LA-UR-12-21048
Approved for public release; distribution is unlimited.

Title:	MCNP6 Results for the Phase III Sensitivity Benchmark of the OCED/NEA Expert Group on Uncertainty Analysis for Criticality Safety Assessment
Author(s):	Kiedrowski, Brian C.
Intended for:	OECD/NEA Working Party on Nuclear Criticality Safety Assessment Expert Group on Sensitivity and Unce Report

Disclaimer:
Los Alamos National Laboratory, an affirmative action/equal opportunity employer,is operated by the Los Alamos National Security, LLC for the National NuclearSecurity Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Departmentof Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

LA-UR-12-21048

MCNP6 Results for the Phase III Sensitivity Benchmark of the OCED/NEA Expert Group on Uncertainty Analysis for Criticality Safety Assessment

B.C. Kiedrowski
X-Computational Physics Division
Los Alamos National Laboratory

Introduction

Within the last decade, there has been increasing interest in the calculation of cross section sensitivity coefficients of k_{eff} for integral experiment design and uncertainty analysis. The OECD/NEA has an Expert Group devoted to Sensitivity and Uncertainty Analysis within the Working Party for Nuclear Criticality Safety. This expert group has developed benchmarks to assess code capabilities and performance for doing sensitivity and uncertainty analysis. Phase III of a set of sensitivity benchmarks evaluates capabilities for computing sensitivity coefficients.

MCNP6 has the capability to compute cross section sensitivities for k_{eff} using continuous-energy physics. To help verify this capability, results for the Phase III benchmark cases are generated and submitted to the Expert Group for comparison.

Description of the Phase III Benchmark

The Phase III benchmark has three cases: III.1, an array of MOX fuel pins, III.2, a series of infinite lattices of MOX fuel pins with varying pitches, and III.3 two spheres with homogeneous mixtures of UF_4 and polyethylene with different enrichments.

Phase III.1: MOX Fuel Pin Lattice

Phase III.1 is an array of MOX fuel pins immersed in light water, simulating a criticality accident where a lattice of MOX fuel in a cask is flooded. This is based off a benchmark within the ICSBEP Handbook with the identifier MIX-COMP-THERM-001-001. Within III.1, there are also four subcases: a detailed model, a homogenized Cartesian model, a homogenized cylindrical model, and an infinite array of fuel pins. MCPN6 results are presented only for the detailed model. The homogenized cases involve requiring special treatment generating something called implicit sensitivities from the homogenization process; MCNP6 does not support homogenization, and is specifically designed for detailed models.

The detailed model is a square lattice with a pitch of 0.9525 cm. The lattice is 28×22, except for the top row, which has only 17 pins, for a total of 605 pins. The fuel pins have a diameter of 0.5842 cm and a height of 91.44 cm. The areas above and below are buffers and are treated as homogenized mixtures of water and pin materials. A light-water scattering kernel is used for thermal scattering with hydrogen in the water.

Phase III.2: Infinite MOX Pin Arrays with Varied Pitches

Phase III.2 is an infinite array of the same MOX fuel pin in Phase III.1. For this phase, there are seven different subcases with pitches for the lattice: 0.586 cm, 0.60 cm, 0.66 cm, 0.73 cm, 0.9525 cm, 1.05 cm, and 1.15 cm. Sensitivity coefficients are computed for each subcase. The real purpose of this benchmark is to test the implicit sensitivity coefficient calculation, which is the differential change in k from the energy group collapse. Since this is a relic of multigroup codes, and MCNP's purpose is continuous-energy physics, there is no implicit sensitivity coefficient. In either case, MCNP6 should be able to match results.

Phase III.3: Spheres of Homogeneous UF_4/Polyethylene Mixtures with Varied Enrichments

Phase III.3 has two subcases: one using low-enriched uranium (LEU) of 2% and the other using intermediate-enriched uranium (IEU) of 50% (atom percent used for enrichment here). The radii of the two subcases are

36 cm and 18.2 cm respectively. Thermal scattering of hydrogen is treated with a polyethylene scattering kernel.

Results

All results are generated using ENDF/B-VII.0 continuous-energy cross sections. The following reactions are considered where applicable: total, capture (n,γ), elastic scattering, inelastic scattering (n,n$'$ from discrete levels and continuum), fission, and nubar (fission ν). While calculations are continuous energy in nature, the sensitivity coefficients can be integrated on bins of an energy grid. To help facilitate comparisons, the same grid that represents the 238-group library found in TSUNAMI-3D is used; note that the energy grid structure is completely arbitrary, however, much like standard tallies in MCNP, and no multigroup cross sections are generated anywhere.

Phase III.1 Results

The value of k_{eff} obtained for this benchmark is 0.99918(1), where the number in parentheses is the (1-sigma) uncertainty of the last digit. Results of energy-integrated sensitivity coefficients are presented, in Table I, for all isotopes in the problem. The first number is the sensitivity and the second is the relative uncertainty. The energy-resolved sensitivity coefficients for various are shown for ^{1}H, ^{16}O, ^{56}Fe, ^{238}U, ^{239}Pu, and ^{240}Pu in Figs. 1-6. Error bars, representing statistical uncertainties from the Monte Carlo random solution process, are displayed, except in the case of ^{56}Fe elastic, where a few of the data points, because of their small magnitude, have very large statistical uncertainties, although they match the general trend.

Phase III.2 Results

For the seven pitches, the following critical heights obtained (in order of increasing pitch) are 28.3 cm, 28 cm, 26.9 cm, 25.04 cm, 20.52 cm, 19.5 cm, 18.84 cm. The corresponding values of k_{eff} calculated by MCNP6 are 1.00050(2), 0.99932(2), 1.00127(3), 1.00039(3), 0.99912(3), 0.99968(2), 1.00016(2). Sensitivities to the total cross sections for each isotope are given in Table II. Several of the more important isotopes are selected – ^{1}H, ^{16}O, ^{56}Fe, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Pu – and the cross section sensitivities by reaction are given in Tables III-X. No energy-resolved sensitivities were calculated because of the sheer volume of the information.

Phase III.3 Results

The values of k_{eff} obtained for the LEU and IEU subcases are 0.98858(1) and 0.98985(1) respectively. The energy-integrated sensitivity coefficients (for both subcases) are given in Table XI, and the energy-resolved total cross section sensitivity coefficients are given in Figs. 7 and 8 for the LEU and IEU subcases respectively.

Acknowledgments

Funding for this work was provided by the US DOE/NNSA Nuclear Criticality Safety Program.

Table I: Energy-integrated cross section sensitivities for isotopes in the Phase III.1 MOX Lattice

	Total	Capture	Elastic	Inelastic	Fission	Nubar
^{1}H	3.35E-01 0.00	-7.99E-02 0.00	4.15E-01 0.00			
C	9.11E-06 0.30	-5.23E-08 0.00	9.00E-06 0.31	1.60E-07 0.55		
^{16}O	8.54E-02 0.00	-1.72E-03 0.00	8.66E-02 0.00	5.23E-04 0.01		
^{28}Si	4.69E-05 0.17	-1.44E-05 0.00	4.29E-05 0.19	1.84E-05 0.08		
^{29}Si	7.10E-06 0.26	-6.10E-07 0.00	6.29E-06 0.29	1.42E-06 0.28		
^{30}Si	4.16E-06 0.36	-1.01E-06 0.00	3.72E-06 0.39	1.45E-06 0.19		
^{50}Ni	-6.74E-04 0.02	-8.09E-04 0.00	9.34E-05 0.16	4.13E-05 0.06		
^{52}Ni	1.12E-03 0.03	-7.97E-04 0.00	1.10E-03 0.03	8.22E-04 0.01		
^{53}Ni	-1.57E-03 0.02	-1.96E-03 0.00	2.59E-04 0.10	1.31E-04 0.03		
^{54}Ni	4.98E-05 0.13	-1.08E-05 0.00	3.38E-05 0.18	2.67E-05 0.07		
^{55}Mn	-1.64E-03 0.02	-2.22E-03 0.00	4.45E-04 0.08	1.34E-04 0.03		
^{54}Fe	-9.02E-05 0.27	-7.17E-04 0.00	4.56E-04 0.05	1.71E-04 0.02		
^{56}Fe	-2.62E-03 0.04	-1.07E-02 0.00	4.51E-03 0.02	3.53E-03 0.01		
^{57}Fe	-4.74E-05 0.32	-2.57E-04 0.00	8.80E-05 0.16	1.20E-04 0.04		
^{58}Fe	4.88E-06 0.94	-2.16E-05 0.00	1.34E-05 0.33	1.30E-05 0.09		
^{58}Cr	-1.45E-03 0.04	-3.06E-03 0.00	1.22E-03 0.04	3.90E-04 0.02		
^{60}Cr	-9.47E-05 0.22	-6.40E-04 0.00	3.46E-04 0.06	2.00E-04 0.02		
^{61}Cr	-1.49E-06 3.22	-2.74E-05 0.00	9.72E-06 0.47	1.61E-05 0.09		
^{62}Cr	-2.79E-04 0.05	-4.31E-04 0.00	1.20E-04 0.13	3.22E-05 0.05		
^{64}Cr	1.17E-05 0.36	-1.25E-05 0.00	1.69E-05 0.25	7.18E-06 0.11		
^{92}Mo	4.98E-05 0.16	-2.21E-05 0.00	4.20E-05 0.19	3.00E-05 0.05		
^{94}Mo	2.49E-05 0.25	-2.37E-05 0.00	1.95E-05 0.31	2.89E-05 0.06		
^{95}Mo	-1.29E-03 0.01	-1.47E-03 0.00	1.22E-04 0.08	6.44E-05 0.04		
^{96}Mo	-1.93E-04 0.05	-2.81E-04 0.00	3.38E-05 0.28	5.42E-05 0.04		
^{97}Mo	-1.59E-04 0.04	-2.11E-04 0.00	1.46E-05 0.43	3.62E-05 0.06		
^{98}Mo	-2.80E-05 0.38	-1.73E-04 0.00	7.05E-05 0.14	7.31E-05 0.04		
^{100}Mo	1.84E-05 0.37	-4.35E-05 0.00	2.87E-05 0.23	3.25E-05 0.06		
^{234}U	-4.07E-07 0.13	-4.42E-07 0.01	-8.09E-09 5.69	2.65E-08 0.87	1.64E-08 0.16	2.03E-08 0.13
^{235}U	2.62E-03 0.00	-3.09E-03 0.00	2.42E-05 0.37	7.08E-05 0.05	5.61E-03 0.00	1.62E-02 0.00
^{238}U	-9.86E-03 0.01	-5.03E-02 0.00	9.68E-03 0.01	1.27E-02 0.00	1.72E-02 0.00	2.49E-02 0.00
^{238}Pu	-4.73E-04 0.01	-4.84E-04 0.00	3.45E-06 0.79	2.09E-06 0.26	5.56E-06 0.07	6.61E-05 0.01
^{239}Pu	1.20E-01 0.00	-2.61E-01 0.00	1.40E-03 0.04	1.67E-03 0.01	3.78E-01 0.00	9.25E-01 0.00
^{240}Pu	-5.40E-02 0.00	-5.90E-02 0.00	8.86E-04 0.03	2.24E-04 0.03	3.87E-03 0.00	5.29E-03 0.00
^{241}Pu	7.46E-03 0.00	-5.27E-03 0.00	1.09E-05 0.70	4.31E-05 0.06	1.27E-02 0.00	2.83E-02 0.00
^{242}Pu	-2.01E-03 0.00	-2.10E-03 0.00	2.36E-06 1.93	6.63E-06 0.18	7.98E-05 0.00	1.13E-04 0.00
^{241}Am	-6.77E-03 0.00	-7.04E-03 0.00	6.65E-06 0.73	1.61E-05 0.10	2.51E-04 0.00	3.67E-04 0.00

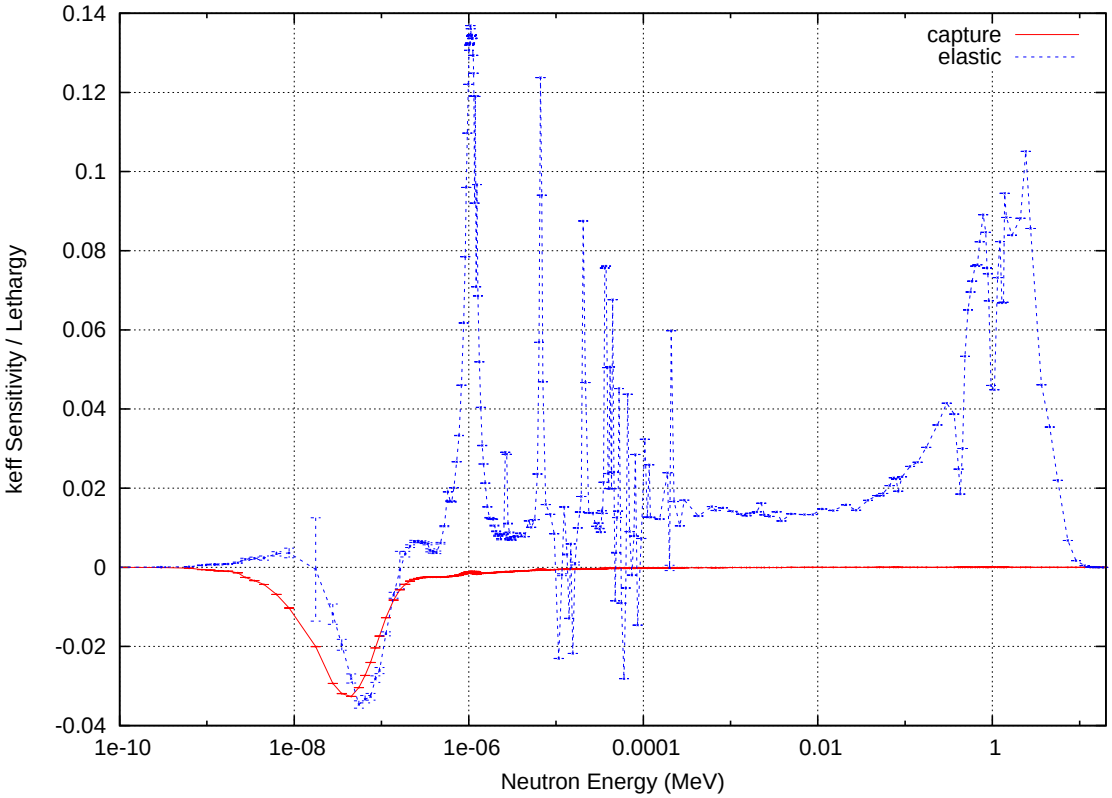

Figure 1: Energy-resolved ^{1}H cross section sensitivities for III.1.

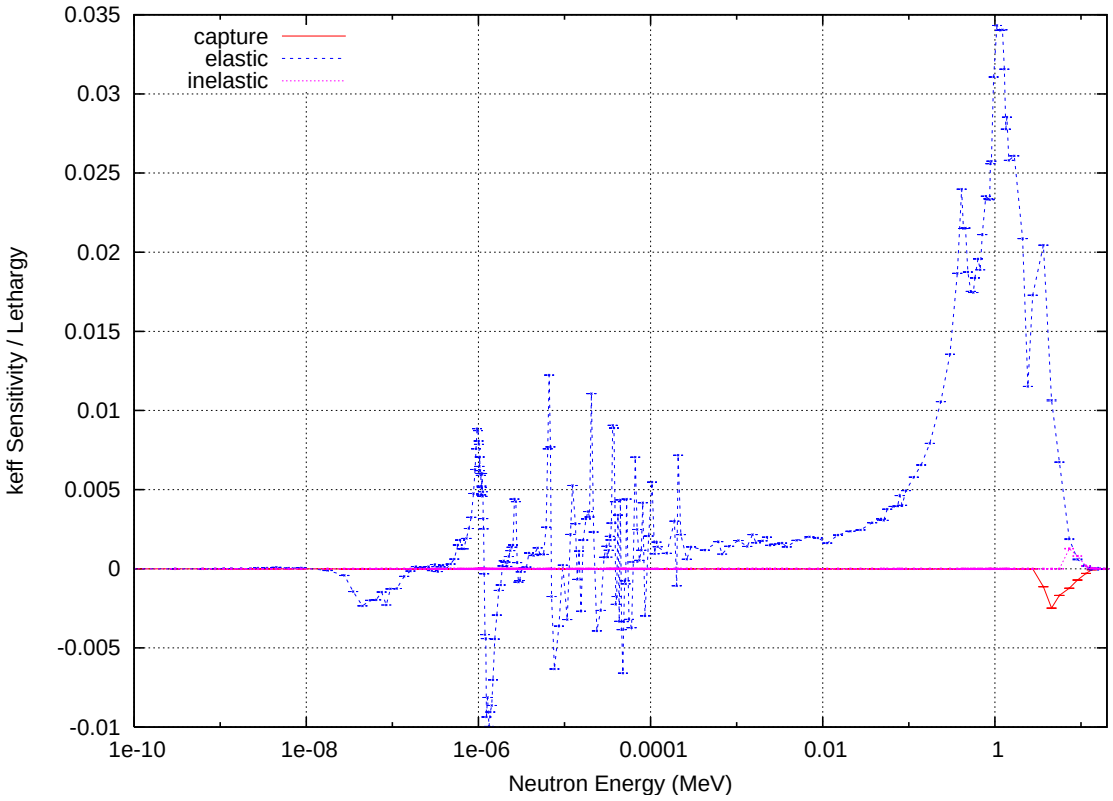

Figure 2: Energy-resolved ^{16}O cross section sensitivities for III.1.

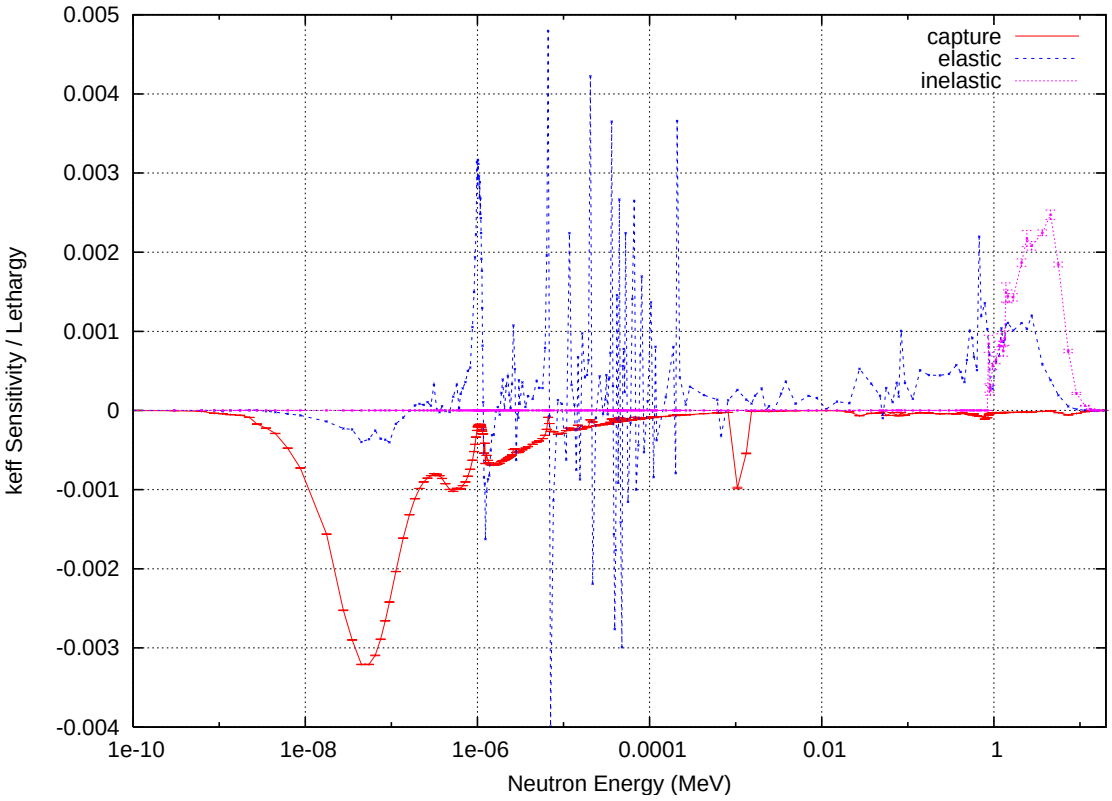

Figure 3: Energy-resolved ^{56}Fe cross section sensitivities for III.1.

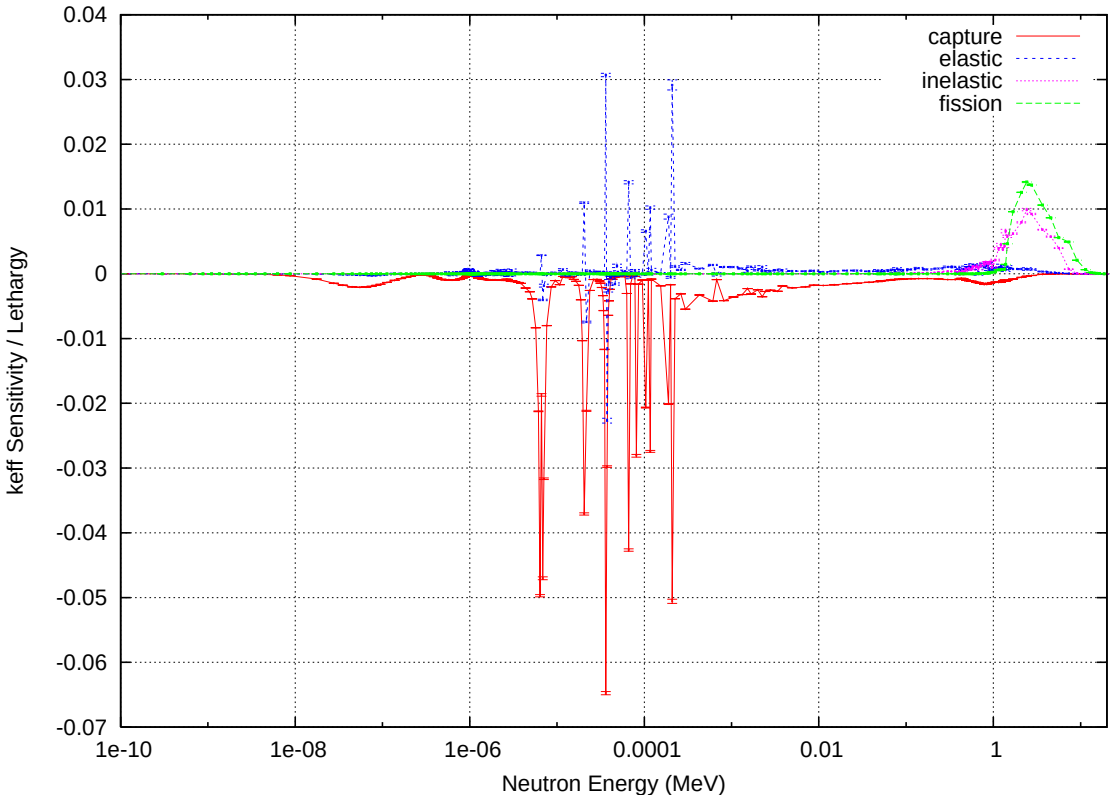

Figure 4: Energy-resolved ^{238}U cross section sensitivities for III.1.

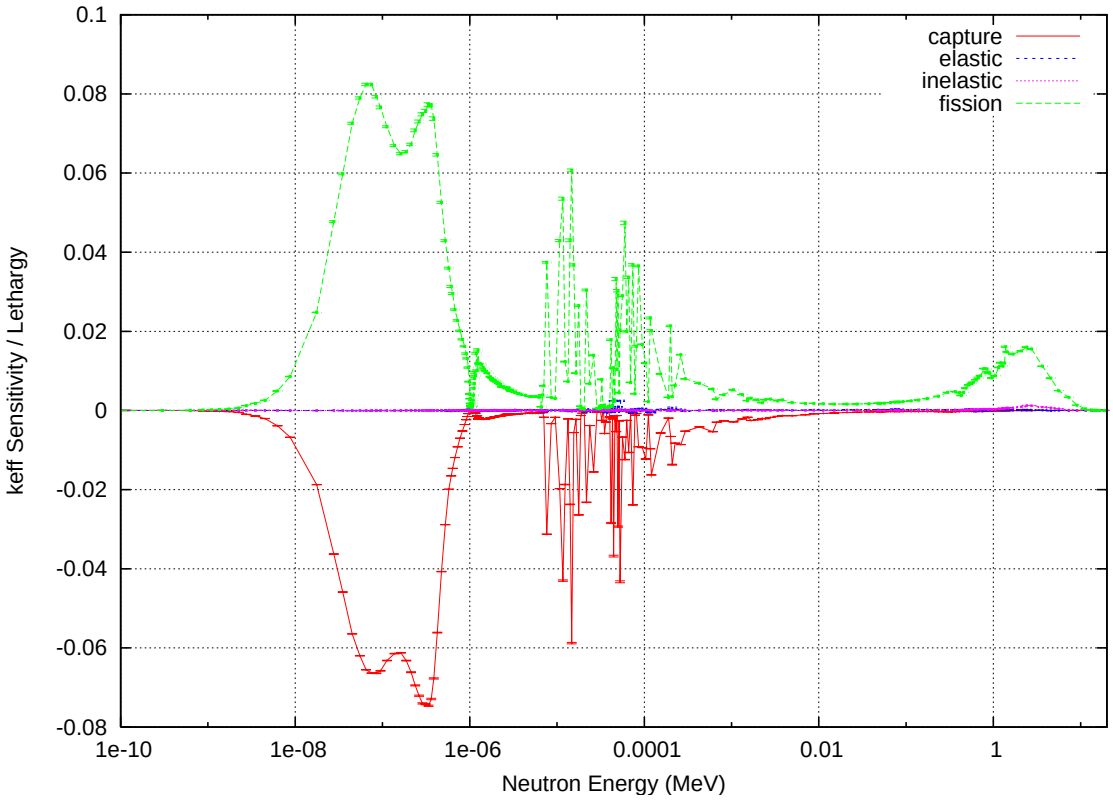

Figure 5: Energy-resolved ^{239}Pu cross section sensitivities for III.1.

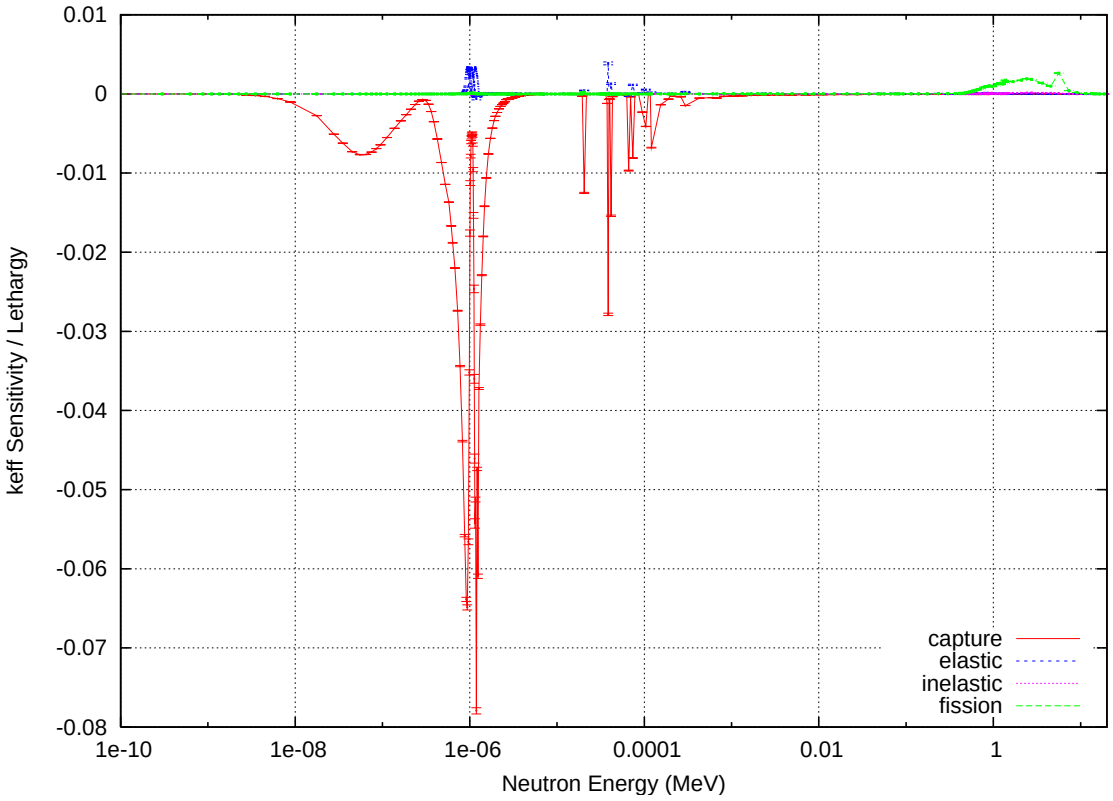

Figure 6: Energy-resolved ^{240}Pu cross section sensitivities for III.1.

Table II: Energy-integrated total cross section sensitivities as a function of pitch for III.2.

	0.586 cm	0.60 cm	0.66 cm	0.73 cm	0.9525 cm	1.05 cm	1.15 cm
^{1}H	1.27E-01 0.01	1.42E-01 0.01	2.16E-01 0.01	3.03E-01 0.00	4.60E-01 0.00	4.85E-01 0.00	4.94E-01 0.00
C	2.57E-05 0.55	4.88E-05 0.28	1.49E-05 1.08	9.85E-06 1.00	1.53E-05 0.48	1.35E-05 0.40	6.83E-06 0.73
^{16}O	5.75E-02 0.01	5.55E-02 0.01	5.48E-02 0.02	5.70E-02 0.01	7.10E-02 0.01	7.51E-02 0.01	7.86E-02 0.01
^{28}Si	3.40E-04 0.13	2.28E-04 0.18	2.75E-04 0.18	1.50E-04 0.20	1.12E-04 0.19	1.00E-04 0.16	7.72E-05 0.18
^{29}Si	-4.34E-06 2.06	9.07E-06 0.98	2.87E-06 3.63	9.18E-06 0.69	8.36E-06 0.56	5.34E-06 0.65	1.06E-05 0.31
^{30}Si	3.52E-07 21.16	-1.80E-06 3.95	-3.31E-06 2.55	3.05E-06 1.75	2.35E-06 1.59	-9.02E-07 2.91	3.26E-06 0.80
^{50}Ni	2.70E-04 0.32	4.89E-05 1.63	-1.64E-05 5.77	-2.51E-04 0.23	-4.94E-04 0.08	-5.61E-04 0.05	-6.30E-04 0.04
^{52}Ni	3.83E-03 0.05	3.19E-03 0.06	2.86E-03 0.07	2.72E-03 0.05	1.87E-03 0.05	1.57E-03 0.04	1.21E-03 0.05
^{53}Ni	5.00E-04 0.28	3.10E-04 0.42	-2.36E-04 0.65	-3.91E-04 0.24	-1.10E-03 0.06	-1.29E-03 0.04	-1.48E-03 0.03
^{54}Ni	5.05E-05 0.67	1.61E-04 0.20	1.76E-04 0.22	9.58E-05 0.24	7.77E-05 0.21	3.48E-05 0.34	3.85E-05 0.28
^{55}Mn	-1.62E-04 1.10	-5.23E-04 0.33	-3.99E-04 0.52	-8.81E-04 0.15	-1.29E-03 0.07	-1.25E-03 0.05	-1.43E-03 0.04
^{54}Fe	8.37E-04 0.16	7.66E-04 0.17	5.77E-04 0.27	3.11E-04 0.30	1.52E-04 0.43	1.26E-05 3.74	-9.26E-05 0.46
^{56}Fe	1.24E-02 0.04	1.13E-02 0.04	8.46E-03 0.06	7.68E-03 0.04	2.72E-03 0.09	9.07E-04 0.22	-1.22E-03 0.15
^{57}Fe	4.98E-04 0.17	5.26E-04 0.15	3.51E-04 0.27	2.96E-04 0.19	6.54E-05 0.60	5.67E-05 0.50	3.61E-05 0.72
^{58}Fe	7.71E-05 0.33	5.53E-05 0.43	7.00E-05 0.40	1.02E-05 1.69	-3.08E-06 3.82	3.44E-06 2.55	8.73E-06 0.91
^{58}Cr	1.24E-03 0.19	1.55E-03 0.15	1.10E-03 0.25	4.59E-04 0.38	1.69E-05 7.95	-5.24E-04 0.19	-8.66E-04 0.10
^{60}Cr	1.10E-03 0.11	8.21E-04 0.13	7.29E-04 0.17	5.56E-04 0.14	1.48E-04 0.37	6.03E-05 0.65	-8.76E-05 0.41
^{61}Cr	1.74E-05 1.34	1.86E-05 1.20	-1.25E-05 2.16	9.61E-07 16.88	-4.64E-06 2.67	1.83E-05 0.50	7.62E-07 10.96
^{62}Cr	3.10E-04 0.26	1.07E-04 0.74	2.16E-04 0.43	-1.66E-05 3.40	-1.33E-04 0.29	-2.49E-04 0.11	-2.93E-04 0.09
^{64}Cr	6.66E-05 0.38	7.29E-05 0.31	2.05E-05 1.33	3.11E-05 0.52	4.44E-05 0.26	8.51E-06 0.93	1.18E-05 0.60
^{92}Mo	6.57E-05 0.64	1.11E-04 0.36	5.53E-05 0.87	5.25E-05 0.54	9.33E-05 0.23	5.98E-05 0.25	5.97E-05 0.24
^{94}Mo	4.52E-05 0.75	-1.22E-05 2.62	1.27E-05 2.91	1.05E-05 2.20	8.06E-05 0.21	5.40E-05 0.23	3.67E-05 0.30
^{95}Mo	-1.93E-03 0.02	-2.01E-03 0.02	-1.98E-03 0.03	-1.89E-03 0.02	-1.40E-03 0.02	-1.26E-03 0.02	-1.11E-03 0.02
^{96}Mo	-6.47E-04 0.08	-5.70E-04 0.08	-4.44E-04 0.13	-3.37E-04 0.11	-1.58E-04 0.16	-1.55E-04 0.12	-1.00E-04 0.17
^{97}Mo	-5.71E-04 0.06	-6.38E-04 0.05	-4.77E-04 0.09	-2.94E-04 0.08	-1.89E-04 0.09	-1.07E-04 0.12	-9.30E-05 0.13
^{98}Mo	-3.18E-04 0.18	-2.59E-04 0.21	-2.78E-04 0.23	-9.78E-05 0.39	-1.25E-05 2.27	2.79E-05 0.74	-1.06E-07 174.07
^{100}Mo	-6.44E-05 0.55	-3.07E-06 11.24	-2.78E-05 1.42	4.60E-05 0.53	4.75E-05 0.37	4.95E-05 0.27	3.23E-05 0.37
^{235}U	8.04E-03 0.01	7.70E-03 0.01	6.12E-03 0.01	4.65E-03 0.01	2.67E-03 0.01	2.40E-03 0.01	2.24E-03 0.01
^{238}U	-8.27E-03 0.08	-9.08E-03 0.07	-1.11E-02 0.07	-9.99E-03 0.05	-4.53E-03 0.07	-3.47E-03 0.07	-2.82E-03 0.08
^{238}Pu	-1.78E-04 0.08	-2.31E-04 0.06	-2.84E-04 0.06	-3.32E-04 0.03	-4.44E-04 0.02	-4.59E-04 0.01	-4.93E-04 0.01
^{239}Pu	3.42E-01 0.00	3.26E-01 0.00	2.64E-01 0.00	2.13E-01 0.00	1.31E-01 0.00	1.18E-01 0.00	1.10E-01 0.00
^{240}Pu	-1.43E-02 0.01	-2.05E-02 0.01	-4.04E-02 0.00	-5.22E-02 0.00	-5.70E-02 0.00	-5.44E-02 0.00	-5.17E-02 0.00
^{241}Pu	1.68E-02 0.00	1.68E-02 0.00	1.50E-02 0.00	1.26E-02 0.00	8.17E-03 0.00	7.25E-03 0.00	6.64E-03 0.00
^{242}Pu	-1.85E-03 0.01	-2.13E-03 0.01	-2.90E-03 0.01	-3.00E-03 0.01	-2.29E-03 0.01	-1.95E-03 0.01	-1.66E-03 0.01
^{241}Am	-4.67E-03 0.01	-5.26E-03 0.01	-6.93E-03 0.00	-7.70E-03 0.00	-7.18E-03 0.00	-6.69E-03 0.00	-6.30E-03 0.00

Table III: Energy-integrated ^{1}H cross section sensitivities as a function of pitch for III.2.

^{1}H	Total	Capture	Elastic	Inelastic	Fission	Nubar
0.586	1.27E-01 0.01	-8.44E-04 0.00	1.28E-01 0.01			
0.6	1.42E-01 0.01	-1.15E-03 0.00	1.43E-01 0.01			
0.66	2.16E-01 0.01	-2.90E-03 0.00	2.19E-01 0.01			
0.73	3.03E-01 0.00	-5.72E-03 0.00	3.08E-01 0.00			
0.9525	4.60E-01 0.00	-1.98E-02 0.00	4.80E-01 0.00			
1.05	4.85E-01 0.00	-2.84E-02 0.00	5.13E-01 0.00			
1.15	4.94E-01 0.00	-3.85E-02 0.00	5.33E-01 0.00			

Table IV: Energy-integrated ^{16}O cross section sensitivities as a function of pitch for III.2.

^{16}O	Total	Capture	Elastic	Inelastic	Fission	Nubar
0.586	5.75E-02 0.01	-2.81E-03 0.00	6.06E-02 0.01	-2.96E-04 0.05		
0.6	5.55E-02 0.01	-2.77E-03 0.00	5.85E-02 0.01	-3.04E-04 0.04		
0.66	5.48E-02 0.02	-2.58E-03 0.00	5.75E-02 0.02	-1.03E-04 0.19		
0.73	5.70E-02 0.01	-2.36E-03 0.00	5.93E-02 0.01	2.50E-05 0.53		
0.9525	7.10E-02 0.01	-1.93E-03 0.00	7.26E-02 0.01	3.45E-04 0.04		
1.05	7.51E-02 0.01	-1.81E-03 0.00	7.65E-02 0.01	4.22E-04 0.03		
1.15	7.86E-02 0.01	-1.74E-03 0.00	7.99E-02 0.01	4.88E-04 0.02		

Table V: Energy-integrated ^{56}Fe cross section sensitivities as a function of pitch for III.2.

^{56}Fe	Total	Capture	Elastic	Inelastic	Fission	Nubar
0.586	1.24E-02 0.04	-5.67E-03 0.00	1.71E-02 0.03	9.30E-04 0.11		
0.6	1.13E-02 0.04	-6.01E-03 0.00	1.56E-02 0.03	1.73E-03 0.05		
0.66	8.46E-03 0.06	-7.17E-03 0.00	1.26E-02 0.04	3.04E-03 0.04		
0.73	7.68E-03 0.04	-8.14E-03 0.00	1.18E-02 0.03	4.02E-03 0.02		
0.9525	2.72E-03 0.09	-1.00E-02 0.00	8.88E-03 0.03	3.84E-03 0.01		
1.05	9.07E-04 0.22	-1.05E-02 0.00	8.01E-03 0.02	3.41E-03 0.01		
1.15	-1.22E-03 0.15	-1.09E-02 0.00	6.55E-03 0.03	3.15E-03 0.01		

Table VI: Energy-integrated ^{235}U cross section sensitivities as a function of pitch for III.2.

^{235}U	Total	Capture	Elastic	Inelastic	Fission	Nubar
0.586	8.04E-03 0.01	-4.75E-03 0.00	1.57E-04 0.30	5.38E-05 0.32	1.26E-02 0.00	2.32E-02 0.00
0.6	7.70E-03 0.01	-4.81E-03 0.00	1.46E-04 0.31	8.94E-05 0.19	1.23E-02 0.00	2.30E-02 0.00
0.66	6.12E-03 0.01	-4.64E-03 0.00	1.70E-04 0.31	6.05E-05 0.31	1.05E-02 0.00	2.10E-02 0.00
0.73	4.65E-03 0.01	-4.21E-03 0.00	6.84E-05 0.47	8.61E-05 0.14	8.70E-03 0.00	1.89E-02 0.00
0.9525	2.67E-03 0.01	-3.21E-03 0.00	6.89E-05 0.35	8.77E-05 0.10	5.72E-03 0.00	1.58E-02 0.00
1.05	2.40E-03 0.01	-2.96E-03 0.00	6.33E-05 0.28	7.33E-05 0.09	5.21E-03 0.00	1.54E-02 0.00
1.15	2.24E-03 0.01	-2.77E-03 0.00	4.33E-05 0.37	6.74E-05 0.09	4.90E-03 0.00	1.53E-02 0.00

Table VII: Energy-integrated ^{238}U cross section sensitivities as a function of pitch for III.2.

^{238}U	Total	Capture	Elastic	Inelastic	Fission	Nubar
0.586	-8.27E-03 0.08	-1.18E-01 0.00	4.03E-02 0.01	1.07E-02 0.02	5.71E-02 0.00	8.93E-02 0.00
0.6	-9.08E-03 0.07	-1.14E-01 0.00	3.76E-02 0.02	1.27E-02 0.02	5.38E-02 0.00	8.38E-02 0.00
0.66	-1.11E-02 0.07	-1.01E-01 0.00	2.99E-02 0.02	1.60E-02 0.02	4.29E-02 0.00	6.58E-02 0.00
0.73	-9.99E-03 0.05	-8.72E-02 0.00	2.44E-02 0.02	1.72E-02 0.01	3.44E-02 0.00	5.17E-02 0.00
0.9525	-4.53E-03 0.07	-5.67E-02 0.00	1.62E-02 0.02	1.53E-02 0.01	1.98E-02 0.00	2.86E-02 0.00
1.05	-3.47E-03 0.07	-4.83E-02 0.00	1.42E-02 0.02	1.35E-02 0.01	1.63E-02 0.00	2.35E-02 0.00
1.15	-2.82E-03 0.08	-4.16E-02 0.00	1.20E-02 0.02	1.22E-02 0.01	1.39E-02 0.00	1.99E-02 0.00

Table VIII: Energy-integrated ^{239}Pu cross section sensitivities as a function of pitch for III.2.

^{239}Pu	Total	Capture	Elastic	Inelastic	Fission	Nubar
0.586	3.42E-01 0.00	-1.48E-01 0.00	7.11E-03 0.04	2.17E-03 0.04	4.81E-01 0.00	8.30E-01 0.00
0.6	3.26E-01 0.00	-1.58E-01 0.00	6.67E-03 0.04	2.20E-03 0.04	4.75E-01 0.00	8.37E-01 0.00
0.66	2.64E-01 0.00	-1.94E-01 0.00	4.79E-03 0.07	2.37E-03 0.05	4.51E-01 0.00	8.62E-01 0.00
0.73	2.13E-01 0.00	-2.23E-01 0.00	4.33E-03 0.05	2.40E-03 0.03	4.28E-01 0.00	8.84E-01 0.00
0.9525	1.31E-01 0.00	-2.60E-01 0.00	2.62E-03 0.05	2.08E-03 0.02	3.87E-01 0.00	9.20E-01 0.00
1.05	1.18E-01 0.00	-2.64E-01 0.00	2.52E-03 0.04	1.82E-03 0.02	3.78E-01 0.00	9.28E-01 0.00
1.15	1.10E-01 0.00	-2.66E-01 0.00	1.94E-03 0.05	1.64E-03 0.02	3.72E-01 0.00	9.33E-01 0.00

Table IX: Energy-integrated ^{240}Pu cross section sensitivities as a function of pitch for III.2.

^{240}Pu	Total	Capture	Elastic	Inelastic	Fission	Nubar
0.586	-1.43E-02 0.01	-3.20E-02 0.00	1.99E-03 0.06	1.83E-04 0.19	1.56E-02 0.00	2.17E-02 0.00
0.6	-2.05E-02 0.01	-3.70E-02 0.00	1.73E-03 0.06	2.99E-04 0.11	1.44E-02 0.00	2.01E-02 0.00
0.66	-4.04E-02 0.00	-5.32E-02 0.00	1.63E-03 0.08	2.82E-04 0.14	1.09E-02 0.00	1.51E-02 0.00
0.73	-5.22E-02 0.00	-6.24E-02 0.00	1.53E-03 0.05	3.47E-04 0.07	8.33E-03 0.00	1.15E-02 0.00
0.9525	-5.70E-02 0.00	-6.30E-02 0.00	1.25E-03 0.05	3.11E-04 0.06	4.48E-03 0.00	6.08E-03 0.00
1.05	-5.44E-02 0.00	-5.94E-02 0.00	1.08E-03 0.04	2.52E-04 0.05	3.68E-03 0.00	4.97E-03 0.00
1.15	-5.17E-02 0.00	-5.60E-02 0.00	8.97E-04 0.05	2.51E-04 0.05	3.08E-03 0.00	4.16E-03 0.00

Table X: Energy-integrated ^{241}Pu cross section sensitivities as a function of pitch for III.2.

^{241}Pu	Total	Capture	Elastic	Inelastic	Fission	Nubar
0.586	1.68E-02 0.00	-3.81E-03 0.00	2.78E-05 1.39	2.39E-05 0.63	2.05E-02 0.00	3.37E-02 0.00
0.6	1.68E-02 0.00	-4.04E-03 0.00	6.58E-05 0.57	6.75E-05 0.21	2.07E-02 0.00	3.44E-02 0.00
0.66	1.50E-02 0.00	-4.60E-03 0.00	7.13E-05 0.63	3.68E-05 0.44	1.95E-02 0.00	3.41E-02 0.00
0.73	1.26E-02 0.00	-4.87E-03 0.00	4.48E-05 0.61	6.20E-05 0.16	1.74E-02 0.00	3.23E-02 0.00
0.9525	8.17E-03 0.00	-5.18E-03 0.00	3.90E-05 0.51	6.61E-05 0.12	1.32E-02 0.00	2.86E-02 0.00
1.05	7.25E-03 0.00	-5.25E-03 0.00	2.06E-05 0.70	4.52E-05 0.12	1.24E-02 0.00	2.79E-02 0.00
1.15	6.64E-03 0.00	-5.30E-03 0.00	1.15E-05 1.14	3.91E-05 0.12	1.19E-02 0.00	2.75E-02 0.00

Table XI: Energy-integrated cross section sensitivities for LEU and IEU subcases of III.3.

		LEU	IEU
^{1}H	Total	2.41E-01 0.01	4.53E-01 0.00
^{1}H	Capture	-1.02E-01 0.00	-4.16E-03 0.00
^{1}H	Elastic	3.43E-01 0.01	4.57E-01 0.00
C	Total	2.78E-02 0.02	6.56E-02 0.00
C	Capture	-6.63E-04 0.00	-1.12E-04 0.00
C	Elastic	2.82E-02 0.02	6.51E-02 0.00
C	Inelastic	2.89E-04 0.05	5.71E-04 0.02
^{19}F	Total	4.32E-02 0.02	1.18E-01 0.00
^{19}F	Capture	-5.33E-03 0.00	-2.15E-03 0.00
^{19}F	Elastic	3.21E-02 0.02	8.12E-02 0.00
^{19}F	Inelastic	1.63E-02 0.01	3.84E-02 0.00
^{235}U	Total	2.53E-01 0.00	1.30E-01 0.00
^{235}U	Capture	-1.12E-01 0.00	-2.18E-01 0.00
^{235}U	Elastic	2.13E-04 0.36	1.31E-02 0.01
^{235}U	Inelastic	2.27E-04 0.08	1.42E-02 0.00
^{235}U	Fission	3.65E-01 0.00	3.21E-01 0.00
^{235}U	Nubar	9.50E-01 0.00	9.79E-01 0.00
^{238}U	Total	-2.02E-01 0.00	-2.18E-03 0.10
^{238}U	Capture	-2.79E-01 0.00	-5.87E-02 0.00
^{238}U	Elastic	2.69E-02 0.02	2.26E-02 0.01
^{238}U	Inelastic	1.47E-02 0.01	1.84E-02 0.00
^{238}U	Fission	3.40E-02 0.00	1.50E-02 0.00
^{238}U	Nubar	5.02E-02 0.00	2.07E-02 0.00

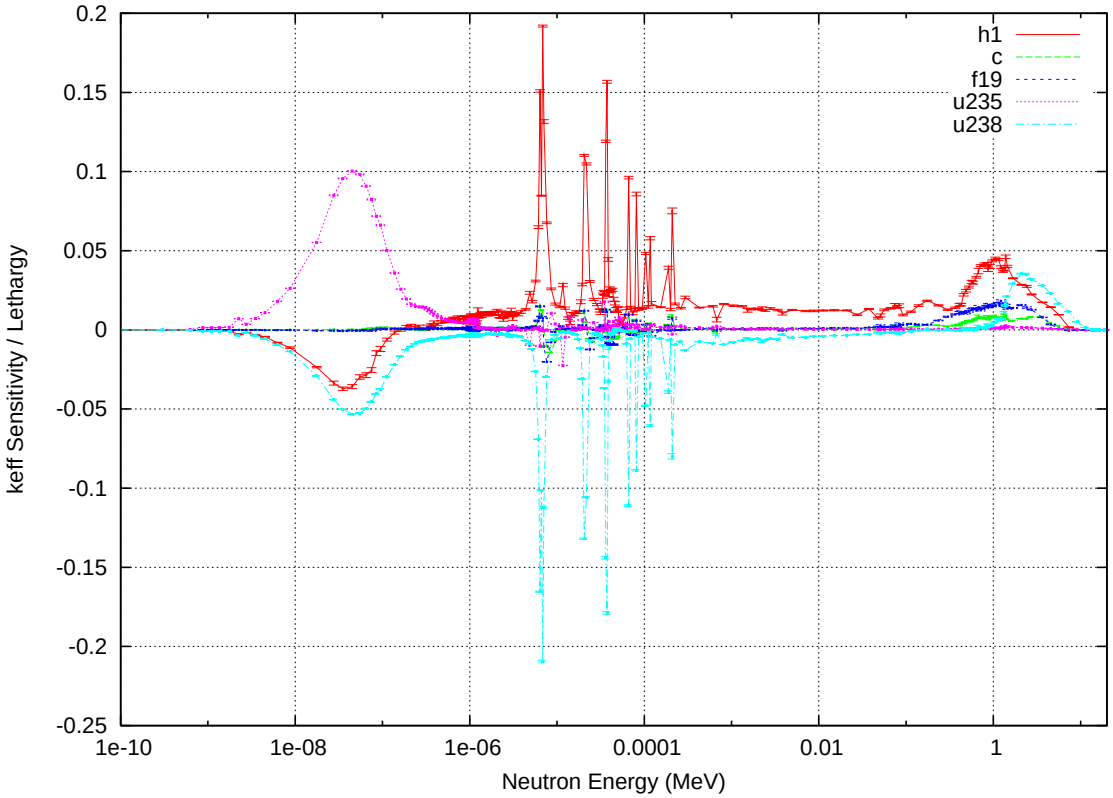

Figure 7: Energy-resolved total cross section sensitivities for III.3 LEU subcase.

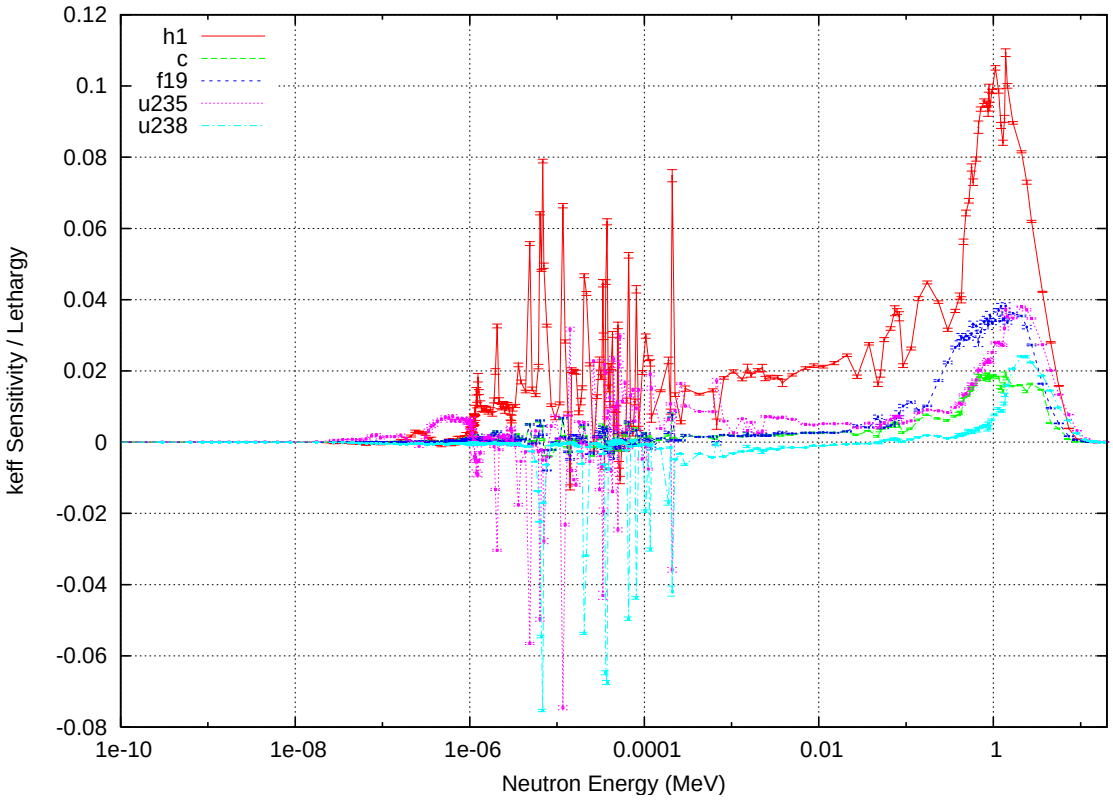

Figure 8: Energy-resolved total cross section sensitivities for III.3 IEU subcase.