# GCFR-PROTEUS EXPERIMENTAL PROGRAM CORE 11- NOMINAL CORE CONFIGURATION BENCHMARK


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# Special Thanks


- This project was supported by the U.S. Department of Energy, NEUP program.


NEUP | Nuclear Energy University Programs

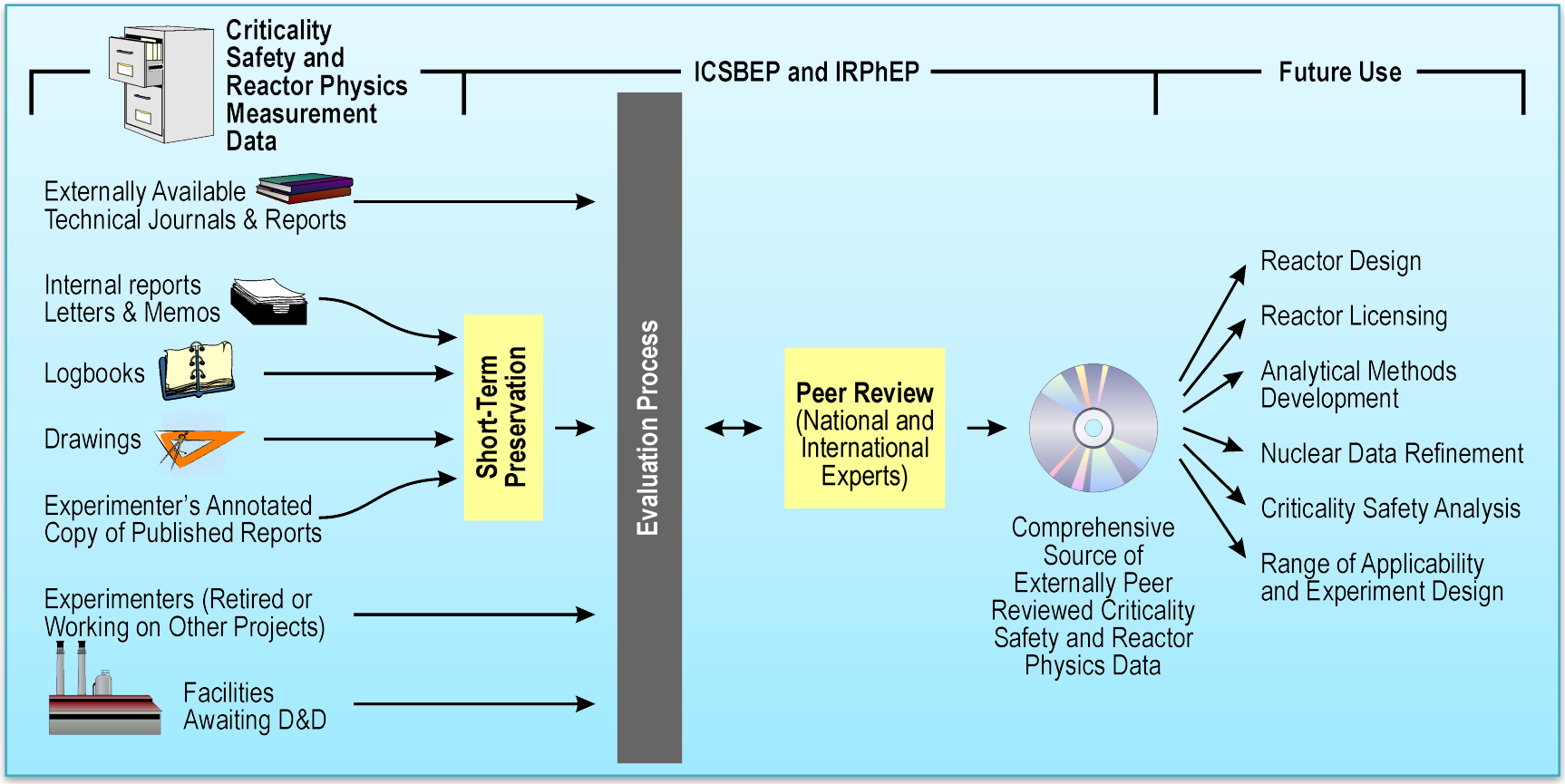
U.S. Department of Energy

# Purpose

- Re-evaluate experiments of GCFR Core designs performed in the 1970s at the PROTEUS reactor.
- Preserve decades old integral nuclear data.

- Enable the validation of thorium, neptunium, plutonium, and uranium cross sections.

# Purpose of the ICSBEP and IRPhEP



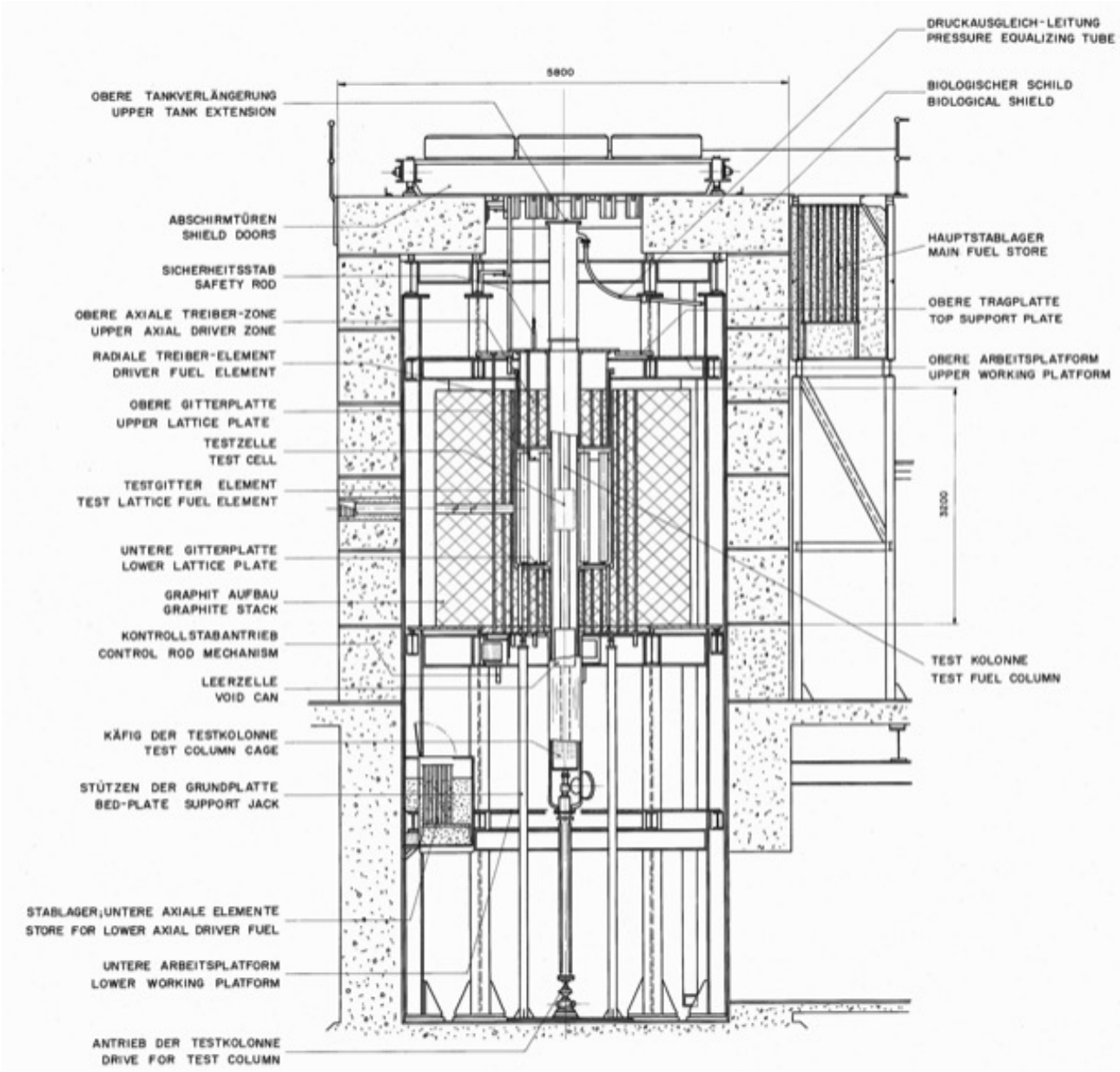
# Benchmark Process General Overview

1. Identify Experiment
2. Evaluate Experiment
   a. Prepare Benchmark Report
3. Internal Review of Benchmark Report
4. Submit Benchmark Experiment to ICSBEP/IRPhEP
5. Independent Review of Benchmark Report
6. Distribution of Benchmark Report to Technical Review Group
7. Technical Review Meeting
8. Resolve Action Items
9. Handbook Publication

# PROTEUS

- Lifetime: February 1968-April 2011
- Thermal Power Rating: 1 kilowatt.
- Driver Region Dimension: 3.5m diameter/ 3.5m height.
- Driver Fuel: 1m length $UO_2$ at 5 w/o.
- Central Cavity Dimension: 1.2m diameter/10m height.
- Central Cavity Fuel: Variable

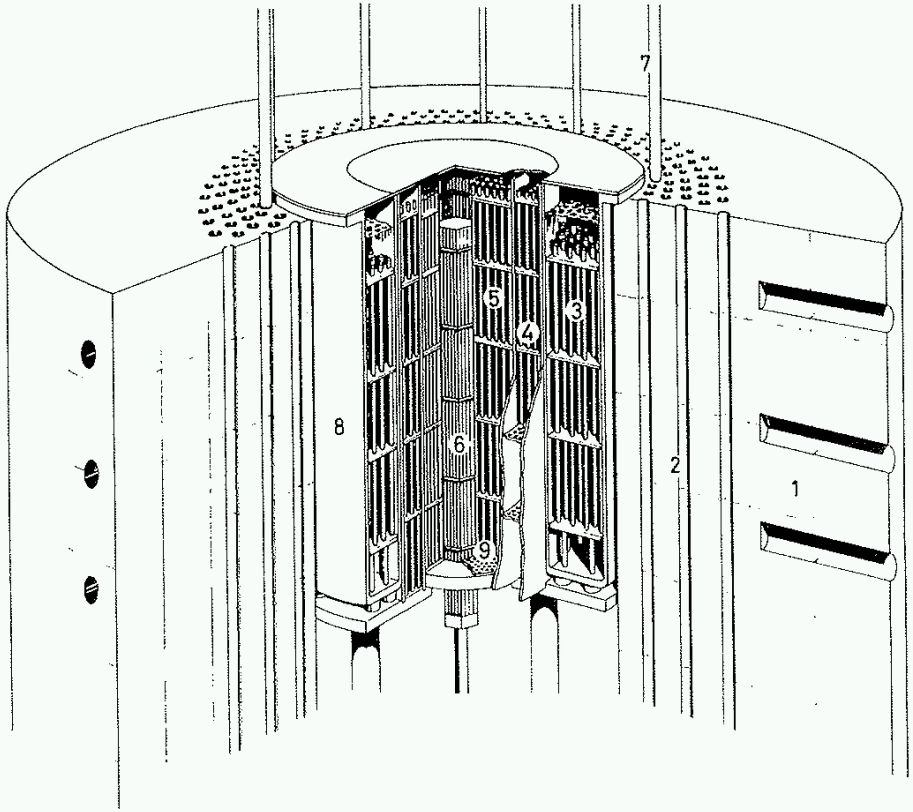
# PROTEUS


5800
3200
OBERE TANKVERLÄNGERUNG
UPPER TANK EXTENSION
ABSCHIRMTÜREN
SHIELD DOORS
SICHERHEITSSTAB
SAFETY ROD
OBERE AXIALE TREIBER-ZONE
UPPER AXIAL DRIVER ZONE
RADIALE TREIBER-ELEMENT
DRIVER FUEL ELEMENT
OBERE GITTERPLATTE
UPPER LATTICE PLATE
TESTZELLE
TEST CELL
TESTGITTER ELEMENT
TEST LATTICE FUEL ELEMENT
UNTERE GITTERPLATTE
LOWER LATTICE PLATE
GRAPHIT AUFBAU
GRAPHITE STACK
KONTROLLSTABANTRIEB
CONTROL ROD MECHANISM
LEERZELLE
VOID CAN
KÄFIG DER TESTKOLONNE
TEST COLUMN CAGE
STÜTZEN DER GRUNDPLATTE
BED-PLATE SUPPORT JACK
STABLAGER;UNTERE AXIALE ELEMENTE
STORE FOR LOWER AXIAL DRIVER FUEL
UNTERE ARBEITSPLATFORM
LOWER WORKING PLATFORM
ANTRIEB DER TESTKOLONNE
DRIVE FOR TEST COLUMN
DRUCKAUSGLEICH-LEITUNG
PRESSURE EQUALIZING TUBE
BIOLOGISCHER SCHILD
BIOLOGICAL SHIELD
HAUPTSTABLAGER
MAIN FUEL STORE
OBERE TRAGPLATTE
TOP SUPPORT PLATE
OBERE ARBEITSPLATFORM
UPPER WORKING PLATFORM
TEST KOLONNE
TEST FUEL COLUMN

# GCFR-PROTEUS

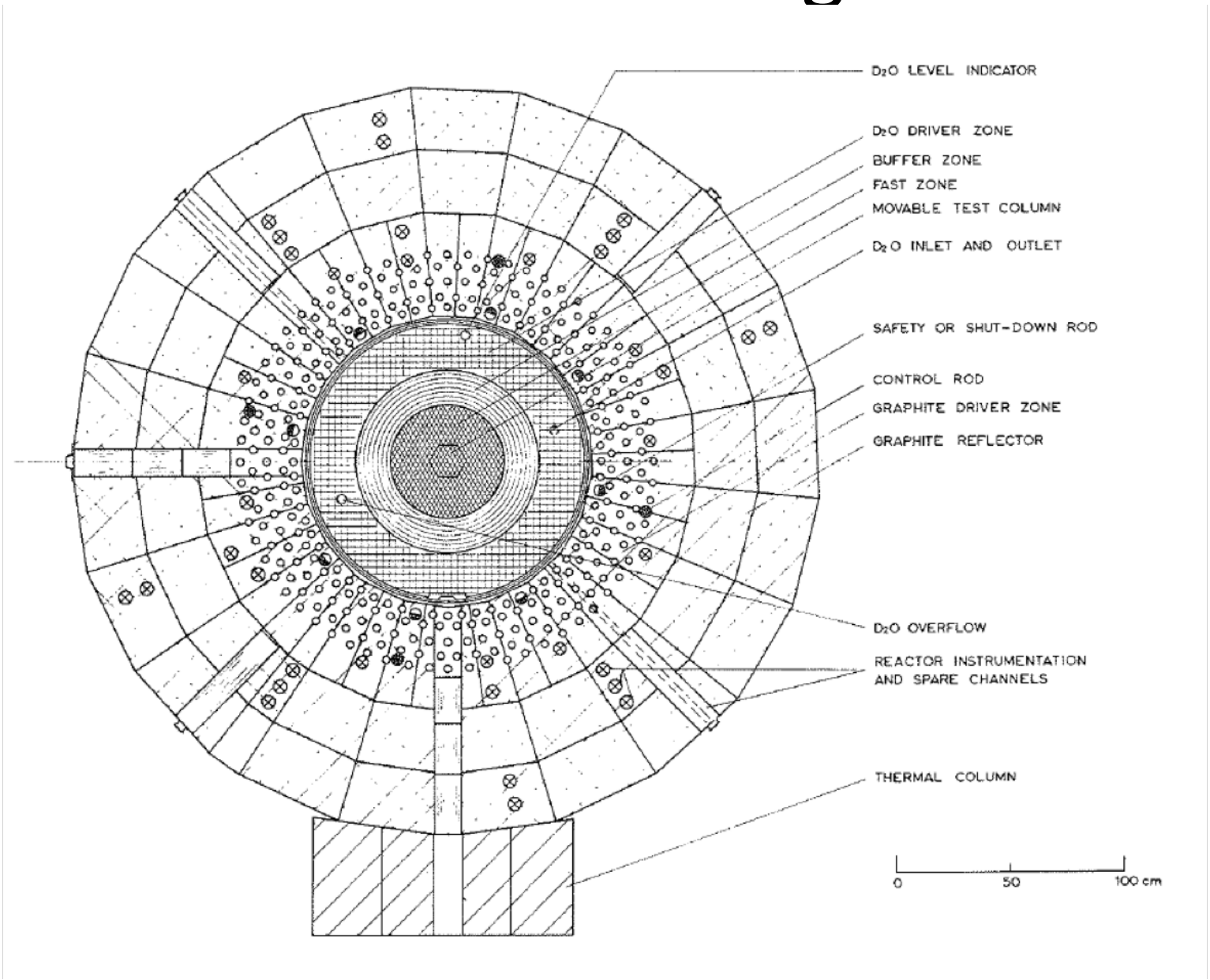
- April 1972 to April 1979 – Benchmark Experiments in PROTEUS to validate Neutronics calculations in GCFR core
- Increased interest in GFR concepts & $Th^{232}/U^{233}$ fuel cycle in the 70's
- Experiments required for accurate measurement of basic neutron cross section data, supplementing design calculations
- Initial cores – MOX cores (U238/Pu239 fuel cycle)
- Latter cores dedicated to Th232/U233 fuel cycle, homogeneous & heterogeneous distributions of Thorium
- C8/F9, F8/F9, C2/F9 etc, characterised breeding ratio, power distribution, neutron spectrum, axial & radial profiles etc.
- Experimental results compared with deterministic calculations

# Proteus GCFR Configuration



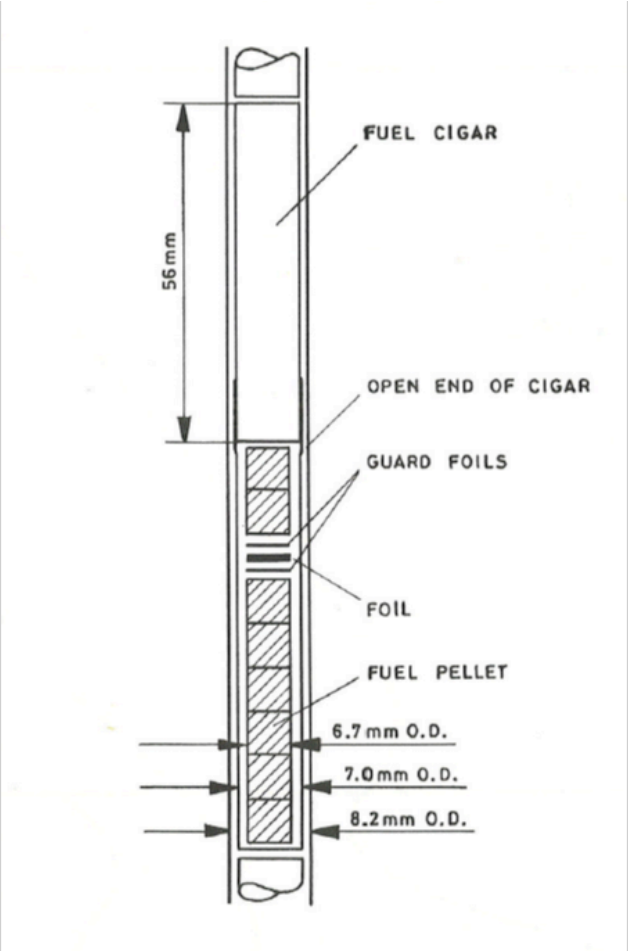

1 GRAPHITE REFLECTOR
2 GRAPHITE DRIVER
3 $D_2O$-DRIVER
4 BUFFER (U-METAL)
5 FAST ZONE ($PuO_2/UO_2$)
6 TEST COLUMN
7 CONTROL ROD
8 MODERATOR TANK
9 REMOVABLE GRID PLATE

# Proteus GCFR Configuration



# Measurement Techniques

- Spectral Indices: Foil activation / fission chambers
- γ-counting : Twin Ge(Li) or NaI detectors

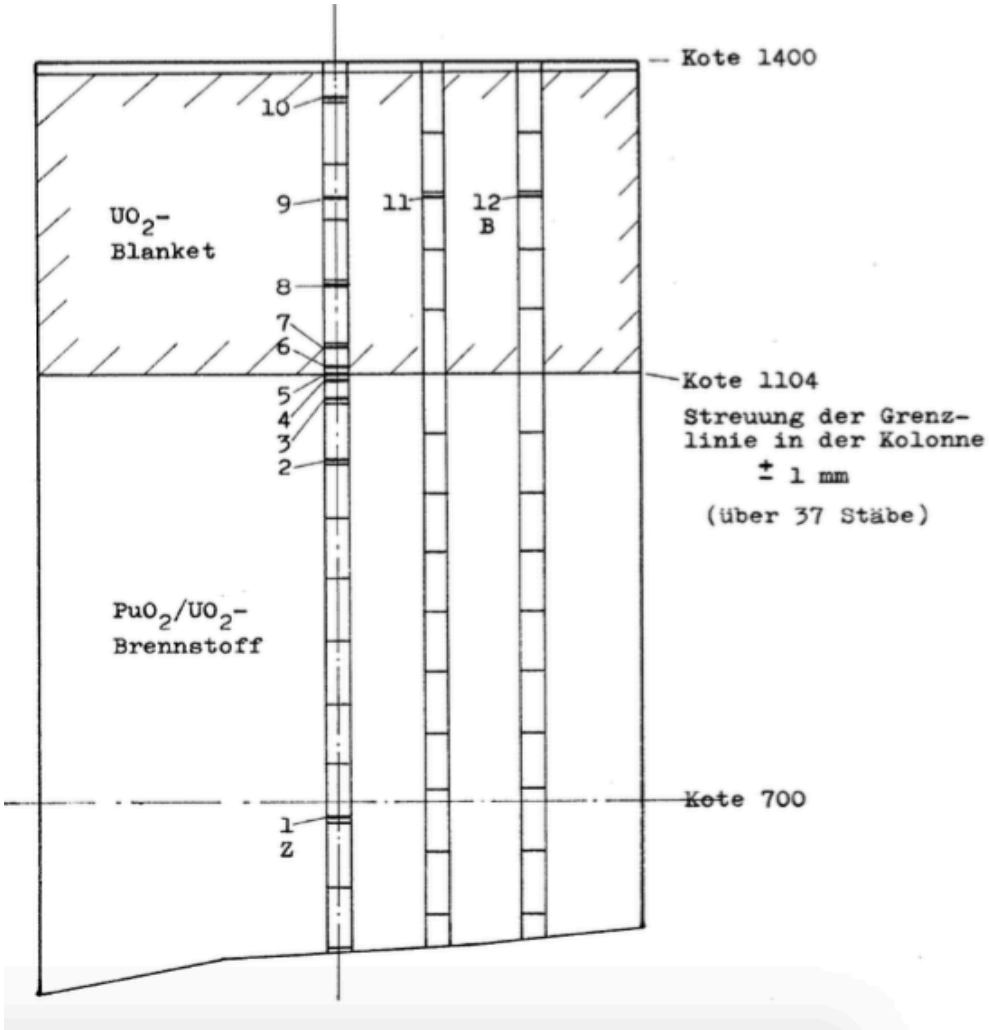


# Foil Measurements

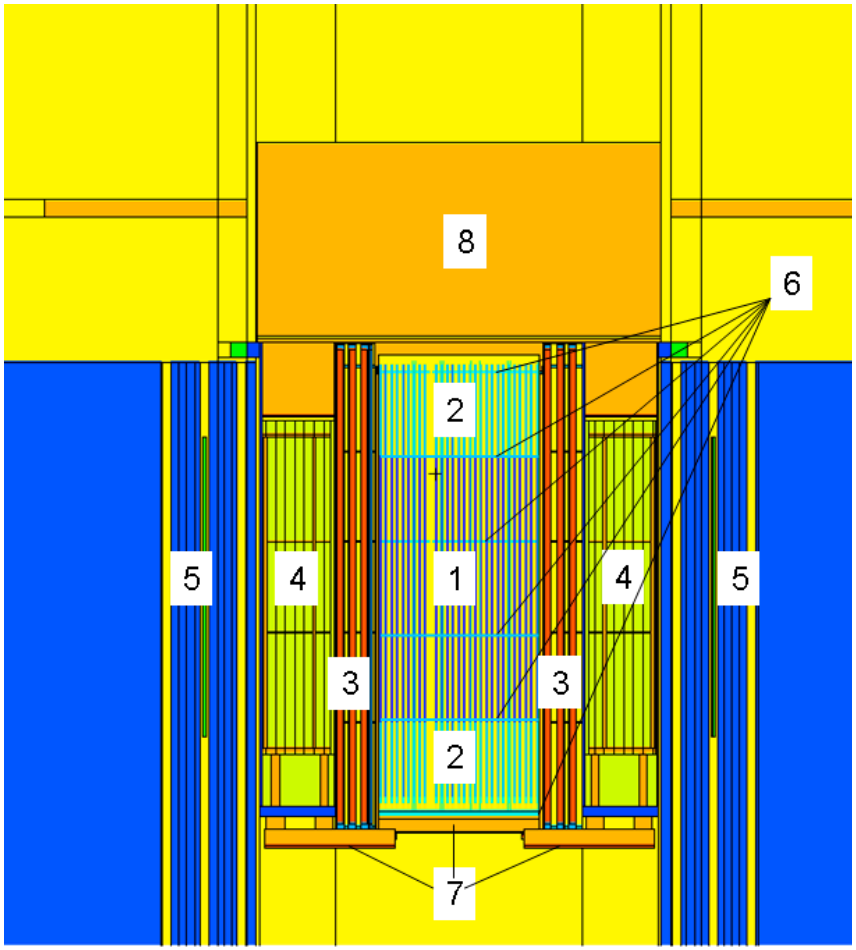
Experiment Values and Uncertainties

| Ratio | Experiment | 1σ |
|---|---|---|
| **c8/f9** | 1.33E-01 | 1.463E-03 (1.1%) |
| **f8/f9** | 3.11E-02 | 4.043E-04 (1.3%) |
| **f5/f9** | 1.01E+00 | 1.414E-02 (1.4%) |
| **c2/f9** | 2.00E-01 | 2.600E-03 (1.3%) |
| **f2/f9** | 8.06E-03 | 1.612E-04 (2.0%) |
| **f3/f9** | 1.52E+00 | 1.976E-02 (1.3%) |
| **(n,2n)2/c2** | 6.84E-03 | 1.710E-04 (2.5%) |
| **c7/f9** | 8.26E-01 | 1.8998E-02 (2.3%) |
| **f7/f9** | 2.27E-01 | 4.086E-03 (1.8%) |

Foil Locations

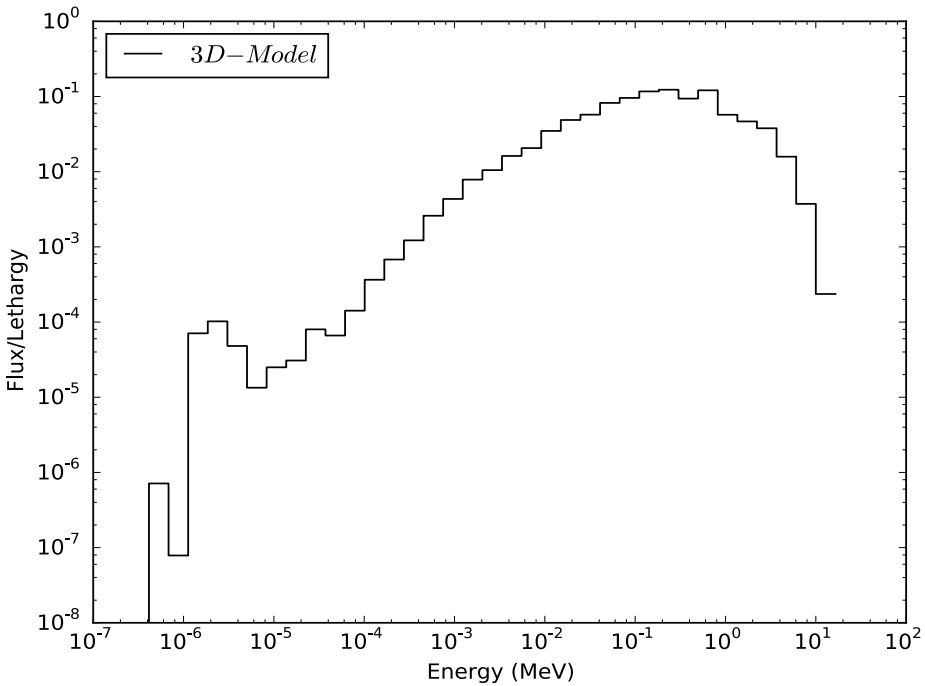


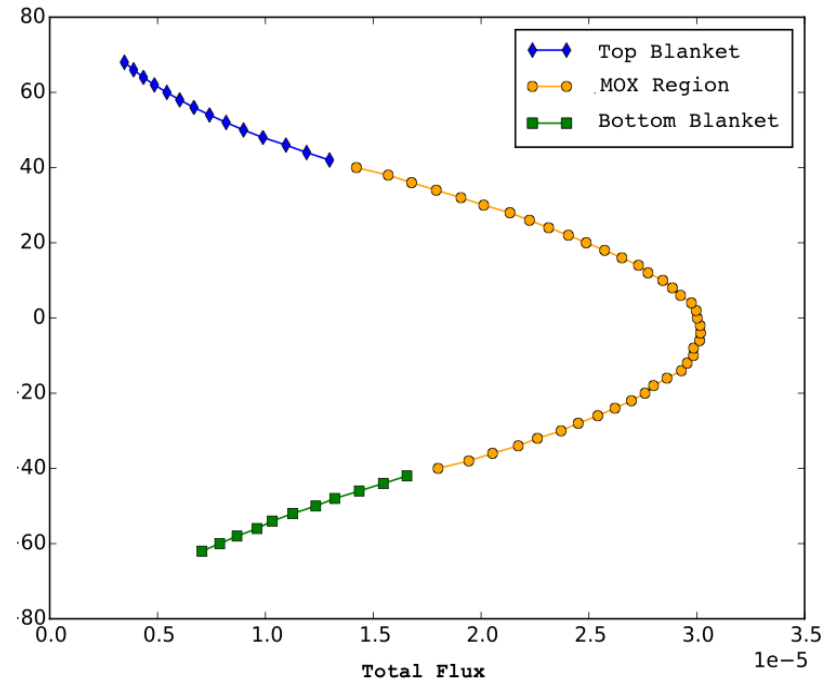
# Core 11 MCNP Model




1 – Test Zone (MOX lattice)
2 – Blanket Zone (UO2 lattice)
3 – Buffer zone
4 – D2O zone
5 – Graphite Driver Zone
6 – Grid plates
7 - Reactor support plates
8 – Steel Shielding

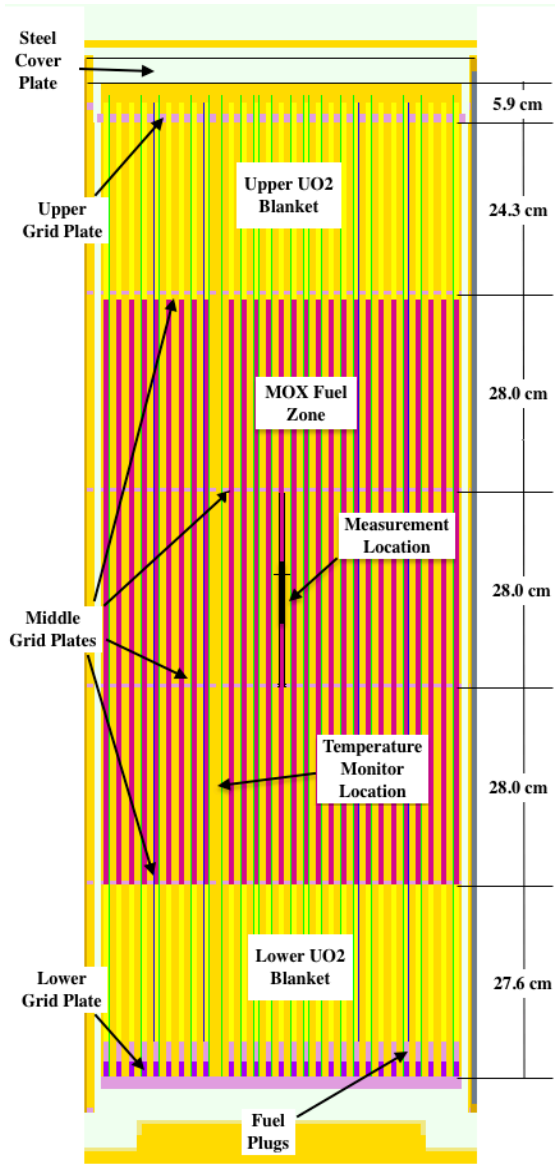
# Core 11 Energy Profile & Axial Flux Distribution



# Model Techniques

- Volume Averaging
- $RR = F4 * XS$
- $Spectral\ Index = \frac{RR_x}{RR_y}$
- Ratio allows for direct comparison between foil and model volumes



# Summary of experimental uncertainties in GCFR-PROTEUS Core 11

| Spectral Indices | Measurement Uncertainty (Δ/MEAN) | Evaluated Experimental Uncertainty (Δ/MEAN) | Total Experimental Uncertainty (Δ/MEAN) |
|---|---|---|---|
| **c8/f9** | 1.4630E-03 (1.100%) | 1.476E-04 (0.112%) | 1.470E-03 (1.106%) |
| **f8/f9** | 4.0430E-04 (1.300%) | 7.427E-05 (0.235%) | 4.111E-04 (1.322%) |
| **f5/f9** | 1.4140E-02 (1.400%) | 6.774E-04 (0.066%) | 1.416E-02 (1.402%) |
| **c2/f9** | 2.6000E-03 (1.300%) | 1.058E-03 (0.514%) | 2.807E-03 (1.404%) |
| **f2/f9** | 1.6120E-04 (2.000%) | 1.855E-05 (0.244%) | 1.623E-04 (2.013%) |
| **f3/f9** | 1.9760E-02 (1.300%) | 1.288E-03 (0.086%) | 1.980E-02 (1.303%) |
| **(n,2n)2/c2** | 1.7100E-04 (2.500%) | 1.018E-04 (1.333%) | 1.990E-04 (2.910%) |
| **c7/f9** | 1.8998E-02 (2.300%) | 1.321E-03 (0.160%) | 1.904E-02 (2.306%) |
| **f7/f9** | 4.0860E-03 (1.800%) | 3.072E-04 (0.135%) | 4.098E-03 (1.805%) |

<u>Perturbations</u>

*Type:*

Density, isotope fraction, composition, impurities

*Materials:*

Fuel, structural materials (steel/aluminum), $D_2O$, graphite

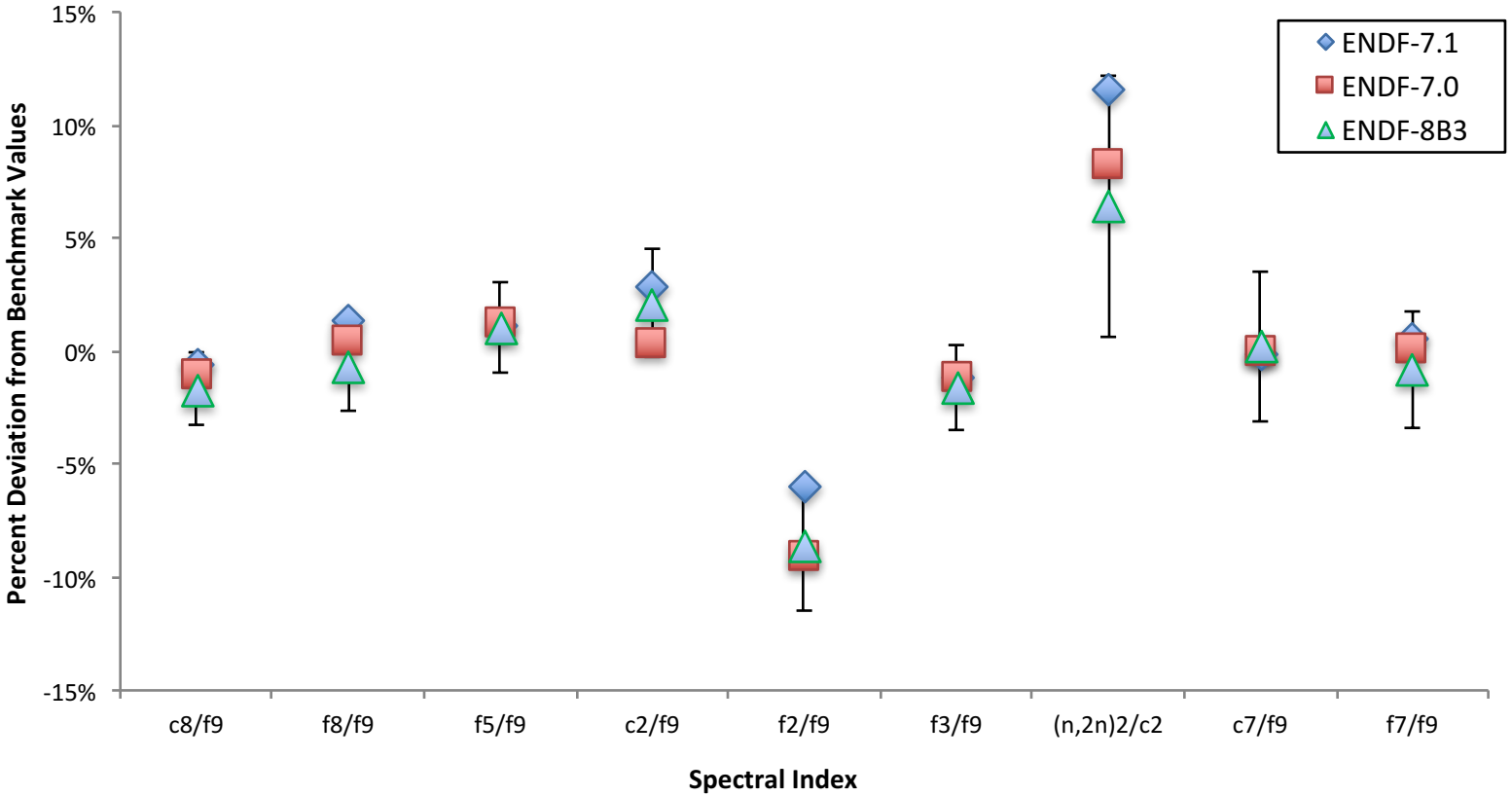
*Scaling Factors:*

MCNP limitations

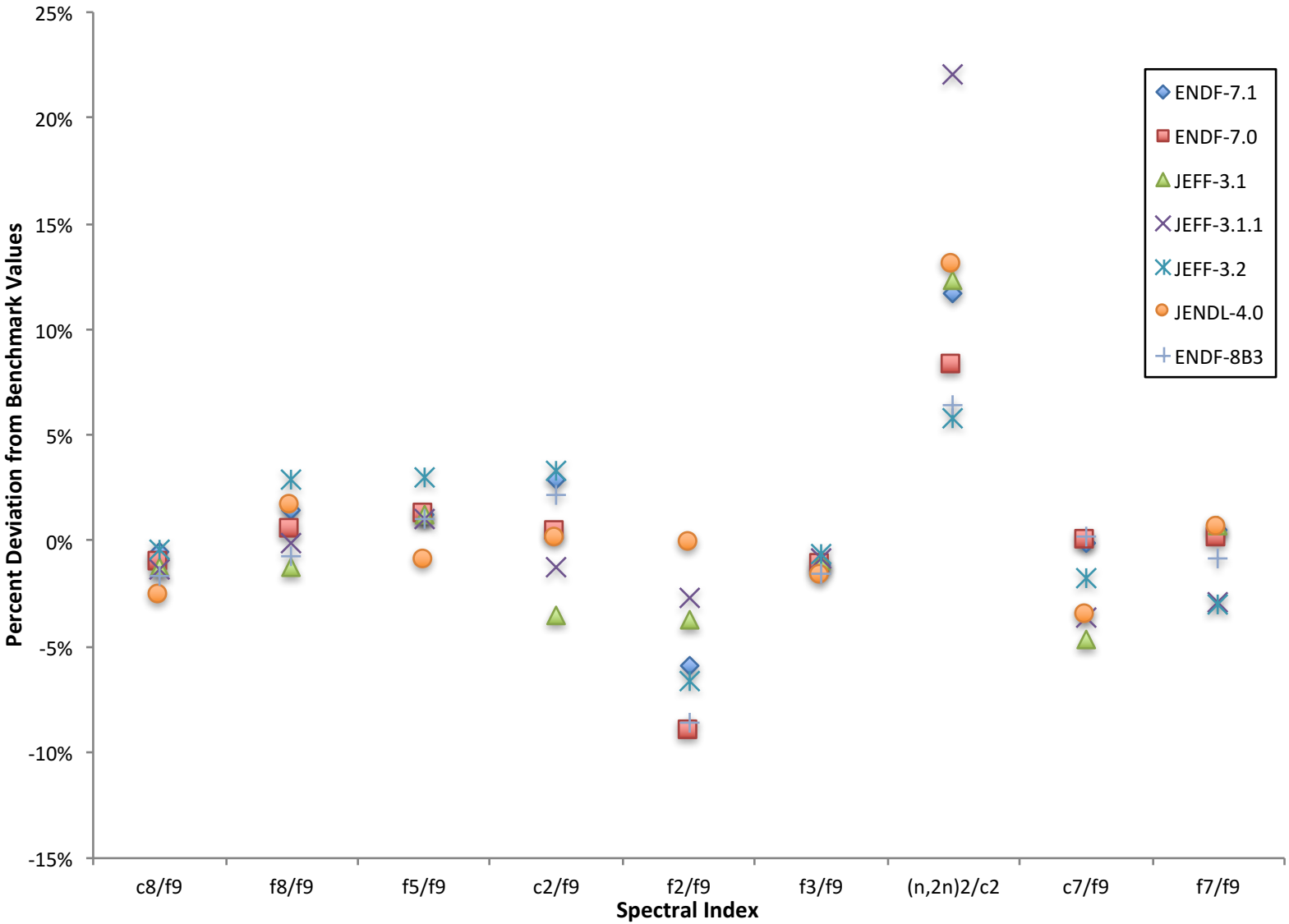
10 to 100

# Comparison of ENDF Cross Sections Core 11

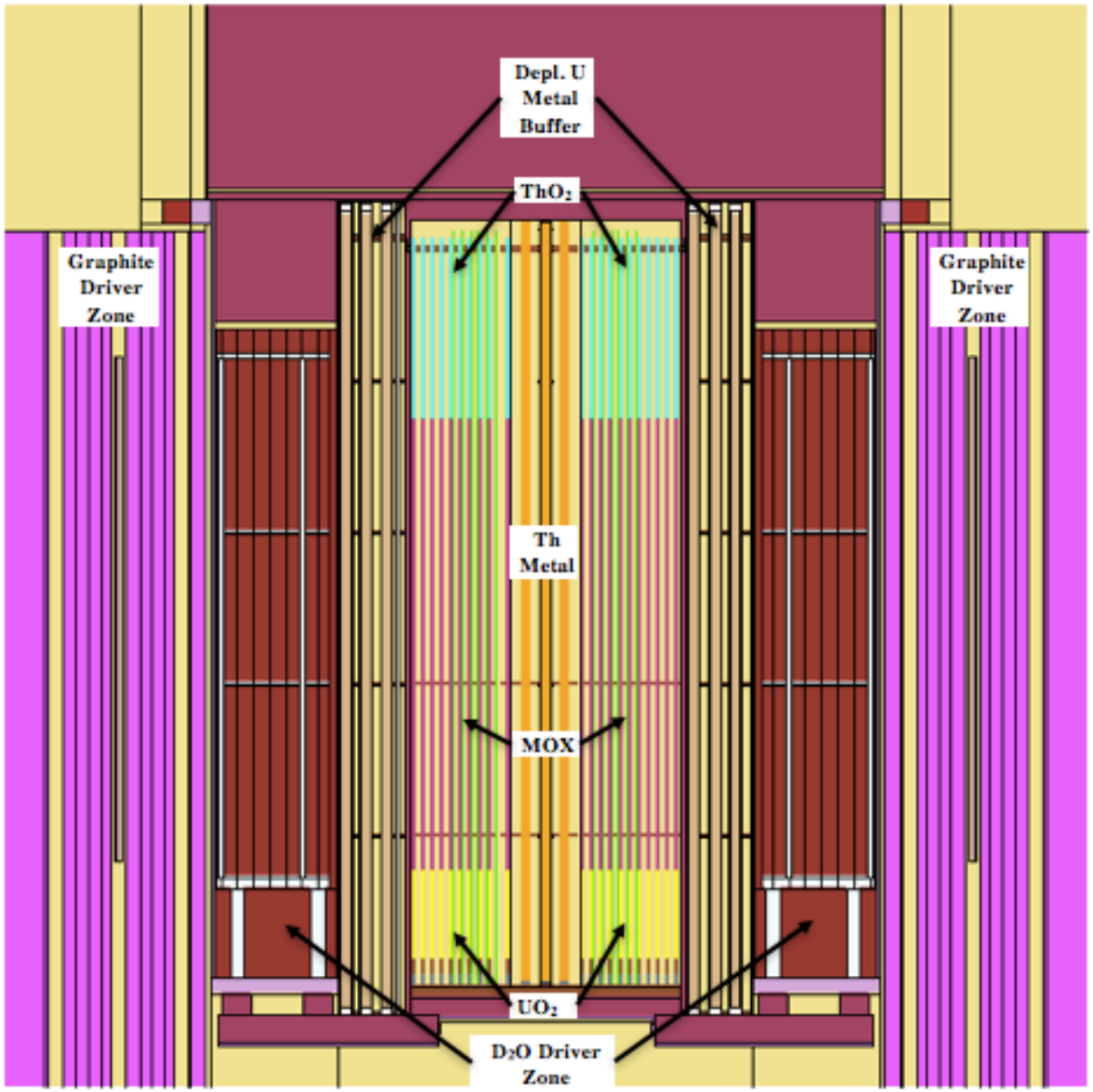
| Spectral Indices | Calculated (ENDF-8B3) | | Benchmark | | (C/E)-1 | |
|---|---|---|---|---|---|---|
| | Value | σ | Value | σ | Value | σ |
| **c8/f9** | 1.31E-01 | 4.69E-04 | 1.330E-01 | 1.470E-03 | -1.65% | 1.60% |
| **f8/f9** | 3.09E-02 | 1.64E-04 | 3.110E-02 | 4.111E-04 | -0.69% | 1.94% |
| **f5/f9** | 1.02E+00 | 2.67E-03 | 1.010E+00 | 1.416E-02 | 1.05% | 2.00% |
| **c2/f9** | 2.04E-01 | 2.72E-03 | 2.000E-01 | 2.807E-03 | 2.14% | 2.39% |
| **f2/f9** | 7.37E-03 | 4.12E-05 | 8.060E-03 | 1.623E-04 | -8.57% | 2.90% |
| **f3/f9** | 1.50E+00 | 5.36E-03 | 1.520E+00 | 1.980E-02 | -1.61% | 1.88% |
| **(n,2n)2/c2** | 7.28E-03 | 2.95E-04 | 6.840E-03 | 1.990E-04 | 6.41% | 5.77% |
| **c7/f9** | 8.28E-01 | 4.71E-03 | 8.260E-01 | 1.904E-02 | 0.21% | 3.31% |
| **f7/f9** | 2.25E-01 | 7.68E-04 | 2.270E-01 | 4.098E-03 | -0.82% | 2.58% |



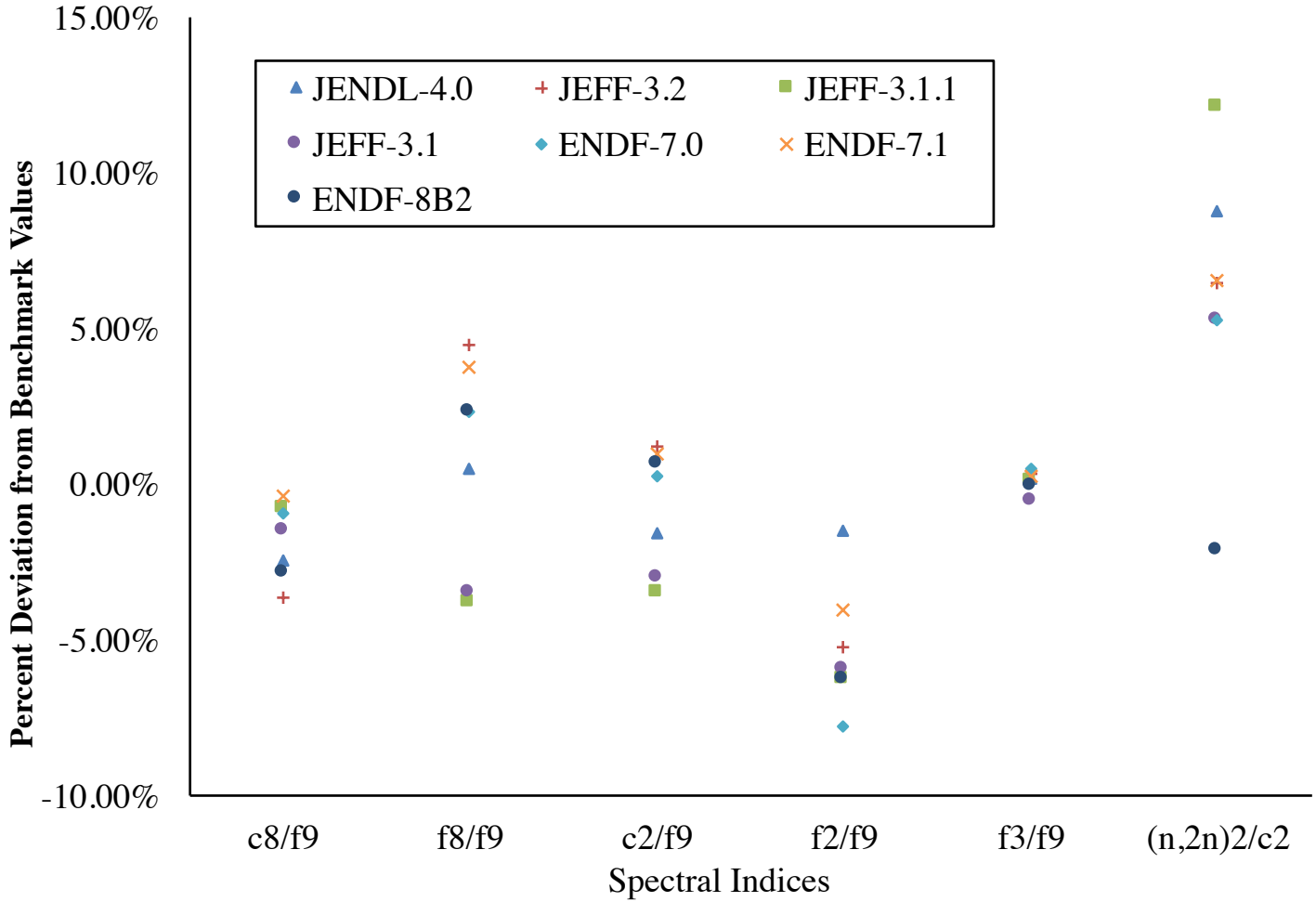
# Comparison of Cross Sections Core 11



# Core 15 Model



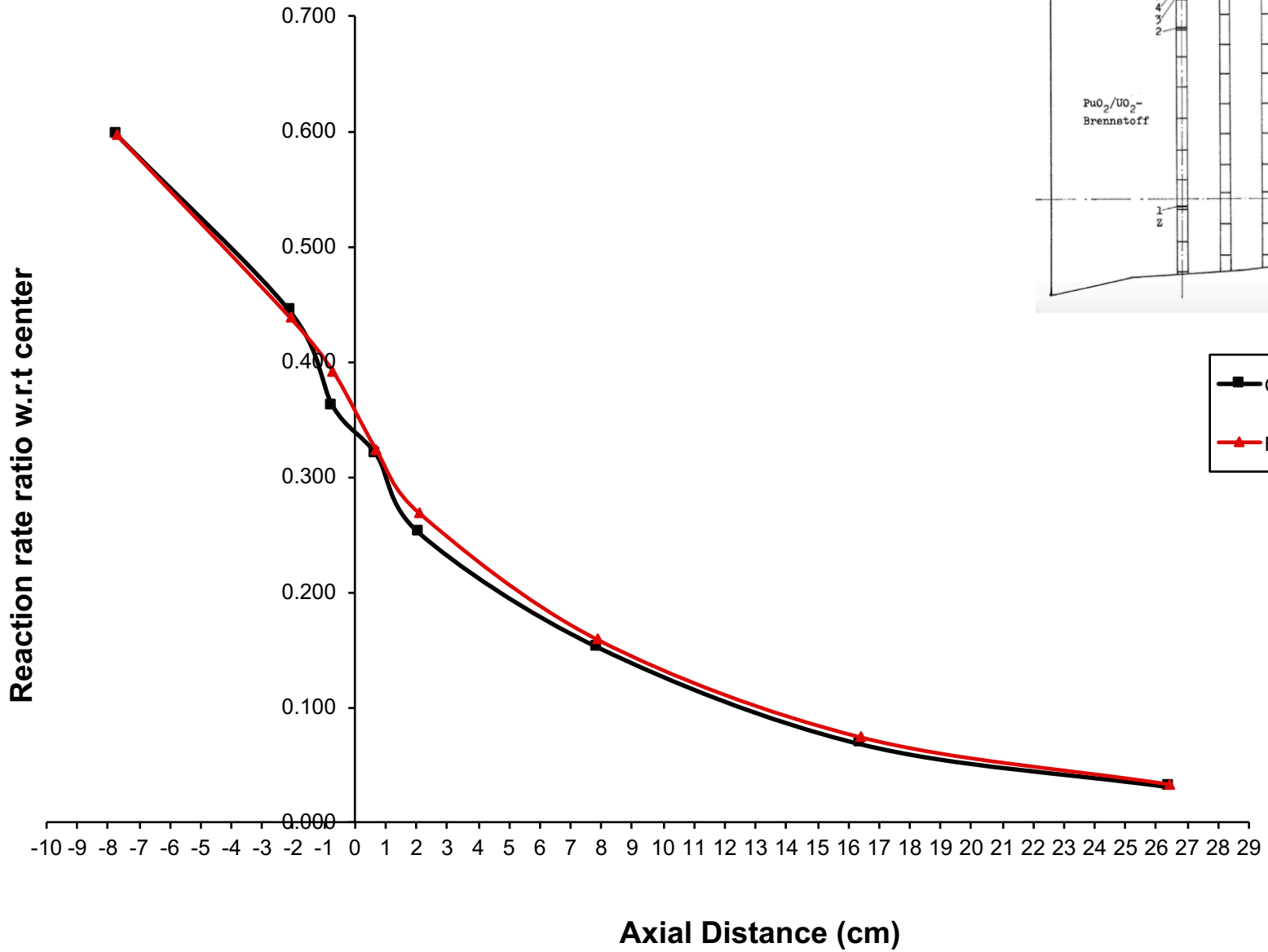
# Comparison of Cross Sections

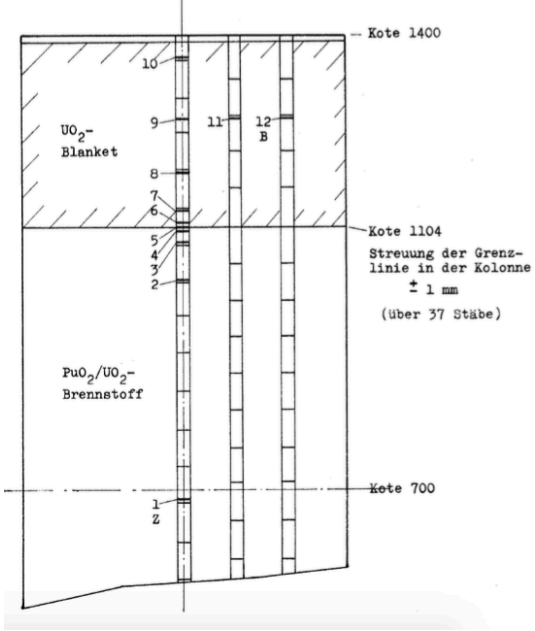


# Questions?

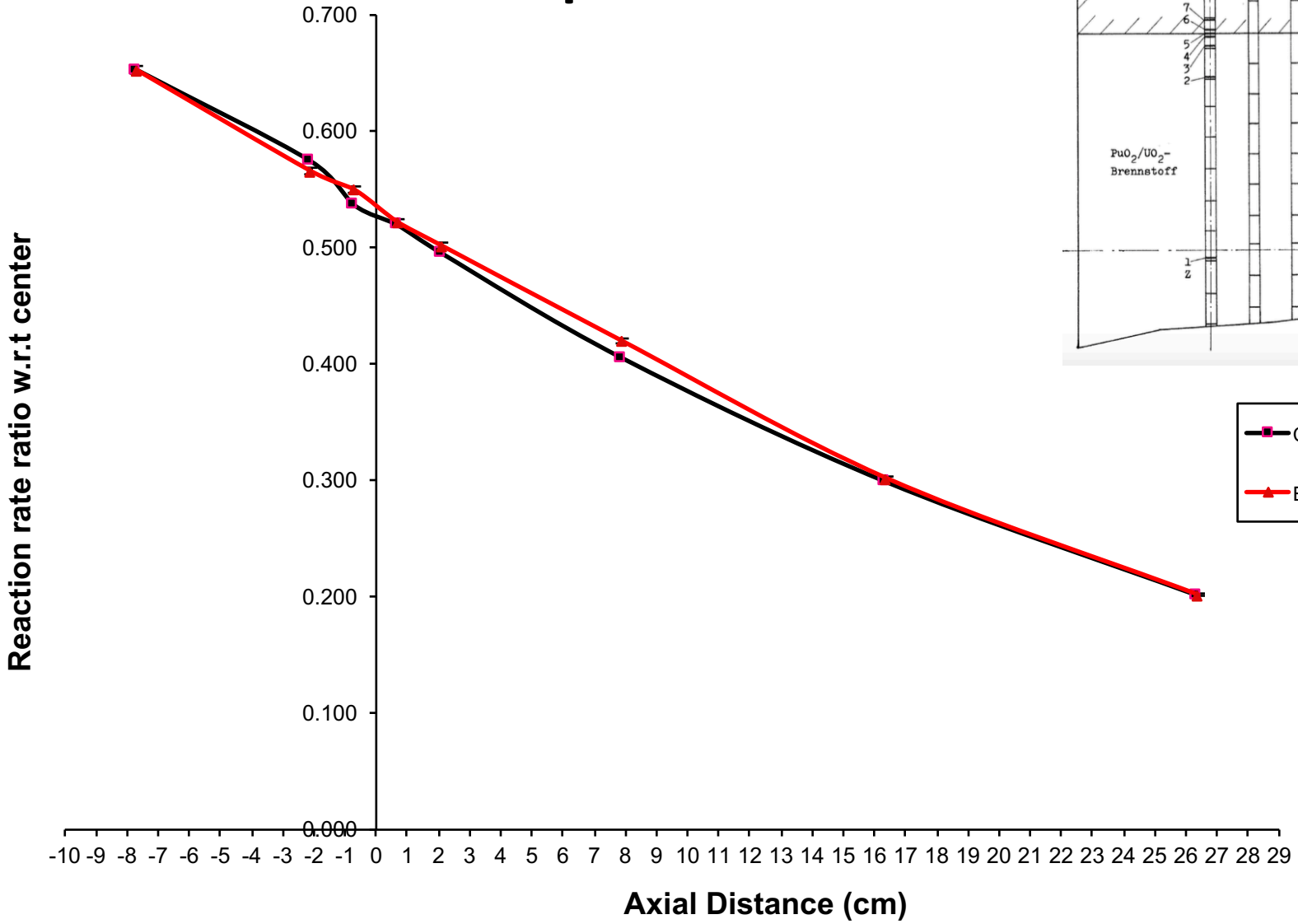

http://blasst.edu.au/benchmarking.html

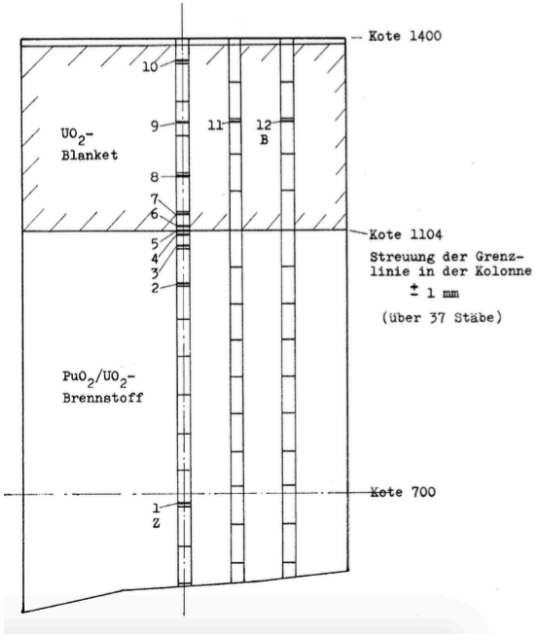
# Fission U238



# Capture U238



# Fission Pu239