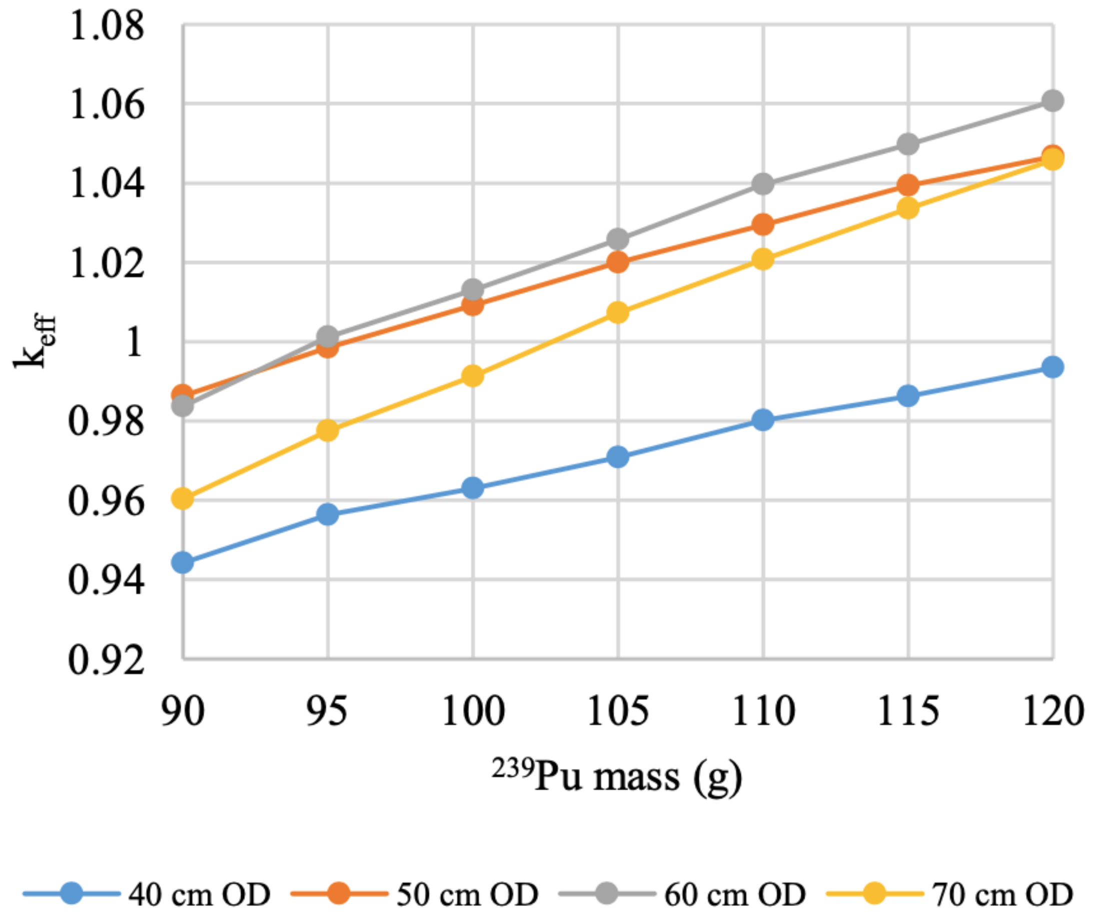
- We reperformed Yates' calculations for $^{239}Pu$ with MCNP6.2 and ENDF/B-VII.1 nuclear data.
  1. Initial calculations were performed at room temperature with S(a,B) cross sections
  2. Used *makxsf* tool to adjust cross section temperatures to 4K
  3. Did not use S(a,B) cross sections at low temperature

# Redux Analysis




390-gram $^{239}$Pu spherical shell at Room Temperature

# Redux Analysis




$D_2O$ reflected $^{239}Pu$ spherical shell at 4K, 220 cm edge length

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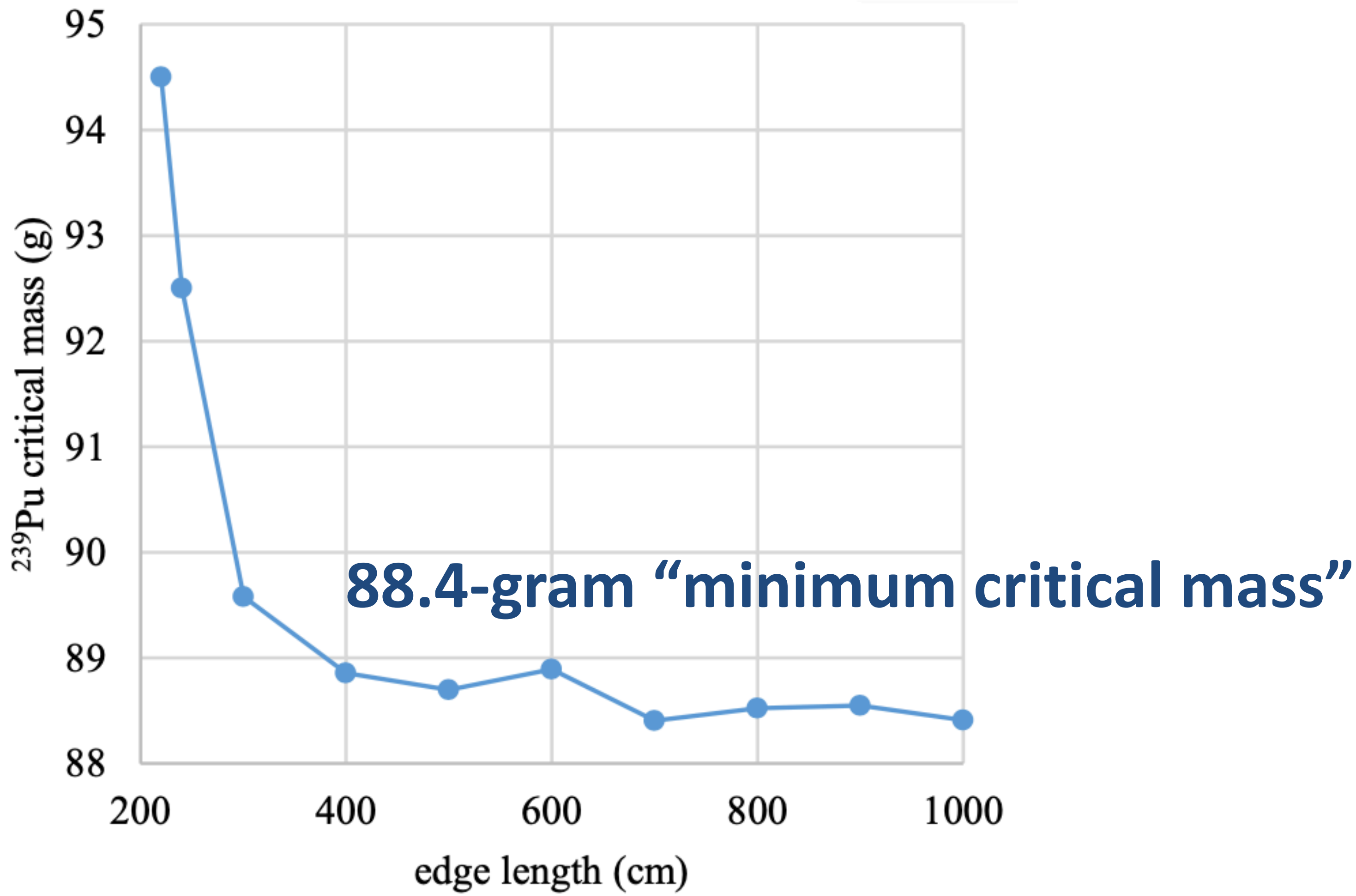


$D_2O$ reflected $^{239}Pu$ spherical shell at 4K (60 cm OD)

# Conclusions

- Our results show that Yates' "minimum critical mass" should have been closer to **88.4-95 grams of $^{239}$Pu**, not **15.6 grams**

- In the next revision of *Anomalies of Nuclear Criticality*, the section on small critical mass concepts should be edited
  - Other sections that reference old or outdated calculations should also be reviewed for accuracy

- There is a need for low-temperature critical benchmark experiments
  - The results of these calculations are **not accurate**
  - The density of the system was held constant, which is not realistic

# Questions?

*“That’s bananas.”*

\- Will Zywiec

(upon hearing about a 15.6-gram minimum critical mass for the first time)