OECD/NEA Meeting: WPEC SG42
"Thermal Scattering Kernel S(α,β): Measurement, Evaluation and Application"
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Considerations for Measurements in Support of Thermal Scattering Data Evaluations

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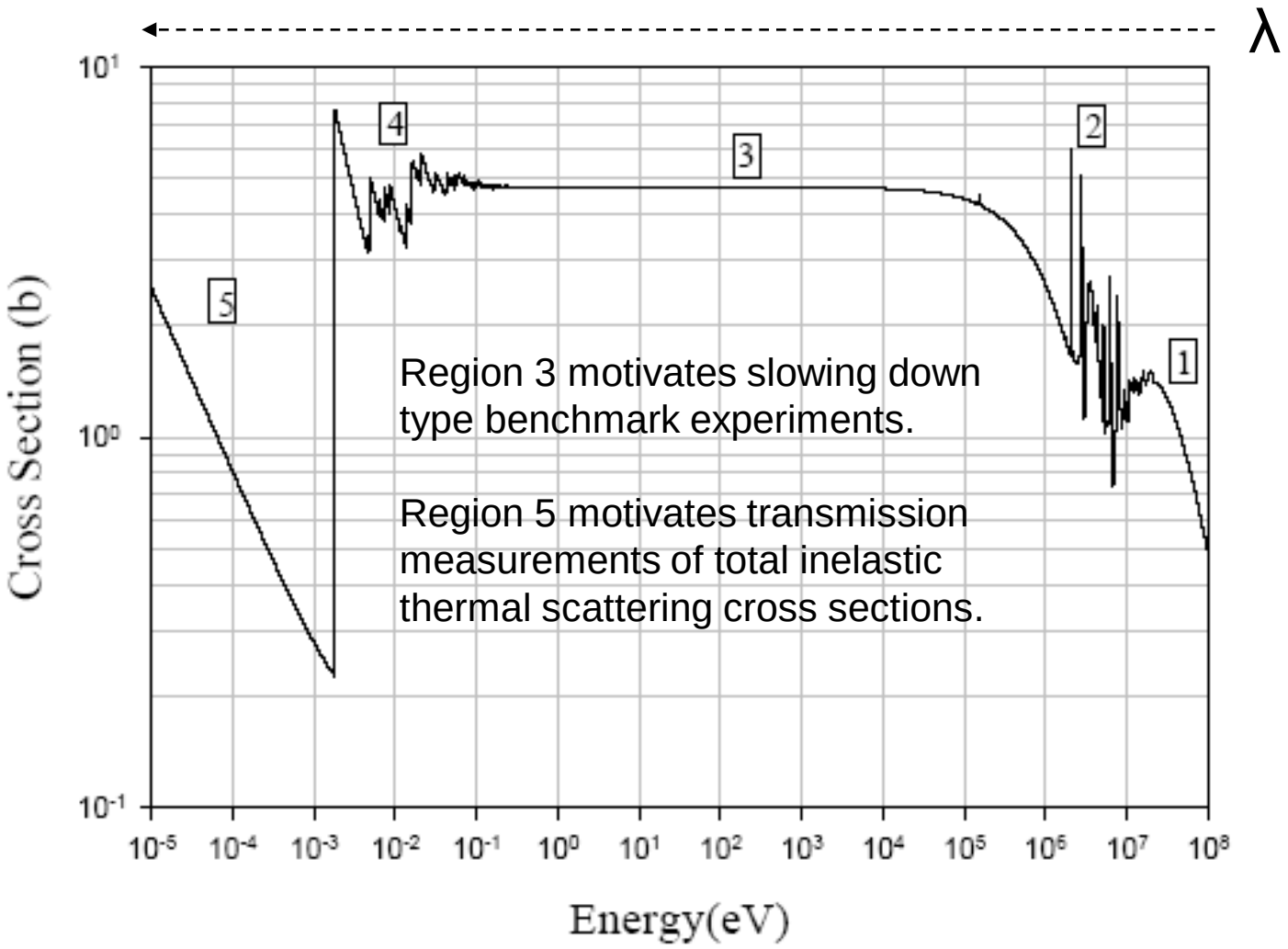
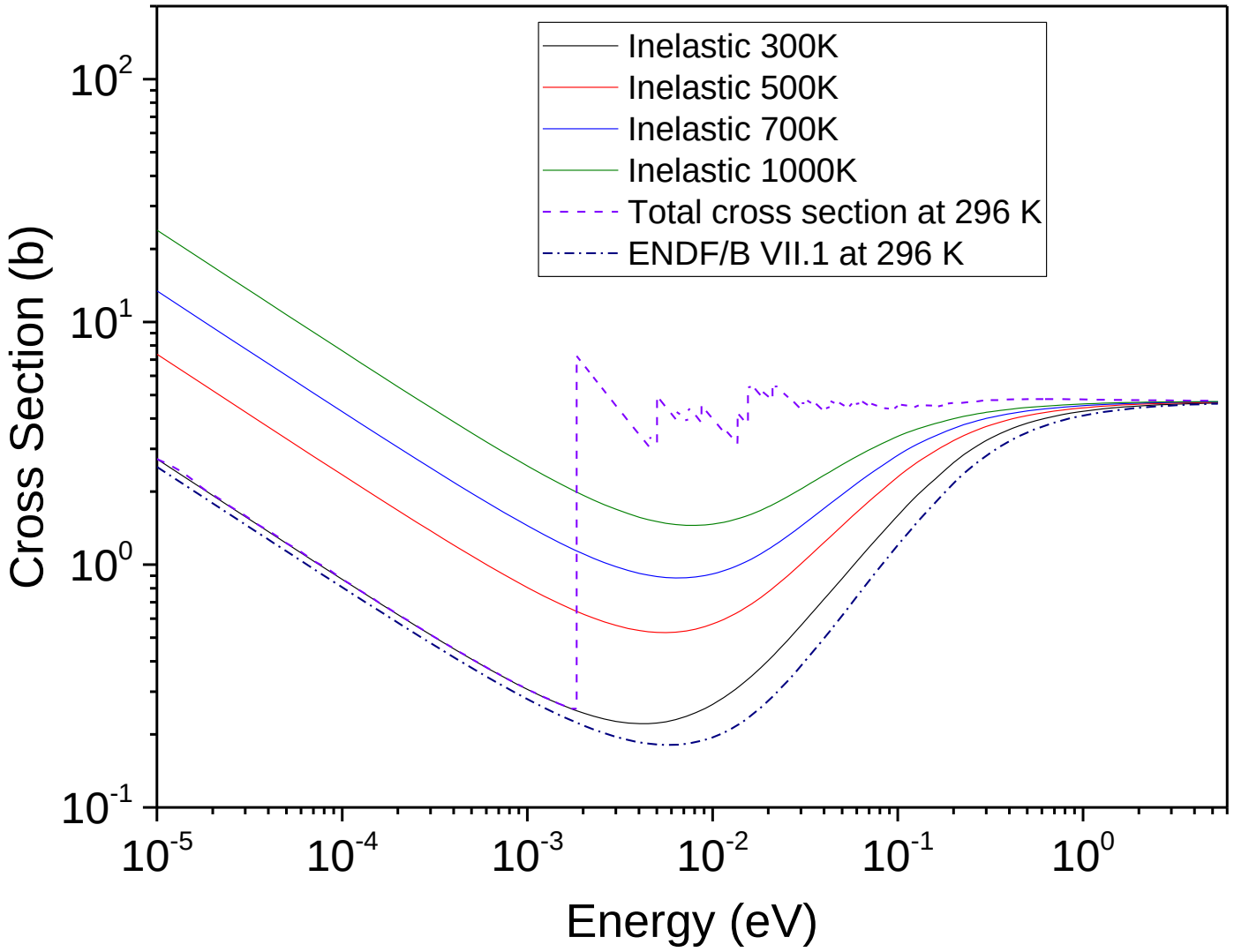
Objective

- Establish a holistic approach for validating thermal neutron scattering cross sections of materials
  - Total cross section measurements
  - Differential measurements
  - Benchmark measurements

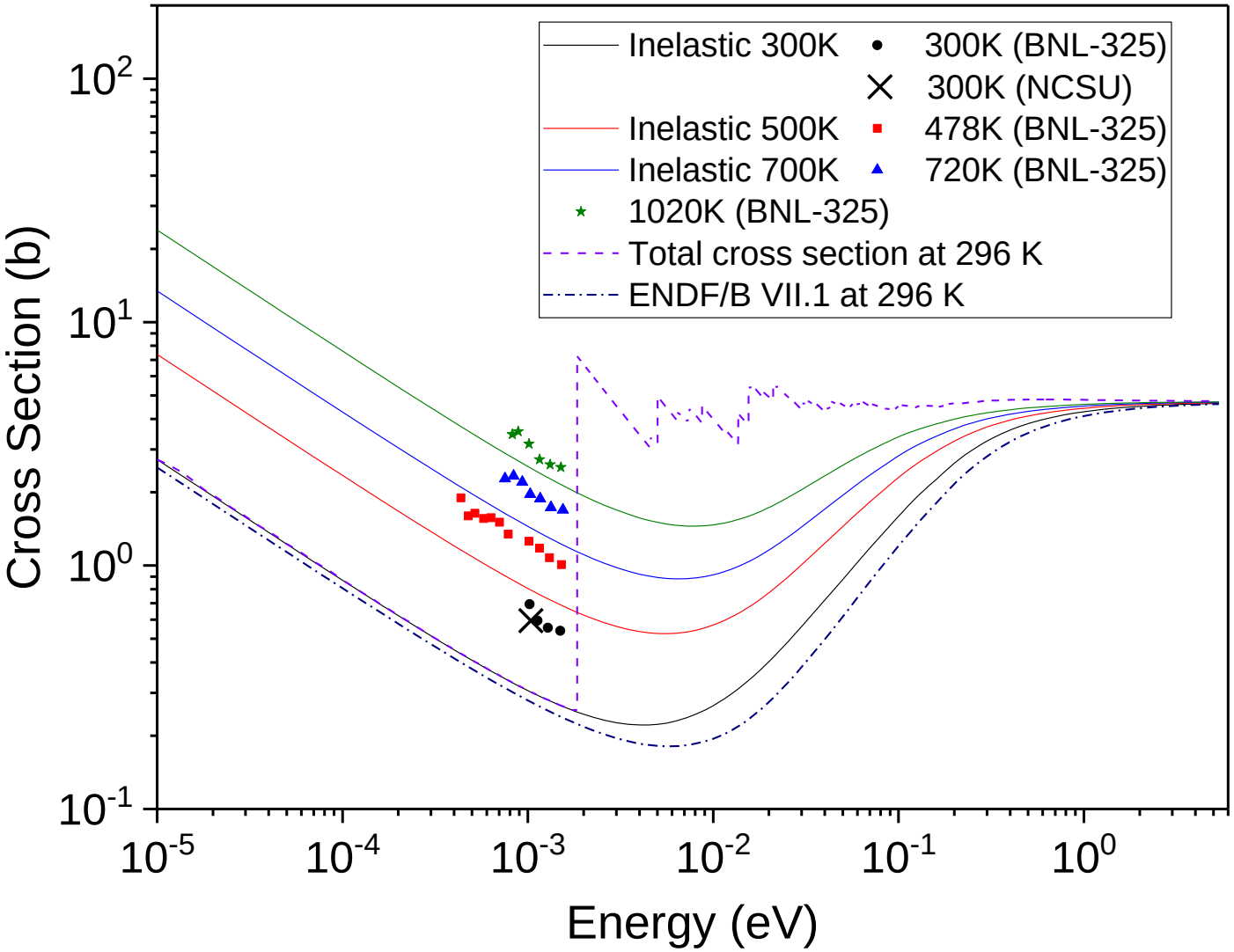
Neutron Interactions – Carbon



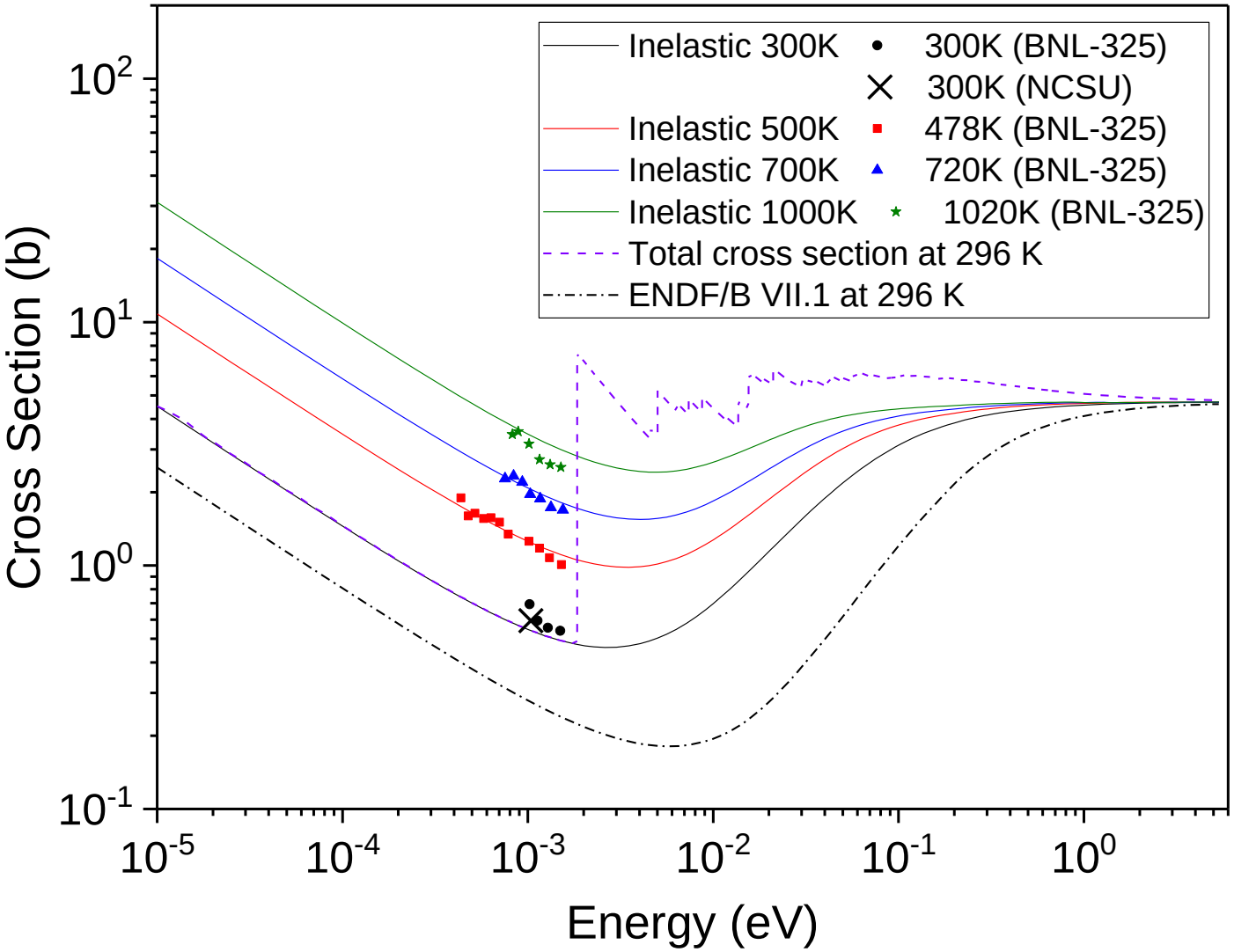
Graphite


Inelastic 300K
Inelastic 500K
Inelastic 700K
Inelastic 1000K
Total cross section at 296 K
ENDF/B VII.1 at 296 K
Cross Section (b)
Energy (eV)
10^2
10^1
10^0
10^-1
10^-5
10^-4
10^-3
10^-2
10^-1
10^0

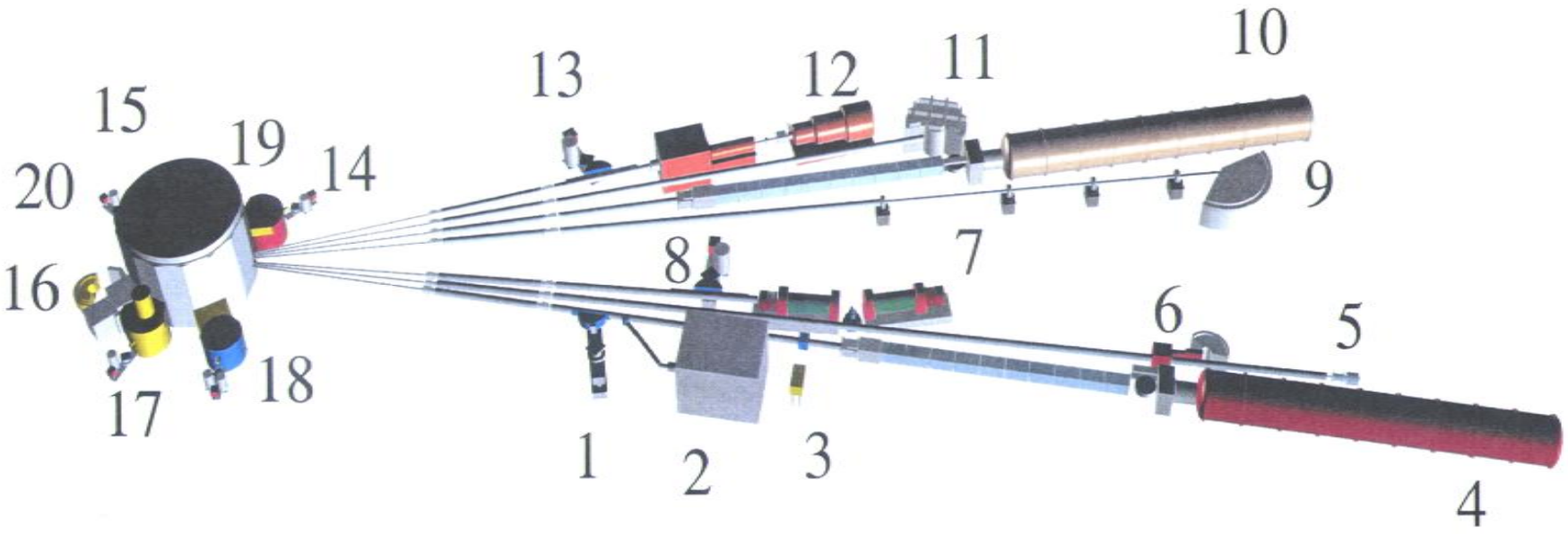
Graphite


Inelastic 300K
300K (BNL-325)
300K (NCSU)
Inelastic 500K
478K (BNL-325)
Inelastic 700K
720K (BNL-325)
1020K (BNL-325)
Total cross section at 296 K
ENDF/B VII.1 at 296 K
Cross Section (b)
Energy (eV)
10^2
10^1
10^0
10^-1
10^-5
10^-4
10^-3
10^-2
10^-1
10^0

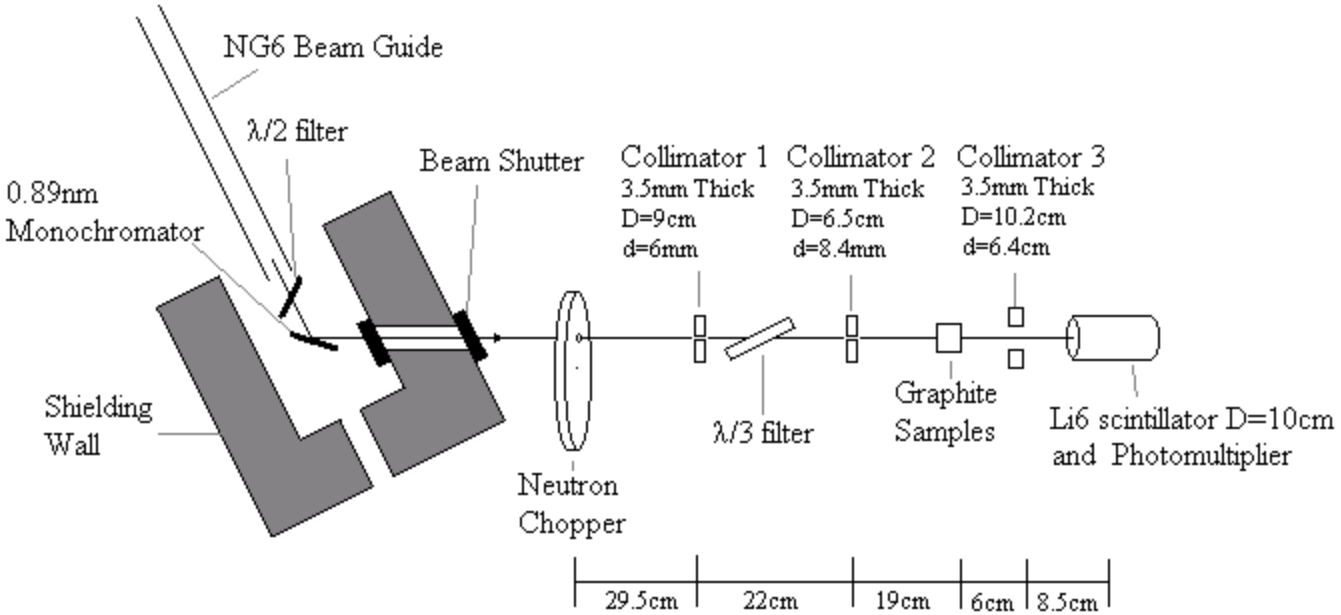
Nuclear Graphite



NIST Center for Neutron Research

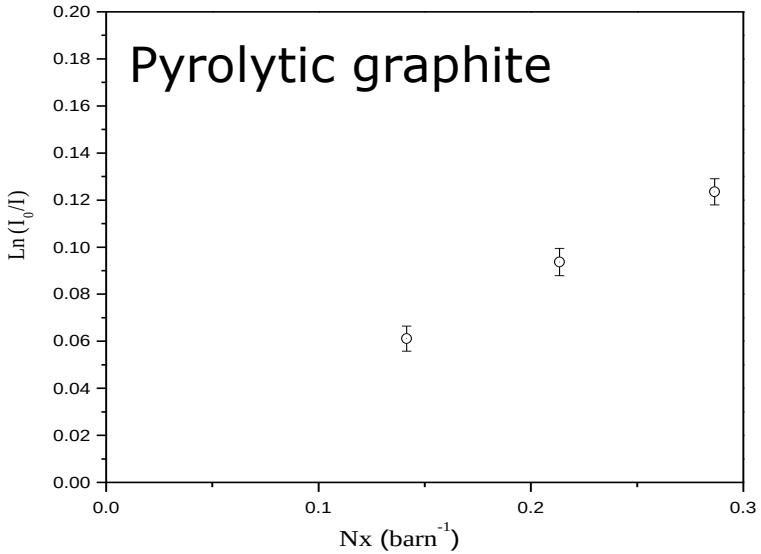


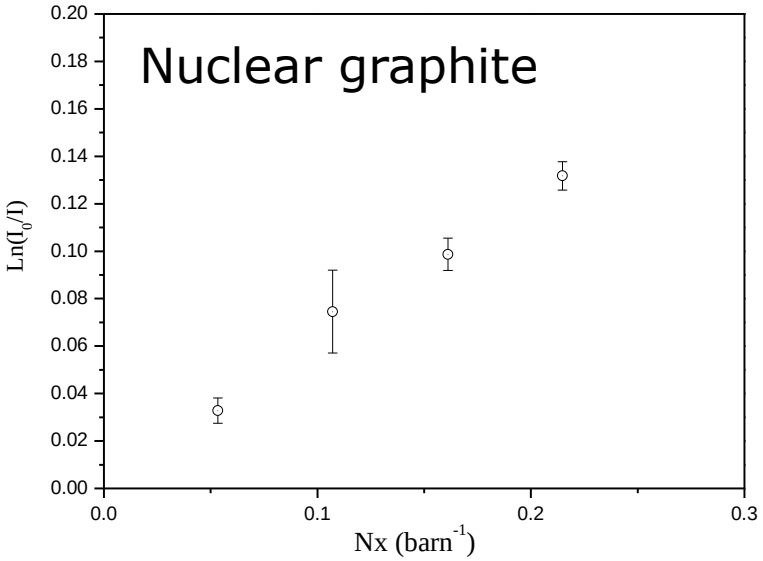
Experimental Setup – NIST NG #6



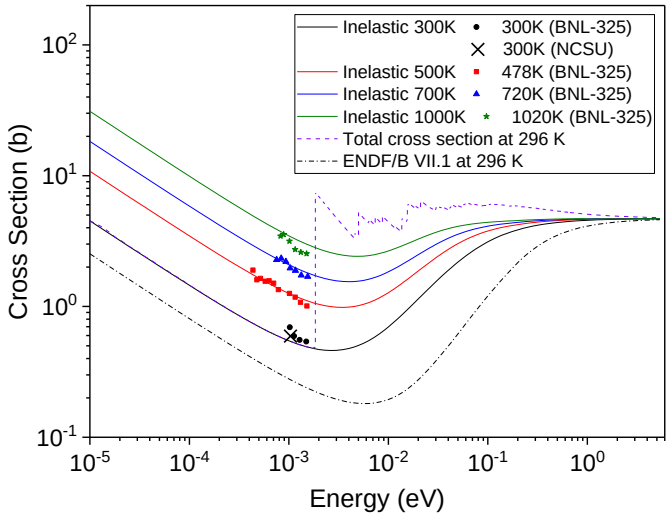
Sample	Density (g/cm^3)	Thickness (inch)
Nuclear graphite	1.66	1/4
pyrolytic graphite	2.2	1/8

9 Angstrom Neutron Transmission

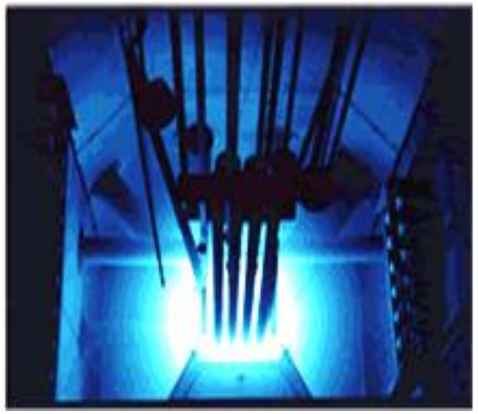


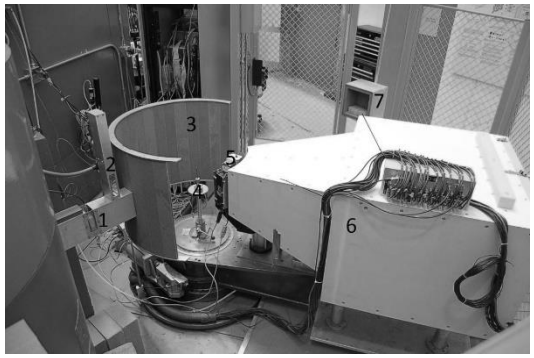


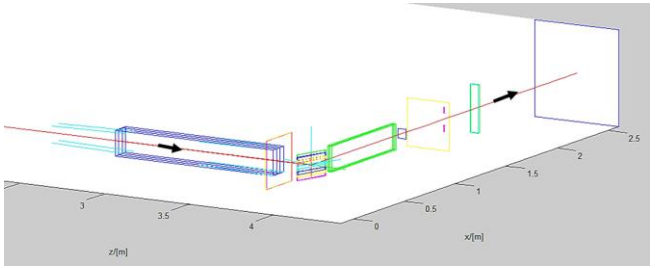
Graphite Type	Cross Section (barn) This work	Cross Section (barn) Previous work
Pyrolytic	0.43 ± 0.05	0.37
Nuclear graphite	0.61 ± 0.05	0.66

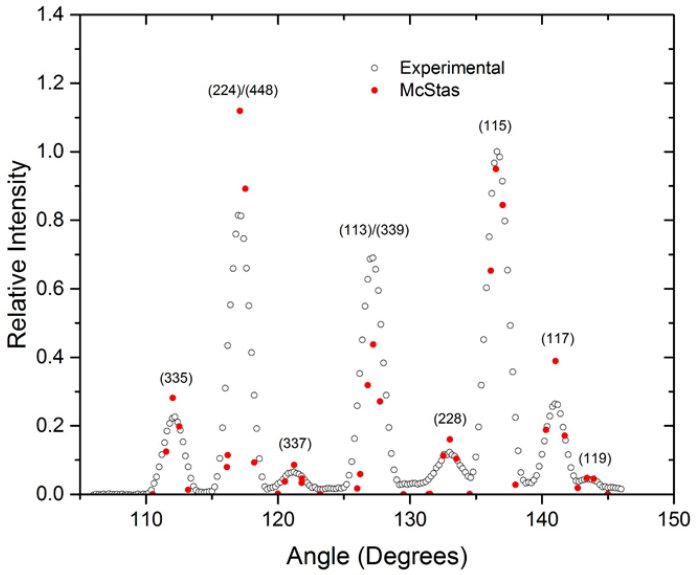


Total Cross Section Measurements PULSTAR Reactor



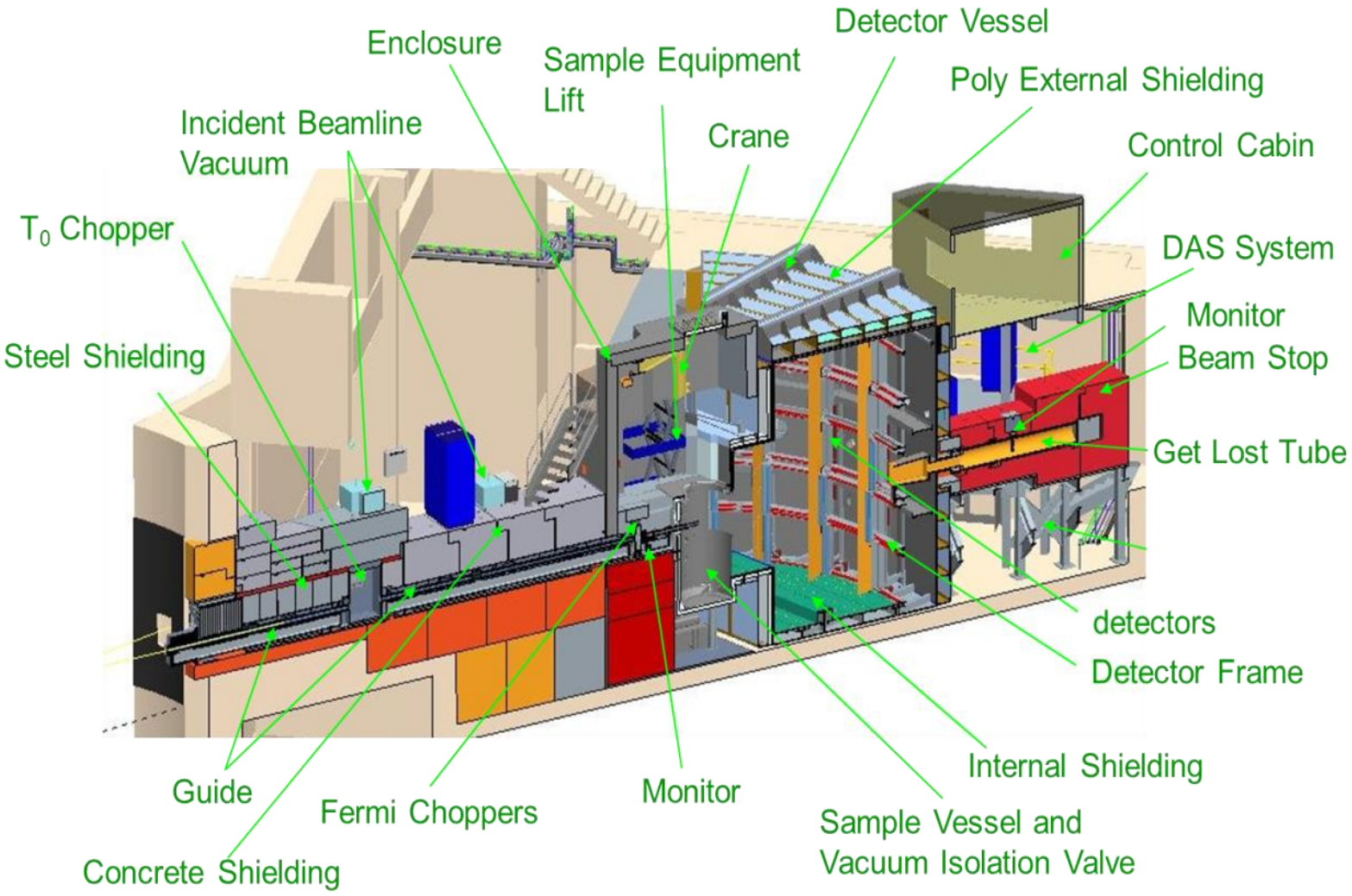






Plane (hkl)	Energy (meV)	McStas Beam Ratio	Exp. Beam Ratio
(115)	37.44	1.000	1.000
(113)	15.25	0.443	0.440
(224)	33.28	1.137	0.768
(335)	59.63	0.276	0.285
(117)	70.73	0.376	0.362
(331)	26.36	0.352	N/A

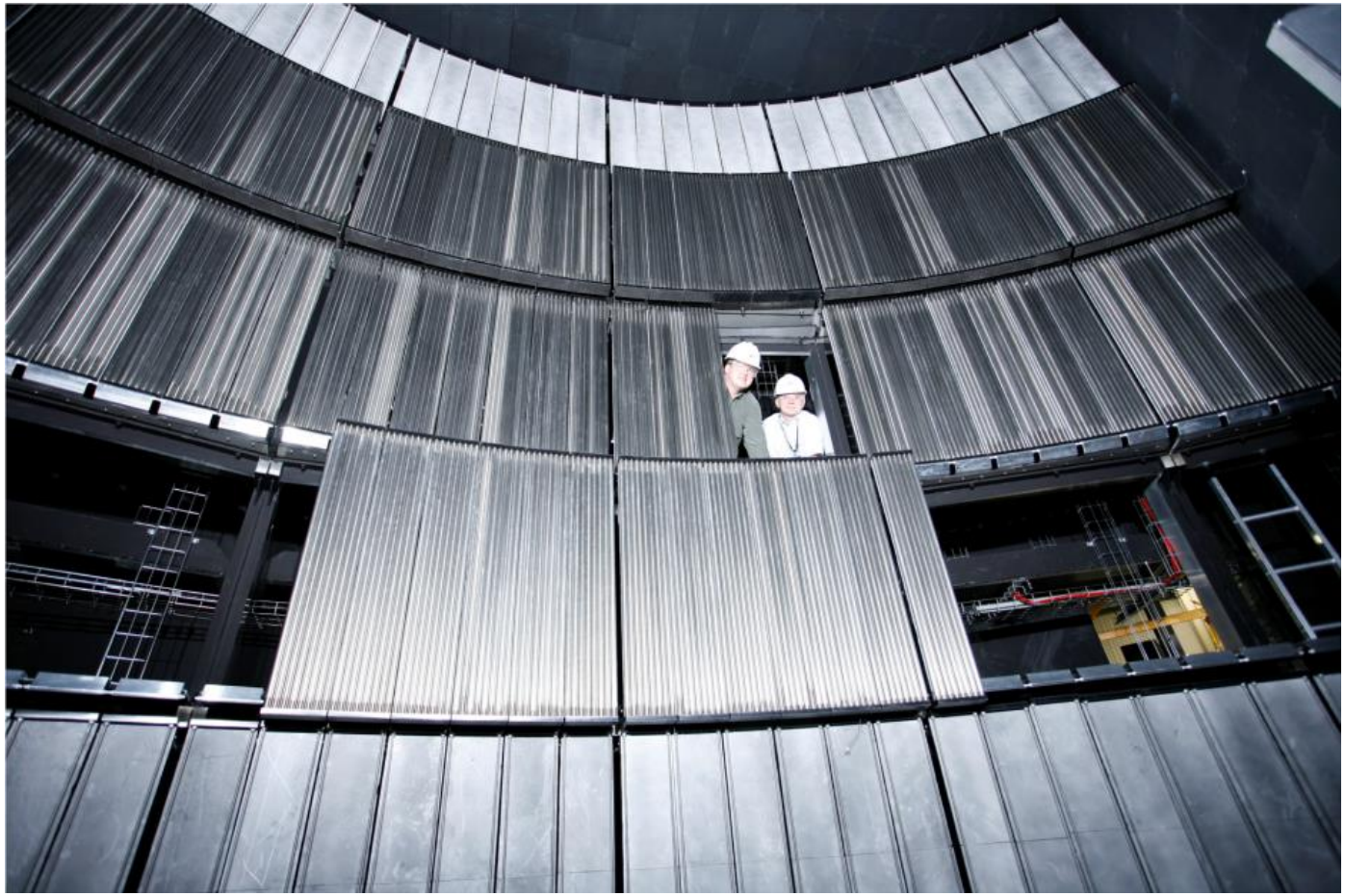
SEQUOIA: The fine resolution thermal to epithermal neutron spectrometer



SEQUOIA Measurements

- SEQUOIA is a fine resolution Fermi chopper time-of-flight spectrometer that is capable of producing variable energy neutron beams in the range of 5 – 4000 meV.
- The scattered neutrons are detected in a cylindrical array of He-3 detectors that cover the angular range of -30° to +60° horizontally and ±18° vertically.
- In this work, incoming neutrons with energies of 30 meV and 280 meV were utilized.
- Room temperature

SEQUOIA Detector Array



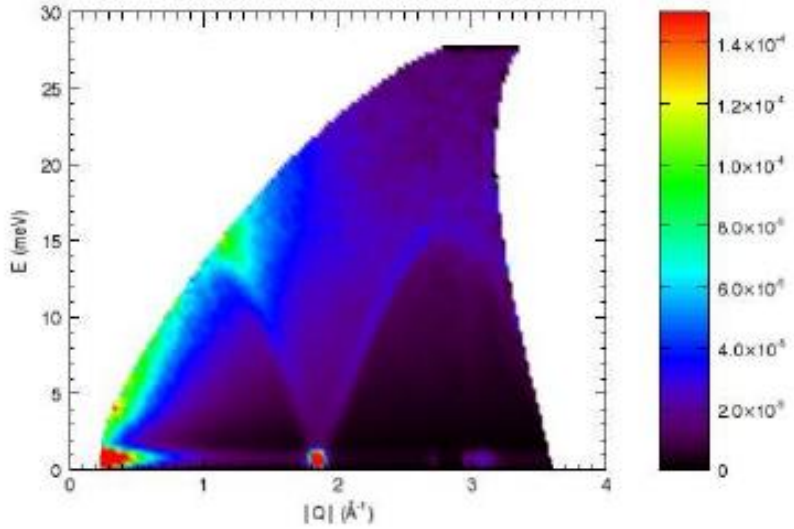
Graphite Samples

Measurements were made using unirradiated and irradiated nuclear graphite samples

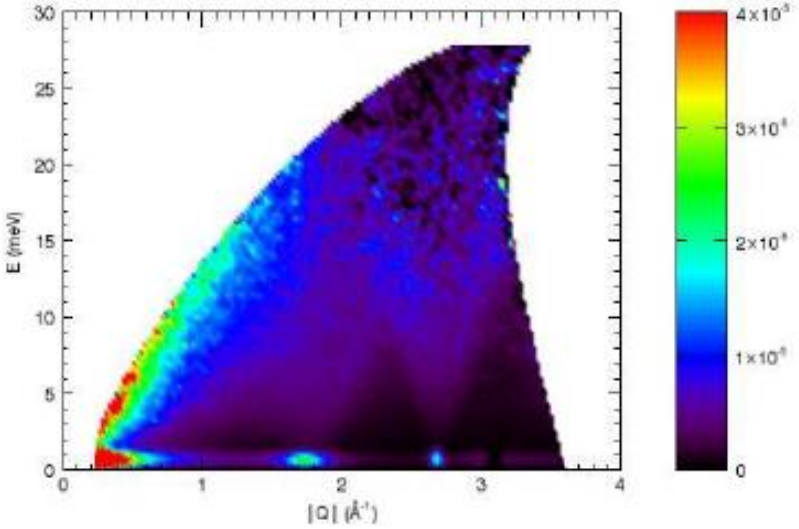
G(Q,E)

30 meV

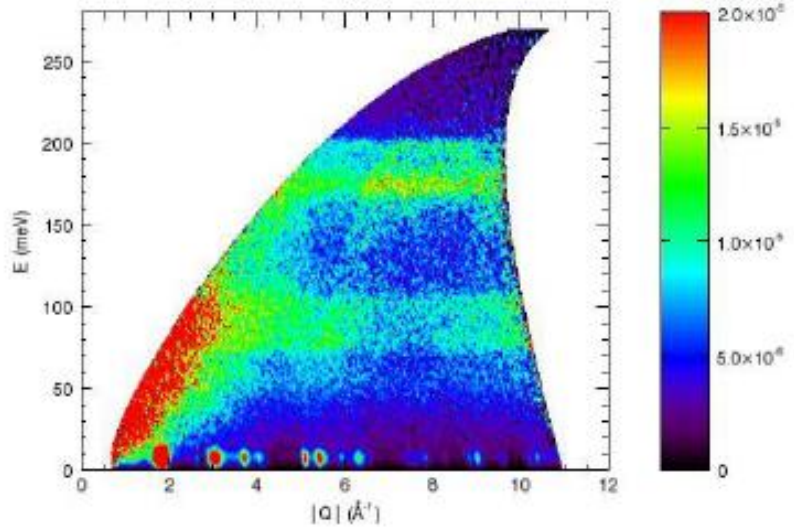
Unirradiated

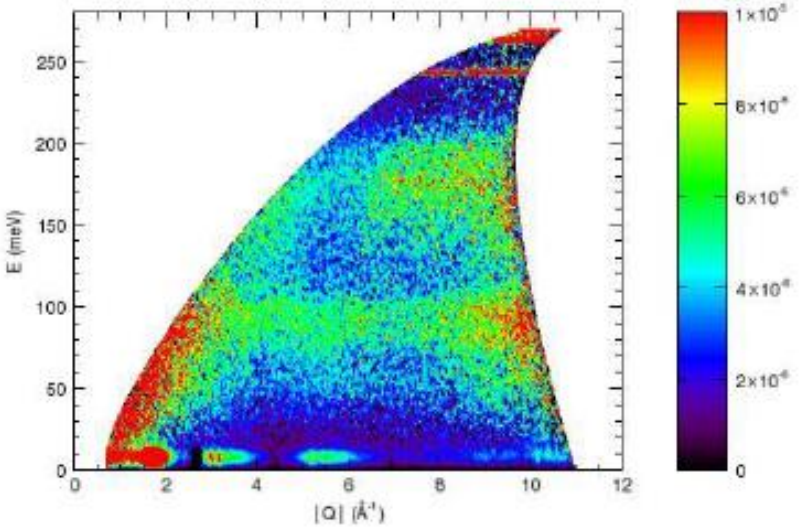


Irradiated

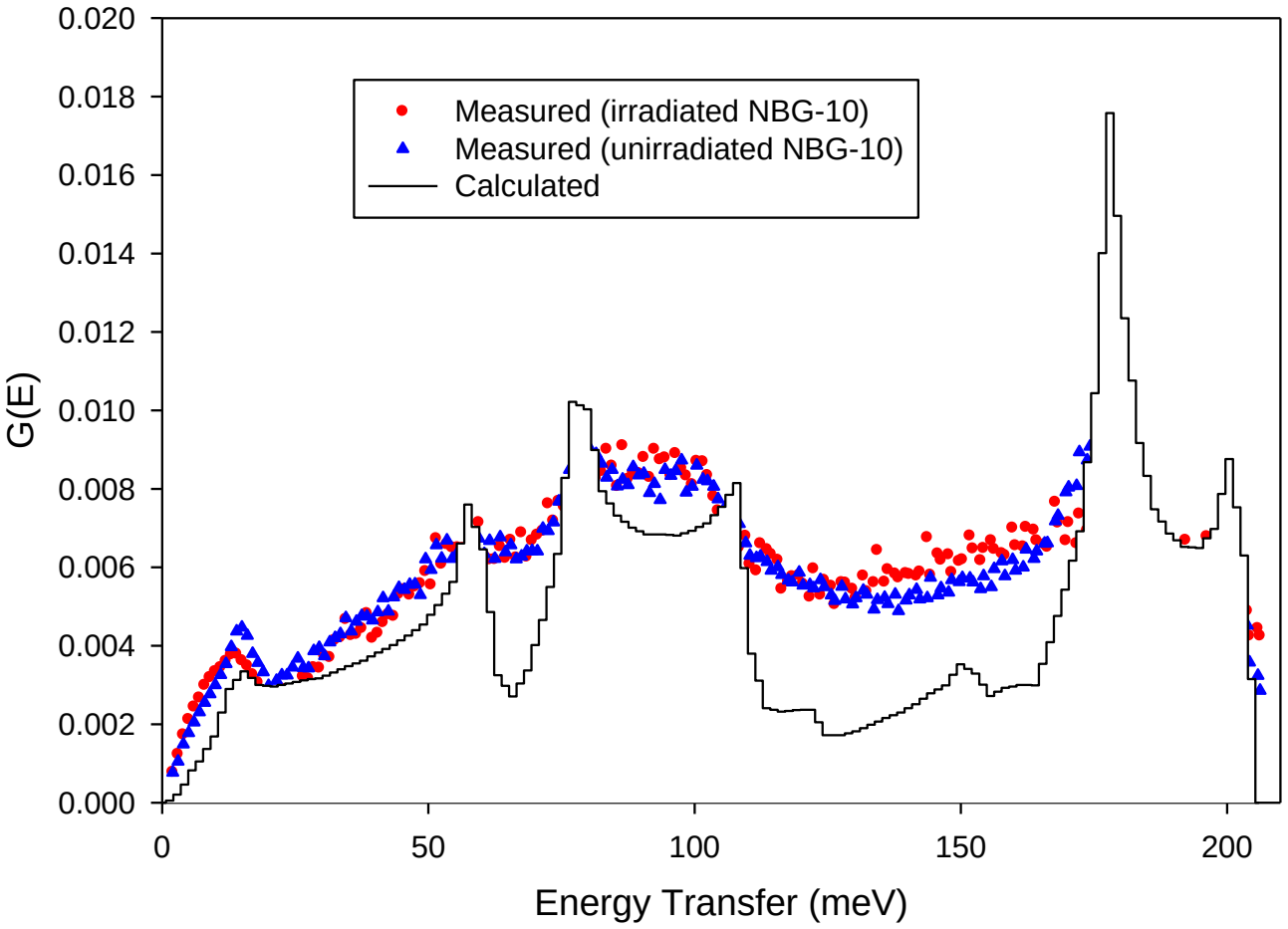


280 meV

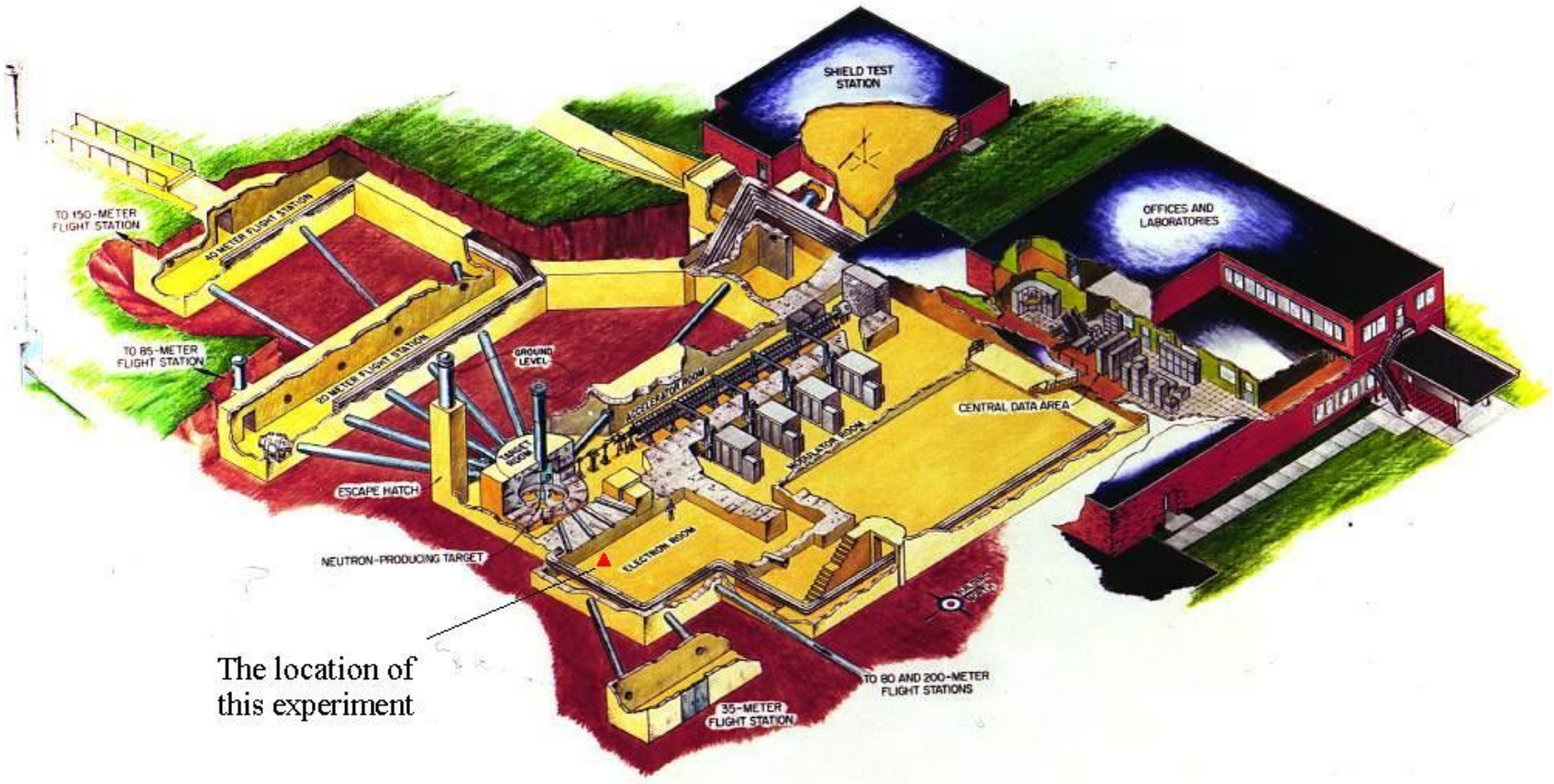




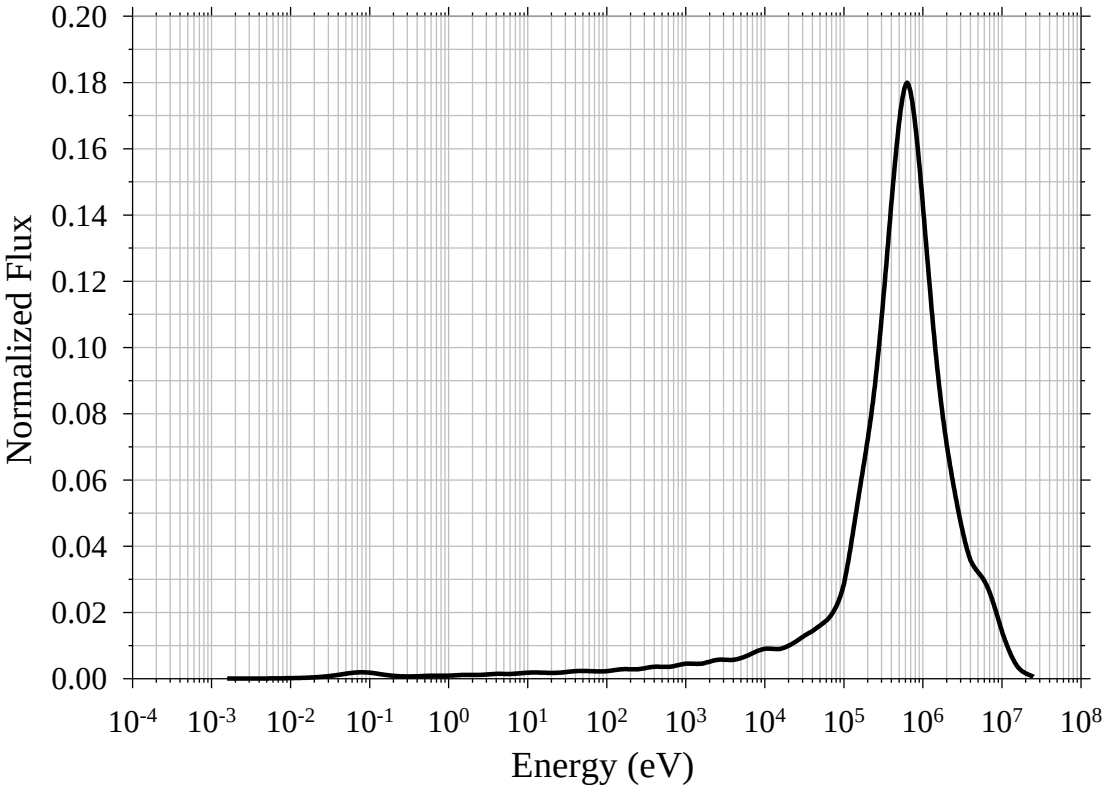
Density of States G(E)

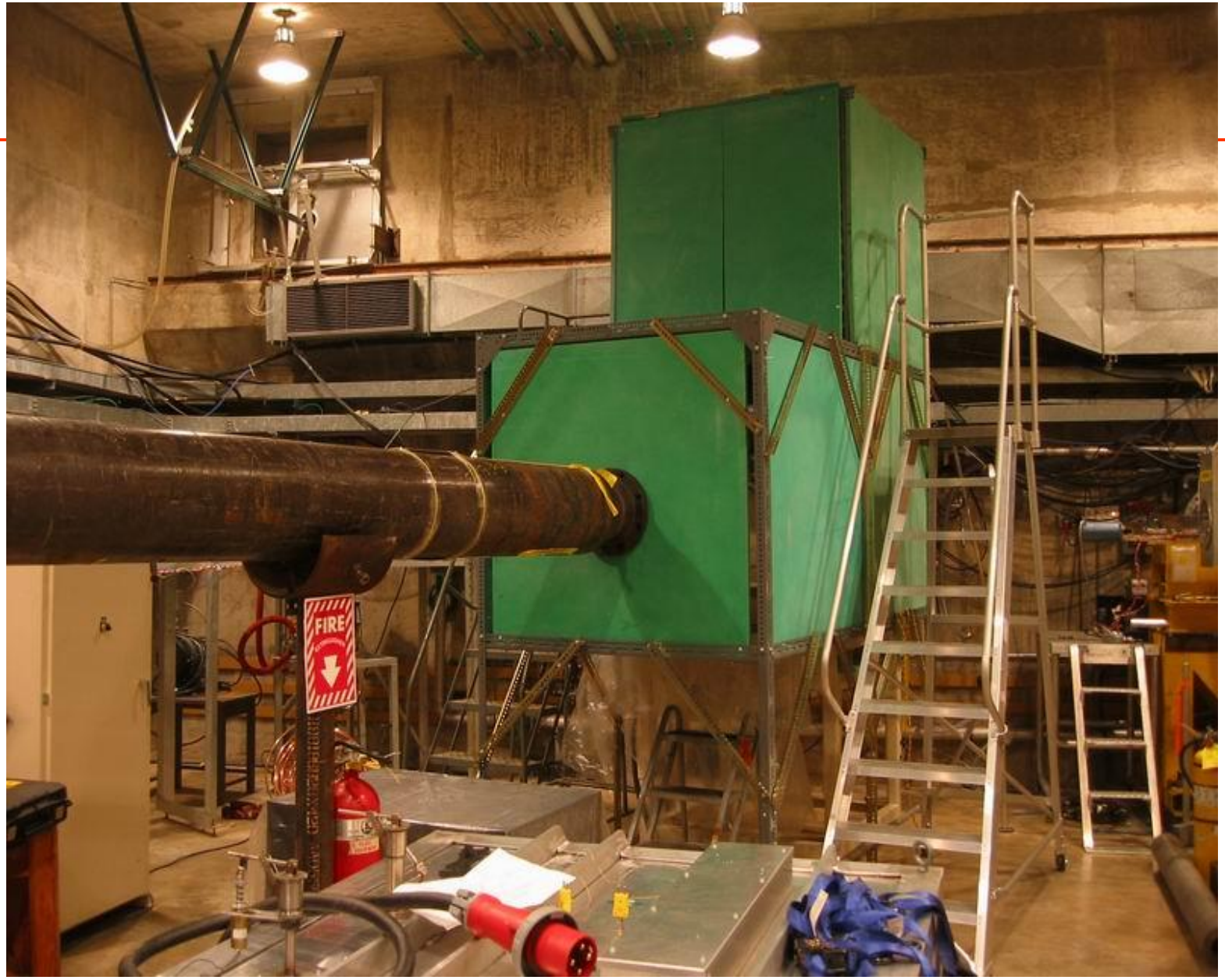


ORELA Facility

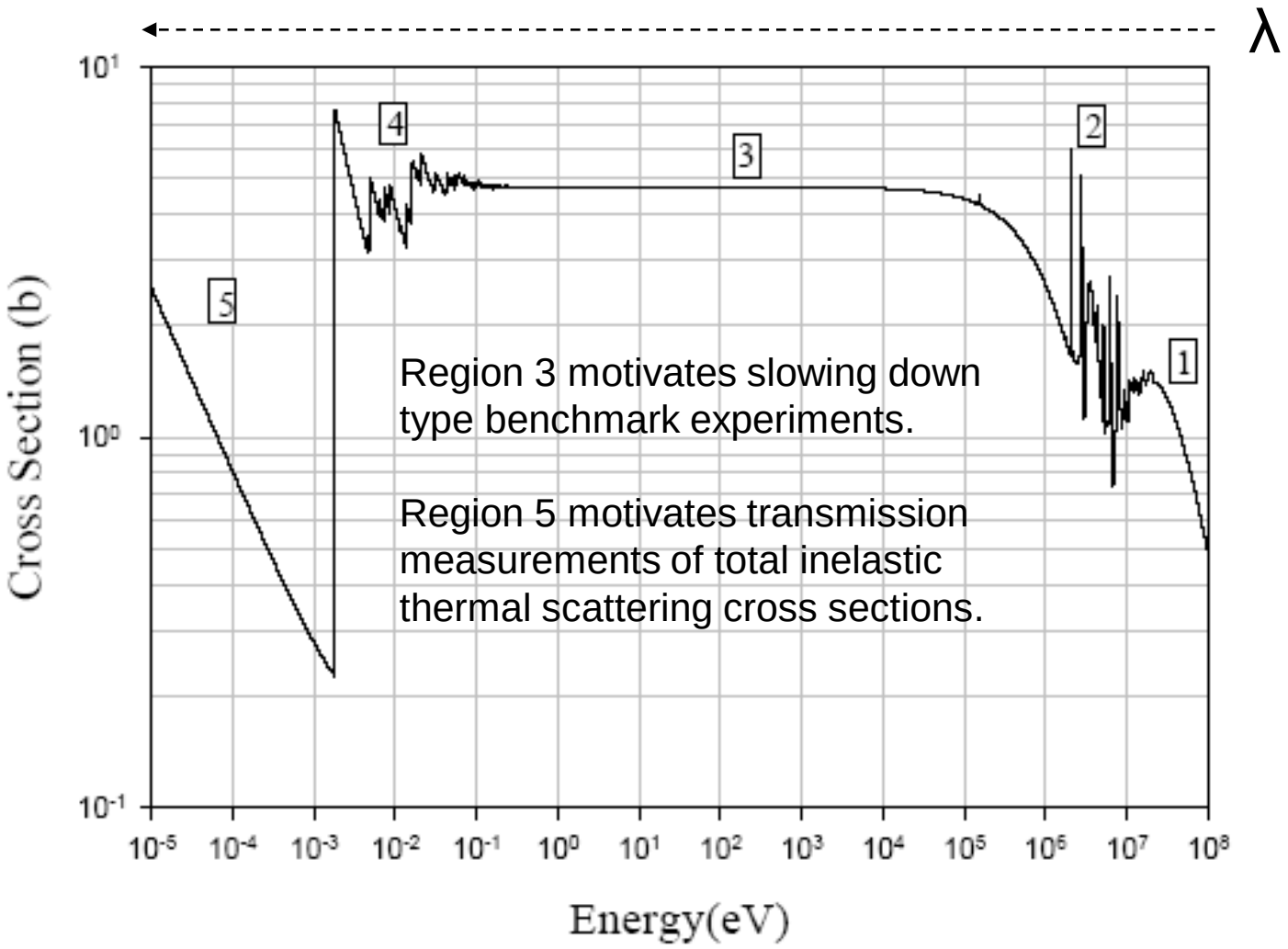


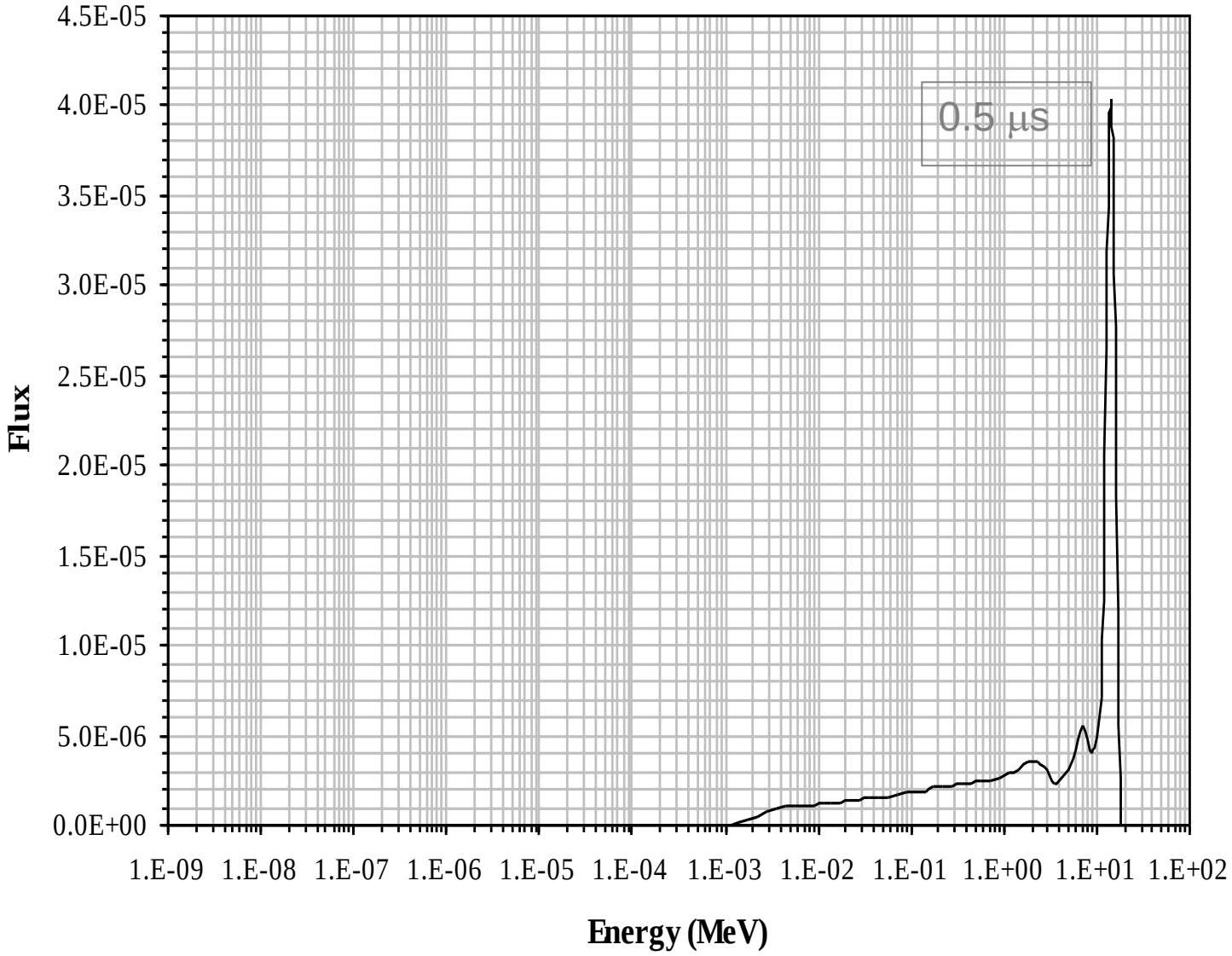
Energy Distribution

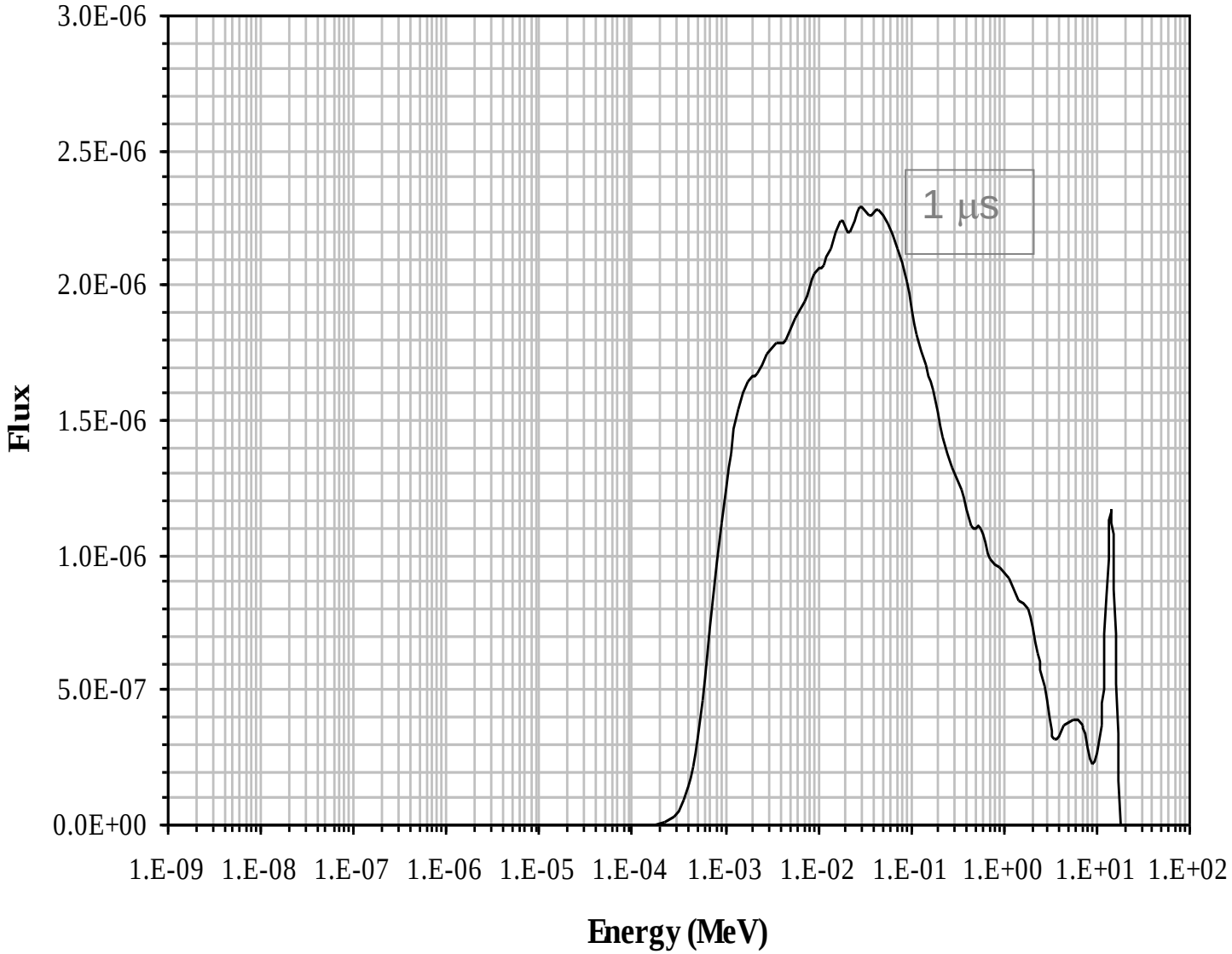


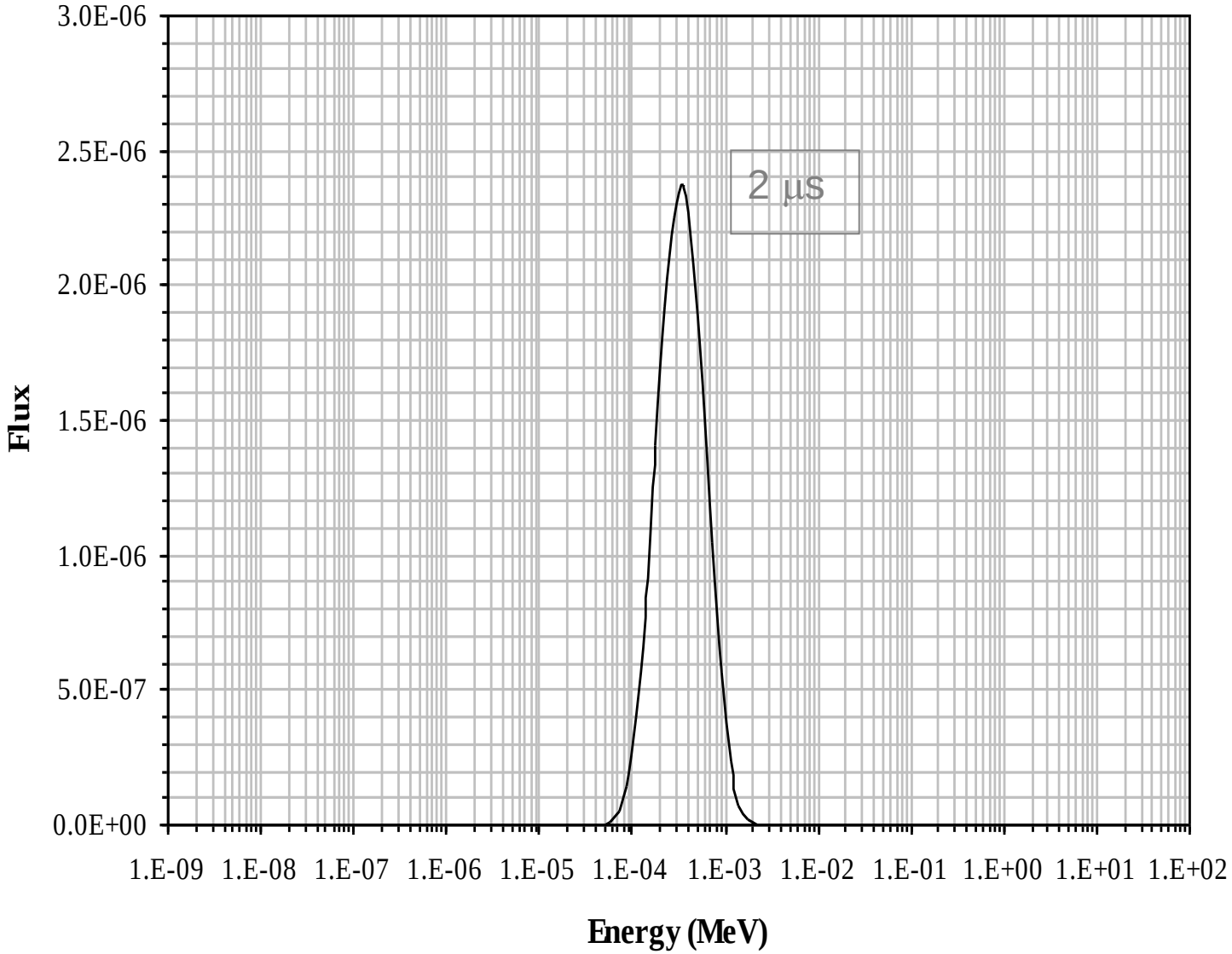

FIRE

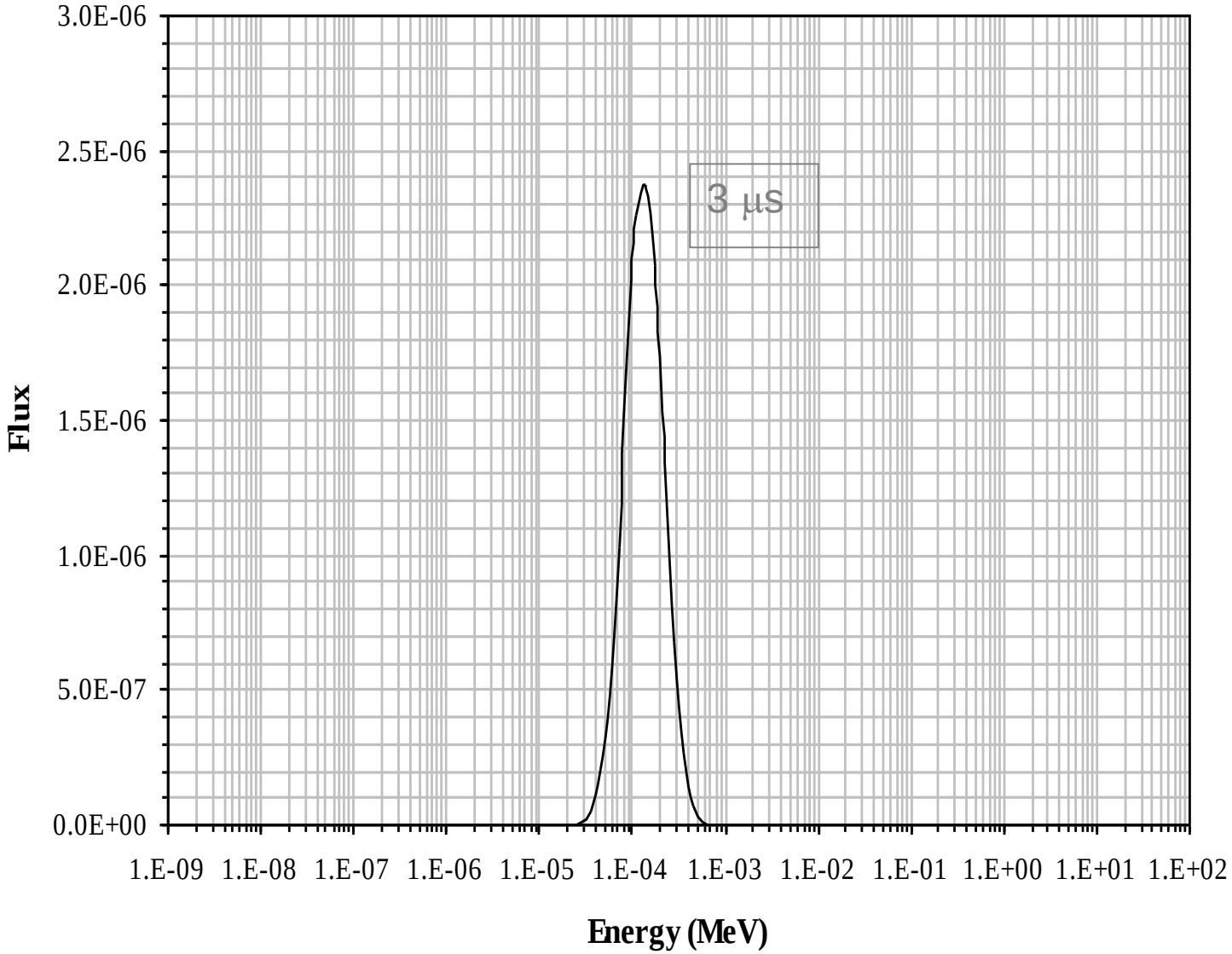
Neutron Interactions – Carbon

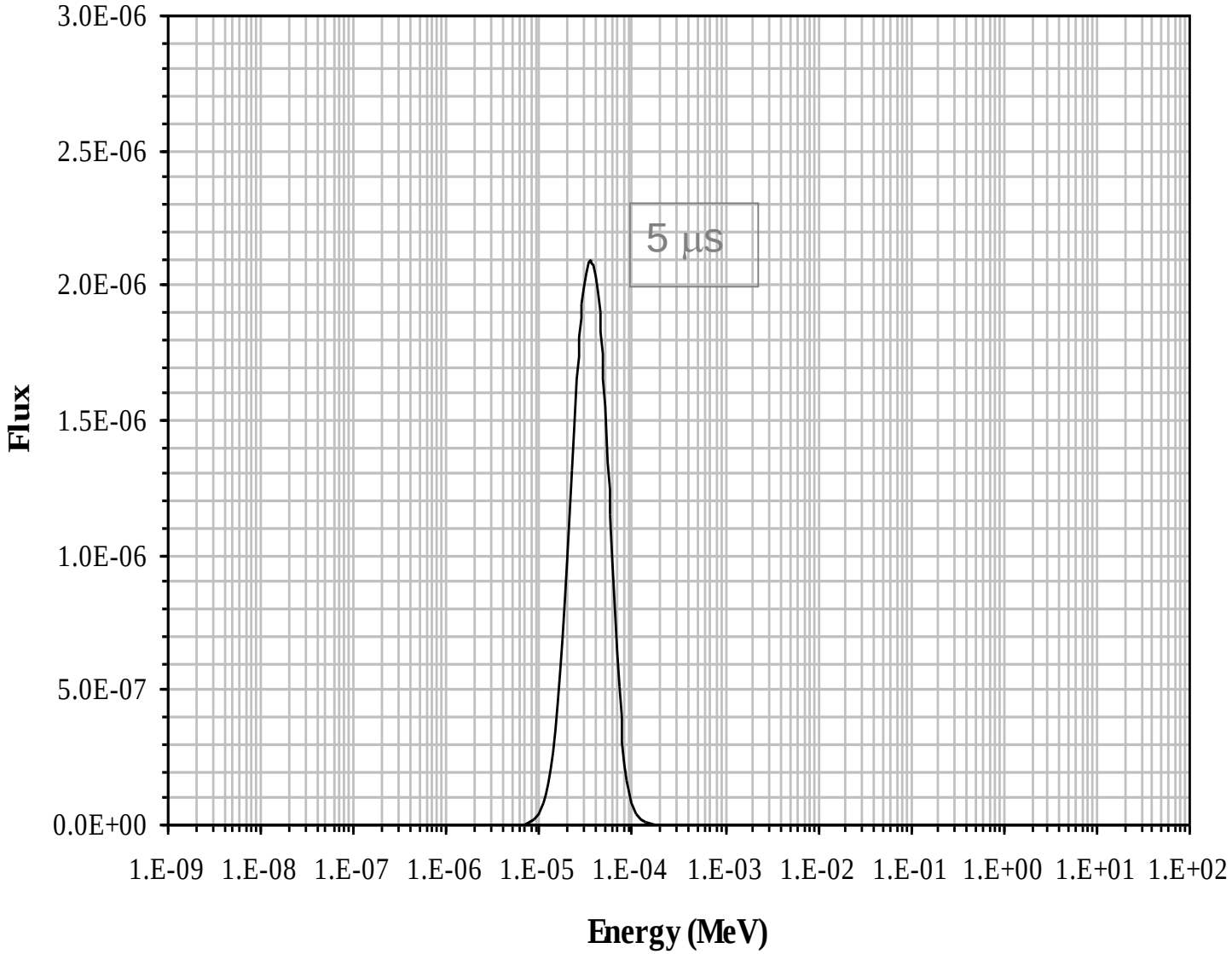


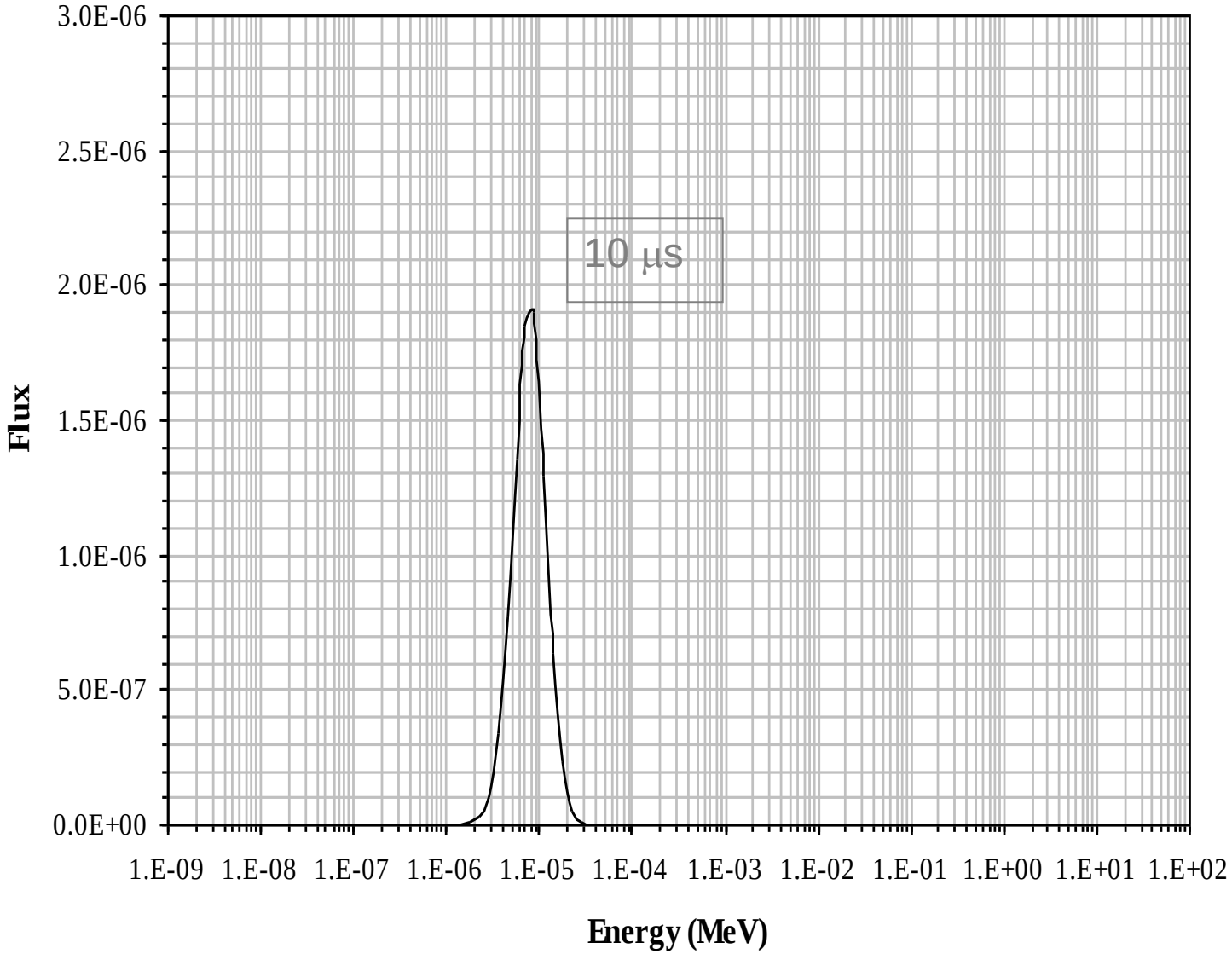

4.5E-05
4.0E-05
3.5E-05
3.0E-05
2.5E-05
2.0E-05
1.5E-05
1.0E-05
5.0E-06
0.0E+00
Flux
0.5 μs
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)

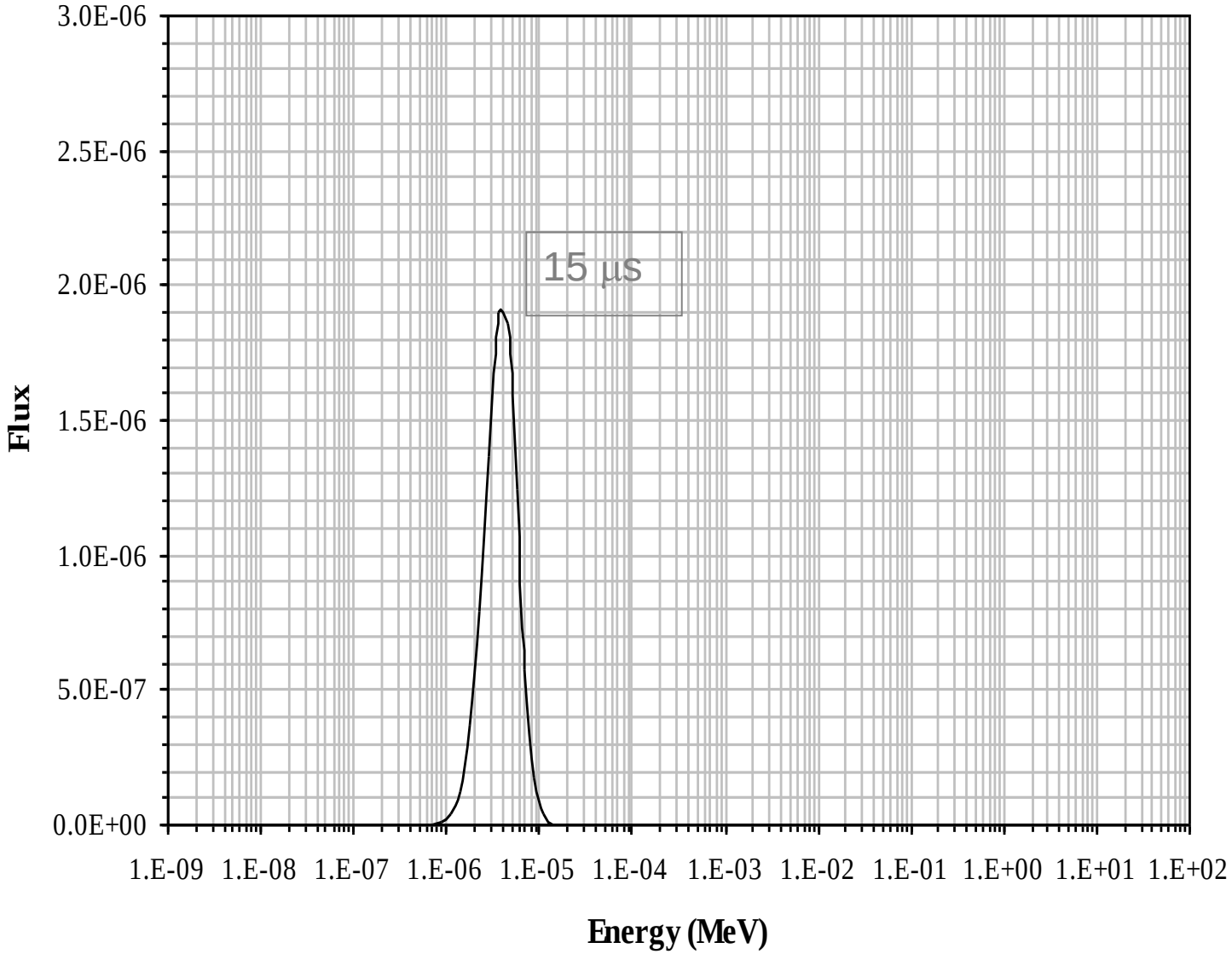

3.0E-06
2.5E-06
2.0E-06
1.5E-06
1.0E-06
5.0E-07
0.0E+00
Flux
1 μs
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)

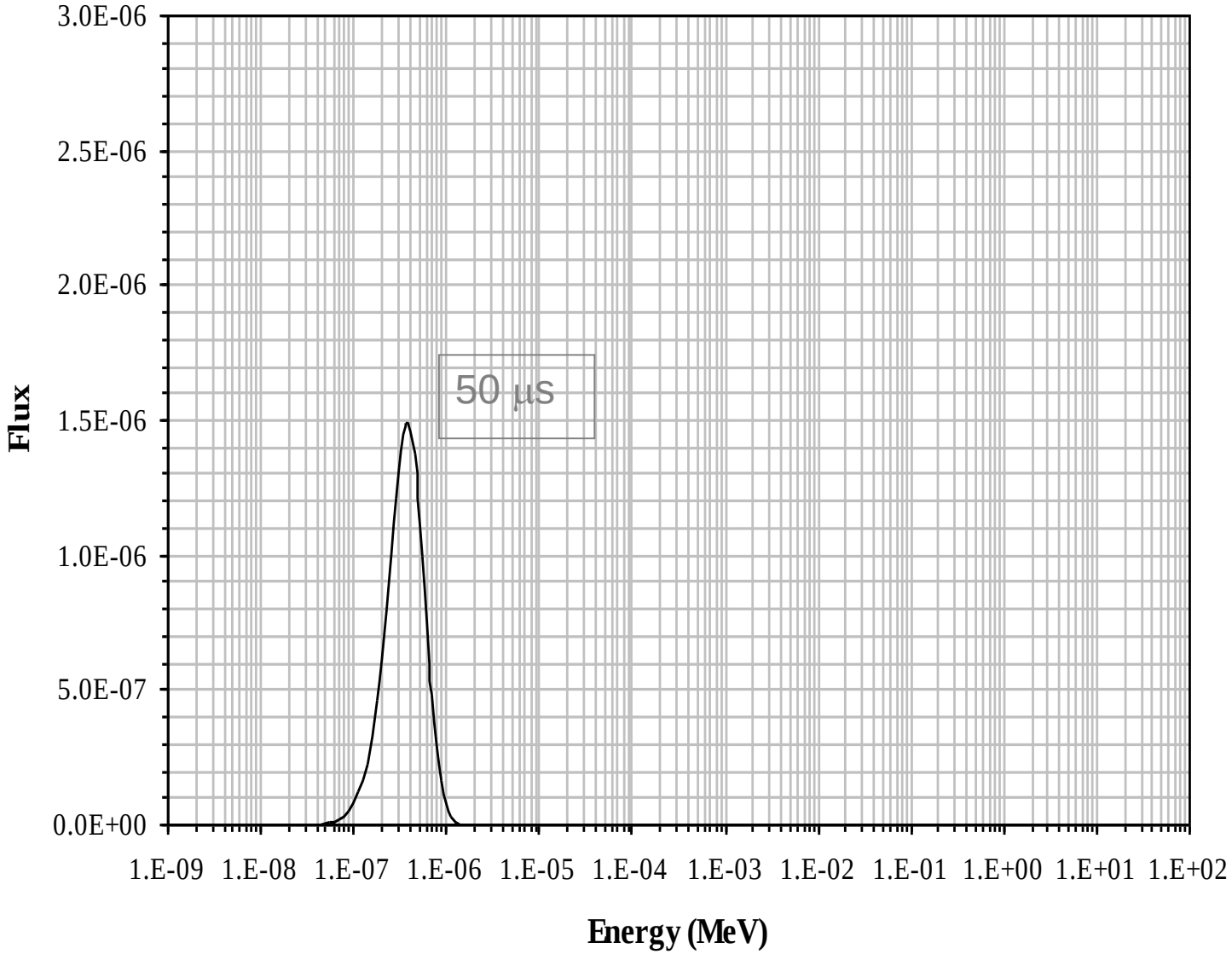

3.0E-06
2.5E-06
2.0E-06
1.5E-06
1.0E-06
5.0E-07
0.0E+00
Flux
2 µs
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)

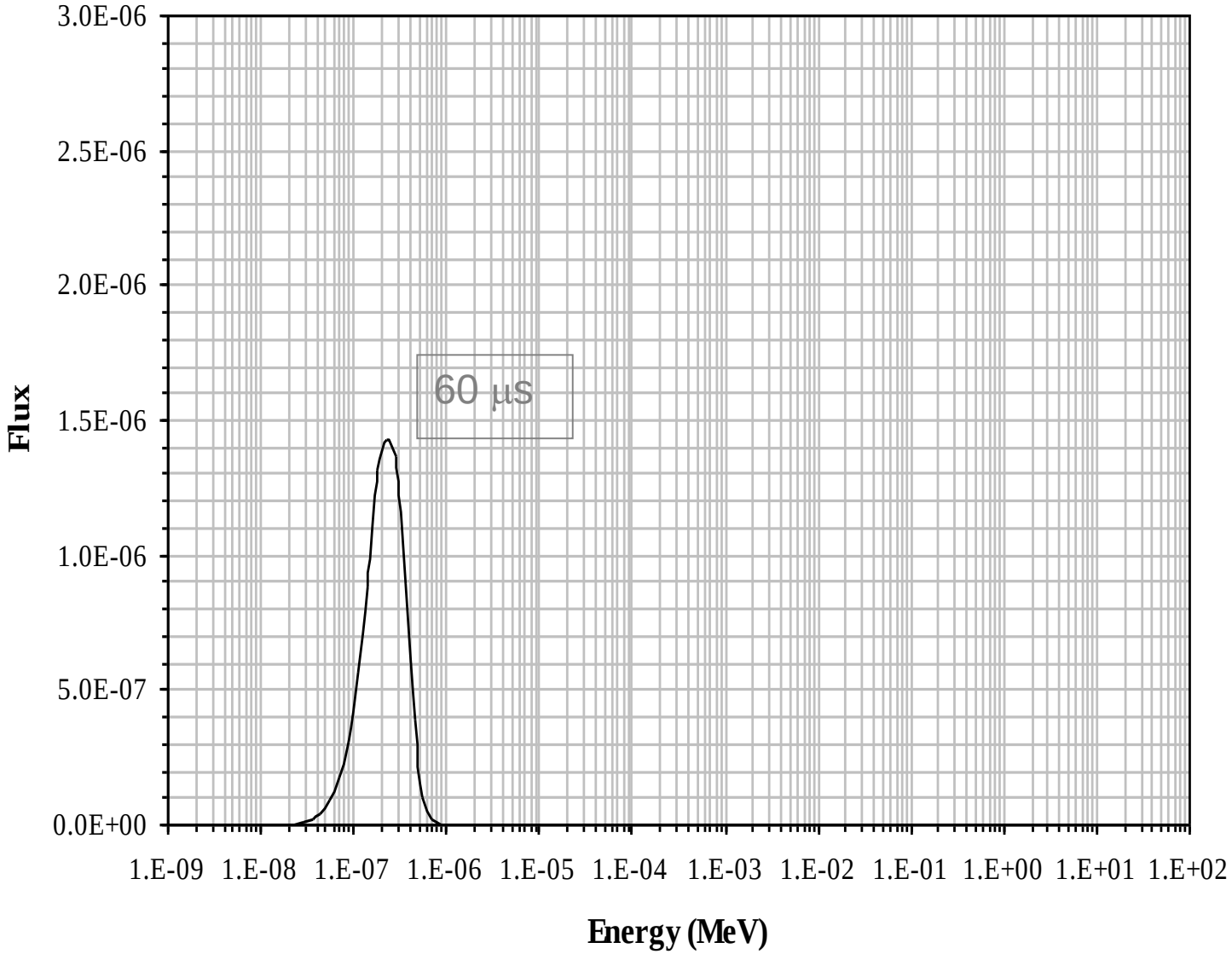

3 μs
Flux
3.0E-06
2.5E-06
2.0E-06
1.5E-06
1.0E-06
5.0E-07
0.0E+00
1.E-09 1.E-08 1.E-07 1.E-06 1.E-05 1.E-04 1.E-03 1.E-02 1.E-01 1.E+00 1.E+01 1.E+02
Energy (MeV)


3.0E-06
2.5E-06
2.0E-06
1.5E-06
1.0E-06
5.0E-07
0.0E+00
Flux
5 μs
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)

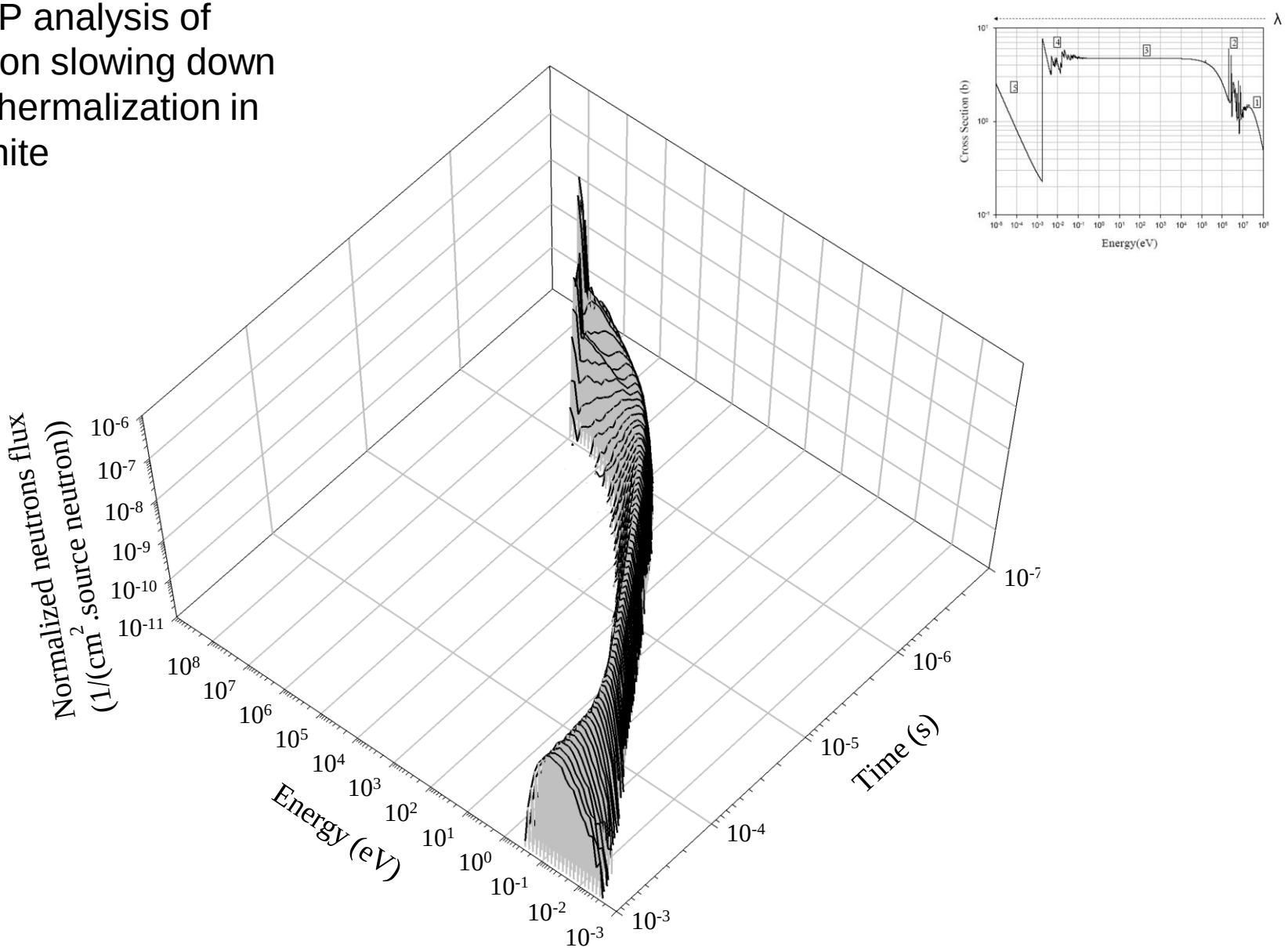

3.0E-06
2.5E-06
2.0E-06
1.5E-06
1.0E-06
5.0E-07
0.0E+00
Flux
10 μs
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)


3.0E-06
2.5E-06
2.0E-06
1.5E-06
1.0E-06
5.0E-07
0.0E+00
Flux
15 μs
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)

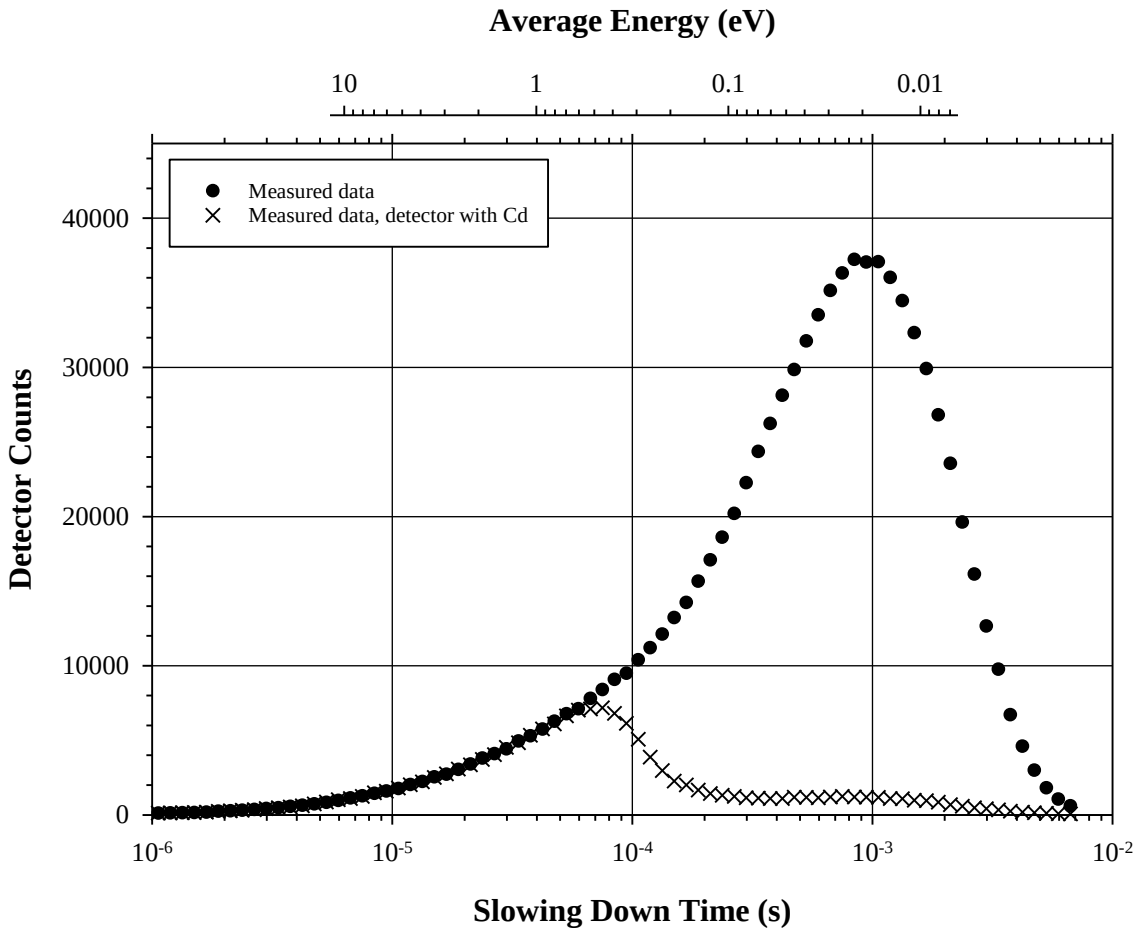

3.0E-06
2.5E-06
2.0E-06
1.5E-06
1.0E-06
5.0E-07
0.0E+00
Flux
50 μs
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)


3.0E-06
2.5E-06
2.0E-06
1.5E-06
1.0E-06
5.0E-07
0.0E+00
Flux
60 μs
1.E-09
1.E-08
1.E-07
1.E-06
1.E-05
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
Energy (MeV)

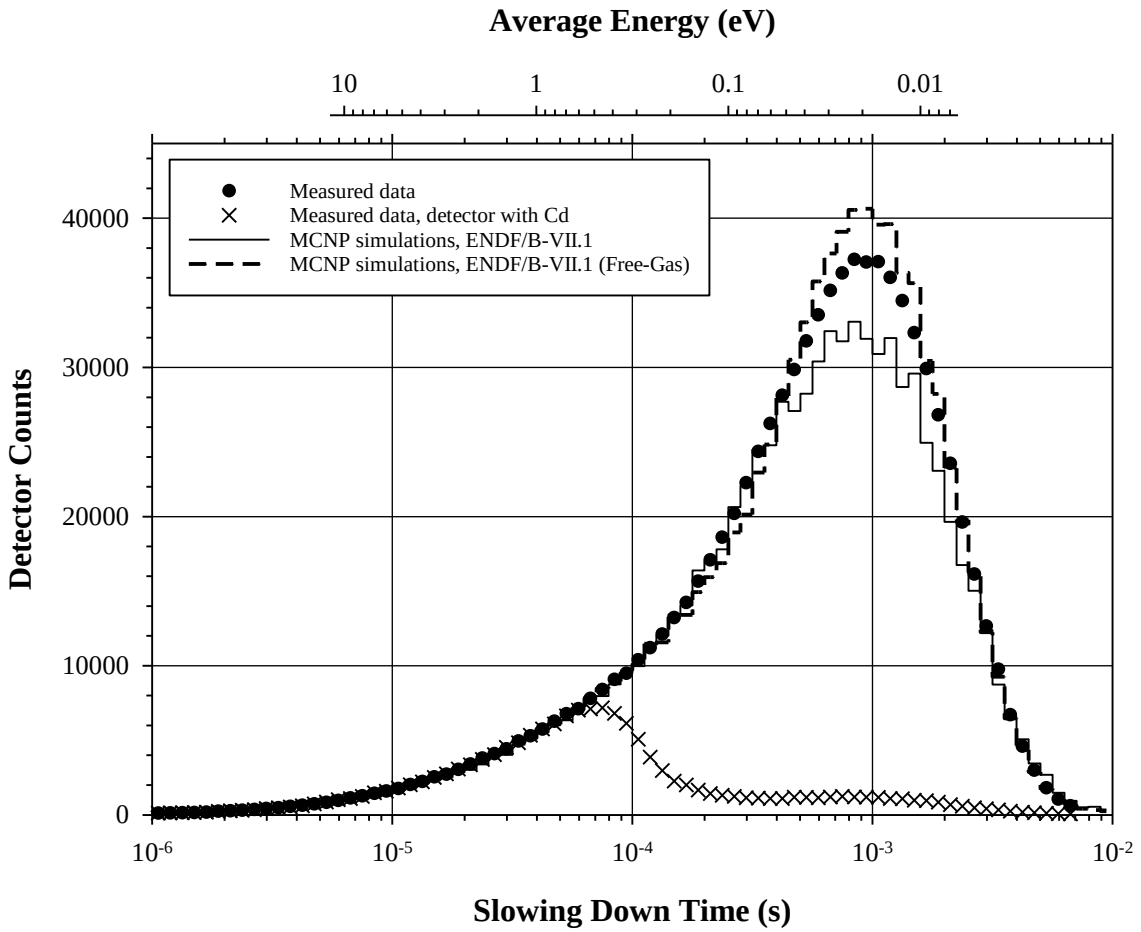
MCNP analysis of neutron slowing down and thermalization in graphite



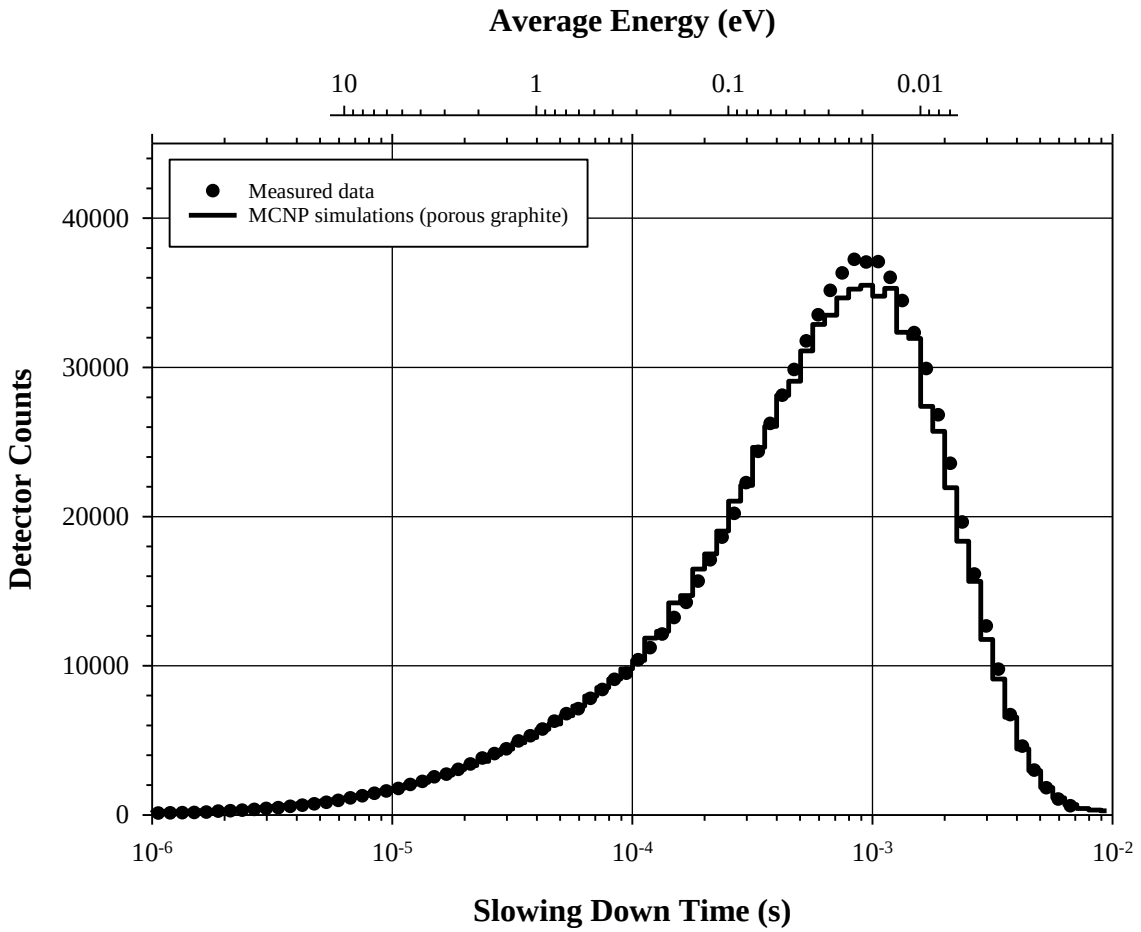
Testing Nuclear Graphite Cross Sections ORELA Experiment



Testing Nuclear Graphite Cross Sections ORELA Experiment



Testing Nuclear Graphite Cross Sections ORELA Experiment



Idaho National Laboratory
TREAT Reactor

CONF-880911--23

DE89 003625

THE EFFECT OF CARBON CRYSTAL STRUCTURE ON TREAT REACTOR PHYSICS CALCULATIONS

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(208) 526-7167

Work Supported by the U. S. Department of Energy, Nuclear Energy Programs, under Contract W-31-109-Eng-38.

submitted to:

1988 International Reactor Physics Conference
Jackson Hole, Wyoming
18-21 September 1988

Table II

Calculated Values of k-effective

Calculational Description	k-effective
Loading 1341 100% Graphite	0.9724 ± 0.0021
Loading 1341 59% Graphite	0.9921 ± 0.0012
Loading 1343 100% Graphite	0.9707 ± 0.0024
Loading 1343 59% Graphite	0.9922 ± 0.0017

Table III

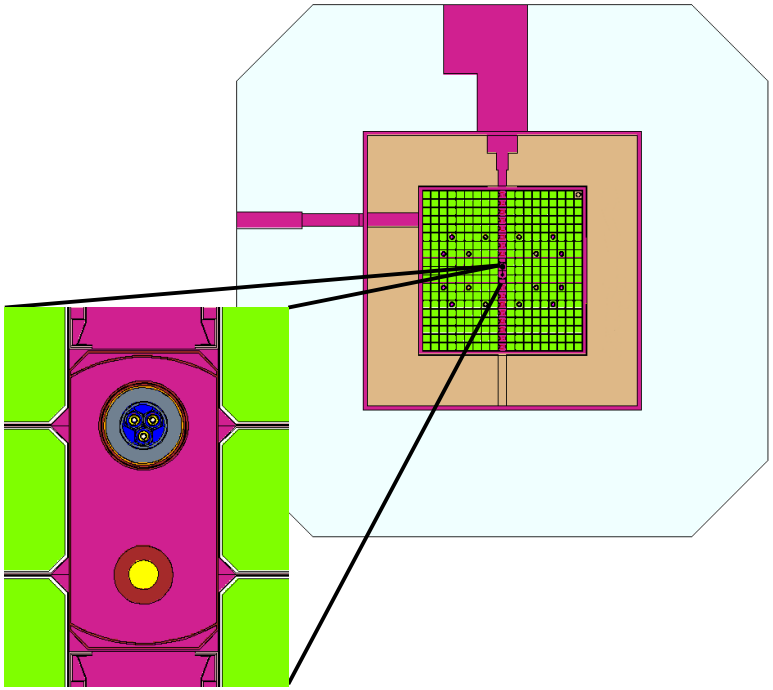
Calculated Fission Density Ratios

Calculational Description	Calculated Fission Density Ratio	Calc.-Exp. / Exp.
100% Graphite	43.2 ± 1.4	+6.9%
59% Graphite	39.4 ± 1.2	-2.5%

Highlighted values are calculated using ENDF/B-VII.1 S(α,β) libraries

TREAT MCNP Model

- Low Level Steady-State (LLSS) critical core configuration
  - Core 1370 and 1372
  - 325 Fuel Elements
  - Graphite Moderator and Reflector
  - 16 Control Rods
    - 4 Transient Rods
    - 12 Shutdown Rods
  - Full-slotted Core
- M2 calibration test vehicle
  - Three test fuel pins or flux wire located at the core center
  - Dysprosium shaping collar
- Material Composition
  - Fuel
    - 0.211wt% uranium
    - 93.1wt% enriched ^{235}U
    - **Graphite matrix average porosity of 13.5%**
  - Boron
    - ~1 ppm in the CP-2 graphite reflector
    - 5.9 ppm in the fuel matrix
  - CP-2 graphite and Zr-3 based on exact composition
  - Standard material compositions for remaining components such as Al-6061, air, etc.



Nuclear Graphite Implementation TREAT (M2CAL)

Specifications	k_{eff}
ENDF/B-VII.1 S(α,β)	0.98357 ± 0.00003 Δ = -1643 pcm

Nuclear Graphite Implementation TREAT (M2CAL)

Specifications	k_{eff}
ENDF/B-VII.1 S(α,β)	0.98357 ± 0.00003 Δ = -1643 pcm
ENDF/B-VIII (10% Porous Graphite) S(α,β)	1.00487 ± 0.00003 Δ = +487 pcm

Summary

1) **Total cross section** measurement produced a highly accurate data point

2) **Differential measurements** illustrated a trend in the DOS as observed in MD

3) **Pulsed slowing down and TREAT "Benchmarks"** showed improvement in the agreement of predicted and measured observable (detector response and keff, respectively) when TSL data consistent with 1 and 2 was used in analysis