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Sensitivity analysis of multiplication neutron factor in various Benchmark

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Abstract

In this paper, five cross-section libraries data ENDF/BVII.0, ENDF/BVII.1, ENDF/BVIII.0, JEFF3.2 and JENDL4U have been studied. The calculation was performed using MCNP6.2 Monte Carlo N-Particle code. Four benchmarks with different fissile materials were modeled (Lady Godiva HEU-MET-FAST-001, Jezebel with Pu fissile material PU-MET-FAST-002 and U233 fissile material U233-MET-FAST-001) and mixed Plutonium – Uranium MIX-MET-FAST-001. The calculations of keff values compared with the experimentally measured results which are available in the Database the International Criticality Safety Benchmark Evaluation Program Handbook. The ksen based on linear-perturbation theory using adjoint weighting has been used in this study. The focus is given to only total cross-section.

Keywords: MCNP6.2, sensitivity, Lady Godiva, Jezebel, ENDF/BVII.0, ENDF/BVII.1, ENDF/BVIII.0, JEFF3.2, JENDL4U

1. Introduction

The sensitivity coefficient can be estimated with Monte Carlo or deterministic methods using perturbation theory. The MCNP6.2 [1] code uses the Iterated Fission Probability method to compute the sensitivity coefficients in a continuous-energy Monte Carlo simulation [2]. The multiplication factor (*keff*) is proportional to the sensitivity coefficient i.e. those with a high magnitude of sensitivity are very important for the determination of *keff*, otherwise, those with lower magnitude are not important. In addition, the value of *keff* is changed with the sign of the sensitivity coefficient.

In this study, four Benchmark experiments were selected from Database the International Criticality Safety Benchmark Evaluation Program Handbook [3] namely Lady Godiva Highly-Enriched Uranium, two Jezebel benchmarks [4], the first with the main fissile isotope Pu-239 and the second U-233 and the last contain a mix of the Plutonium surrounded by highly enriched

uranium [5]. The continuous-energy cross-section data used in this study is at a temperature of 300K.

2. Methodology

The MCNP6.2 code is dotted with the ksen method feature for sensitivity calculation. It is an adjoint-based methodology, but is used with only the fixed source "kcode". The sensitivity coefficient has the property of being additive. The sensitivity of the total cross-section is a sum of the sensitives of all the individual reaction cross-section of a given isotope.

The sensitivity coefficient is the ratio of the resulting relative change in a response keff to the relative change in a system parameter x (cross-section over the same small energy range) is defined:

$$S_{k,x} = \frac{\Delta k/_k}{\Delta x/_x} = \frac{x.\Delta k}{k.\Delta x} \quad (1)$$

Perturbation theory can be used to derive an expression for the sensitivity coefficient:

$$S_{k,x} = \frac{< \psi^+, (\Sigma_x - C_x - 1/_k F_x)\psi >}{< \psi^+, F\psi >} \quad (2)$$

where

Σ_x is the macroscopic cross-section of interest (zero if not a cross-section), C_x is the scattering integral for nuclear data x (zero if no scattering) and F_x is the fission integral for nuclear data x (zero if not fission).

Lady Godiva was in operation from 1951 to 1957. Lady Godiva was a bare sphere of HEU composed of 52.6 kg of enriched uranium not reflected. HEU-MET-FAST-001 highly enriched of Uranium 235 93.71wt%[1] Table 1. simpler than the two-component Topsy core, and was used to provide data and benchmarks for the expected super-prompt critical behavior. Later, the whole thing was used as radiation for biological studies and produced approximately 1,000 pulses of instantaneous radiation.

Table 1: weight fraction composition of the Benchmark HEU-MET-FAST-001

	wt% U234	wt% U235	wt% U236	wt% U238
Benchmark HEU-MET-FAST-001	1.02%	93.71%	-	5.27%

[1]Wight fraction

The critical assembly of the Jezebel was commissioned in 1954. In addition, Jezebel provided neutron systems with plutonium information similar to this enriched uranium information on Lady Godiva. The core was a non-reflected spherical delta phase assembly plutonium. Its mass was 9.46 kg and it had a radius of 6.66 cm. The Jezebel set was also used to study neutron information on U-233. The U-233 components used on the assembly were removed due to the intensity of the activity. Gamma radiation from U-232 impurities. U233-MET-FAST-001 Table2 the main fissile material is U-233 for 98.11wt%.

Table 2: weight fraction composition of the Benchmark U233-MET-FAST-001

	wt% U233	wt% U234	wt% U235	wt% U238
Benchmark U233-MET-FAST-001	98.11%	1.25%	0.03%	0.61%

Table 3: weight fraction composition of the Benchmark Pu-MET-FAST-002

	wt% Pu239	wt% Pu240	wt% Pu241	wt% Pu242
Benchmark Pu-MET-FAST-002	76.31%	20.16%	3.12%	0.4%

The benchmark MIX-MET-FAST-001 is a critical experimental of the fissionable main core material Plutonium is in the form of two hemispheres with a center void of 2.16cm surrounded by highly enriched Uranium [5] is a composite of Pu and U with a ration (Pu/(U+Pu) = 0.45) U-235 93.20wt% and Pu-239 94.77wt%.

Table 4: weight fraction composition of the Benchmark MIX-MET-FAST-001

	Pu/(Pu+U) ratio	wt% Pu239	wt% Pu240	wt% Pu241	wt% U235	wt% U238
Benchmark MIX-MET-FAST-001	0.45	94.77%	4.92%	0.31%	93.20%	6.8%

3. Result and discussion

The calculation was performed by the Monte Carlo N-Particle MCNP6.2 using five different cross-section data. The first step is to calculate the keff and compare the results with reference values [3][6]. The second step is the total cross-section sensitivity coefficient calculation for the isotope of the benchmark using the ENDF/BVII.0 cross-section as the reference of comparison.

3.1. Results of criticality calculations

The benchmarks HEU-MET-FAST-001, U233-MET-FAST-001, MIX-MET-FAST-001 and PU-MET-FAST-002 [6] are designed for physics measurements purpose at Los Alamos National Laboratory LANL. The form of the fuel elements is a spherical single unit. The results of the keff multiplication factor and standard deviation are given in figure 1.

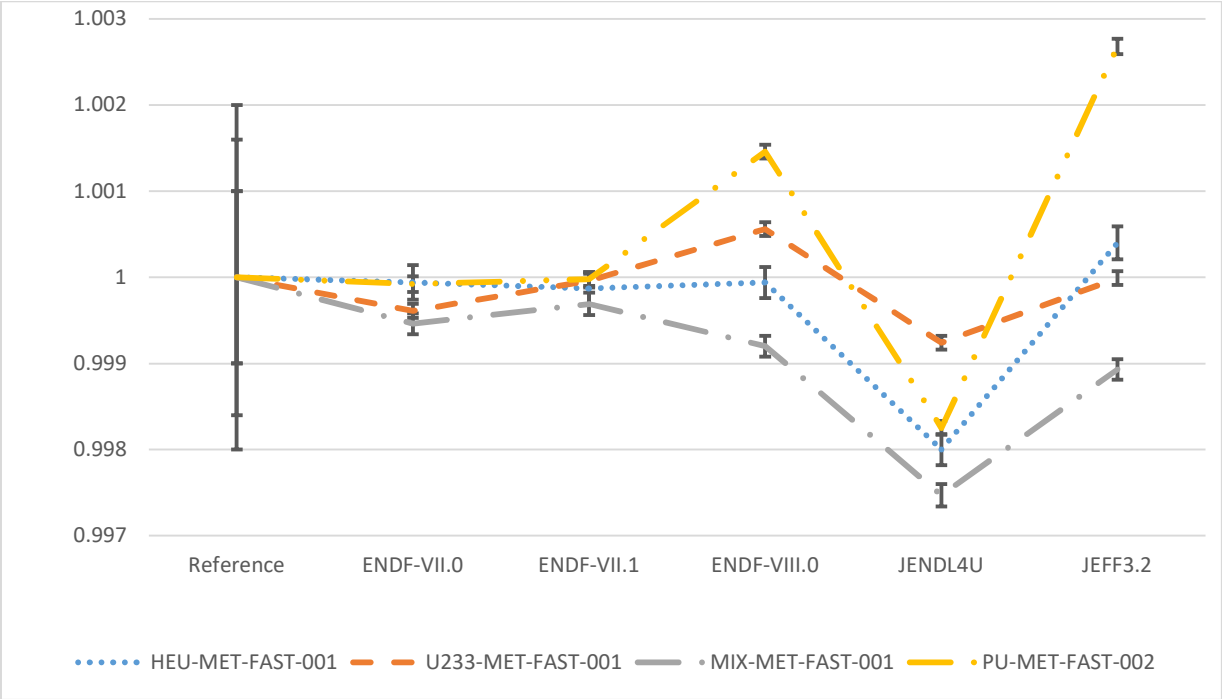

Figure 1: MCNP6 multiplication factor calculation keff values with five data libraries and keff references

The values of $\frac{C}{E} - 1$ ("E" is the expected of the Benchmark value and "C" is the calculated value) using the library ENDF/VII.0 and ENDF/VII.1 were less than 60pcm for all the Benchmark. And where using the library ENDFVIII.0 the values were -6pcm, 56pcm, -80pcm and 146 pcm for the benchmark HEU-MET-FAST-001, U233-MET-FAST-001, MIX-MET-FAST-001 and PU-MET-FAST-002 respectively. All the Benchmark has the highest than 200pcm except U233-MET-FAST-001 is -76pcm with library JENDL4U. And for the library JEFF3.2 the value 40pcm, -1pcm, -107pcm and 268pcm for the benchmark HEU-MET-FAST-001, U233-MET-FAST-001, MIX-MET-FAST-001 and PU-MET-FAST-002 respectively.

3.2. Sensitivity analysis

- Benchmark HEU-MET-FAST-001

The sensitivities coefficients of the total cross-section table 5 for three isotopes of Uranium 235, 238 and 234 are 0.803298, 0.016845and 0.007370 respectively. Clearly, Uranium 235 is the dominating source of *keff* determination. For U-235 all the libraries agree with a difference of 1%.

For U-238 ENDFVII.1 agree with ENDFVII.0 in contrast with the library ENDFVIII.0, JEFF3.2 and JENDL4U whose sensitivities coefficients are lower then ENDFVII.0 by -2.07%, -4.98% and -7.06% respectively. Finally, for U-234 the two libraries ENDFVII.1 and JEFF3.2 agree with ENDFVII.0 results, except ENDFVIII.0 and JENDL4U which are higher by 4.44% and 5.81% respectively.

Table 5: Comparisons for total cross-section sensitivities coefficient for the HEU-MET-FAST-001 using MCNP6.2 code

Isotope	ENDFVII.0	ENDFVII.1		ENDFVIII.0		JEFF3.2		JENDL4U	
	MCNP6.2 $S_{k,x}$	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %
U-235	0,800706 +/- 0,002842	0,808965 +/- 0,003070	**1,03**	0,802893 +/- 0,003087	**0,27**	0,804497 +/- 0,002982	**0,47**	0,809539 +/- 0,002935	**1,10**
U-238	0,019000 +/- 0,000630	0,019175 +/- 0,000675	**0,92**	0,018607 +/- 0,000687	**-2,07**	0,018054 +/- 0,000649	**-4,98**	0,017658 +/- 0,000619	**-7,06**
U-234	0,007335 +/- 0,000280	0,007408 +/- 0,000267	**1,00**	0,007661 +/- 0,000282	**4,44**	0,007298 +/- 0,000253	**-0,50**	0,007761 +/- 0,000260	**5,81**

- Benchmark PU-MET-FAST-002

In this Benchmark, the most important isotope for determination of the *keff* according to the result of the coefficient of the sensitivity table 6 is the Pu-239 with 0.69195, Pu-240 with 0.12958 and finally Pu-242 with 0.00231. in this case, all of the libraries have some impact on the *keff* with a maximal deviation of 1.6%.

Table 6: Comparisons for total cross-section sensitivities coefficient for the PU-MET-FAST-002 using MCNP6.2 code

Isotope	ENDFVII.0	ENDFVII.1		ENDFVIII.0		JEFF3,3		JENDL4U	
	MCNP6.2 $S_{k,x}$	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %
Pu-239	0,69195 +/- 0,00095	0,69332 +/-0,00098	**0,20**	0,68987 +/-0,00096	**- 0,30**	0,69001 +/-0,00097	**-0,28**	0,69334 +/- 0,00097	**0,20**
Pu-240	0,12958 +/- 0,00040	0,13032 +/-0,00039	**0,57**	0,13142 +/-0,00038	**1,42**	0,13098 +/-0,00039	**1,08**	0,12869 +/- 0,00036	**-0,68**
Pu-242	0,00231 +/- 0,00006	0,00234 +/-0,00005	**1,60**	0,00233 +/-0,00005	**1,04**	0,00232 +/-0,00005	**0,61**	0,00231 +/- 0,00005	**0,13**

- Benchmark U233-MET-FAST-001

According of table 7, the isotope U-233 was the most important isotope in the determination of keff with a value of sensitivity of total cross-section 0,800983The remarkable deviation is for U-235 isotope in the library ENDFVII.1 lowest by 14.08% from ENDFVII.0, library ENDFVIII.0 lowest by 5.83% and library JENDL4U higher by 8.74. Moreover, for U-238 isotope the sensitivity lowest by 10.52% and 6.01% for the libraries ENDFVIII.0 and JEFF3.2 respectively.

Table 7: Comparisons for total cross section sensitivities coefficient for the U233-MET-FAST-001using MCNP6.2 code

Isotope	ENDFVII.0	ENDFVII.1		ENDFVIII.0		JEFF3.2		JENDL4U	
	MCNP6.2 $S_{k,x}$	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %
U-233	0,800983 +/- 0,001083	0,801142 +/- 0,001087	**0,02**	0,800672 +/- 0,001088	**-0,04**	0,801633 +/- 0,001080	**0,08**	0,800456 +/- 0,001066	**-0,07**
U-234	0,006828 +/- 0,000096	0,006644 +/- 0,000094	**-2,69**	0,006557 +/- 0,000094	**-3,97**	0,007008 +/- 0,000094	**2,64**	0,006652 +/- 0,000094	**-2,58**
U-235	0,000206 +/- 0,000015	0,000177 +/- 0,000014	**-14,08**	0,000194 +/- 0,000016	**-5,83**	0,000204 +/- 0,000015	**-0,97**	0,000224 +/- 0,000016	**8,74**
U-238	0,001797 +/- 0,000071	0,001742 +/- 0,000073	**-3,06**	0,001608 +/- 0,000071	**-10,52**	0,001689 +/- 0,000071	**-6,01**	0,001766 +/- 0,000070	**-1,73**

- Benchmark MIX-MET-FAST-001

This Benchmark is a composite with two mains fissile materials U-235 and Pu-239, but the contribution of Pu-239 is most important than U-235 in the determination of the *keff*. The most important deviation is for Pu-241. the libraries ENDFVII.1 and ENDFVIII.0 have some value of sensitivity 0,001868 and higher than ENDFVII.0 by 3.22% followed by JENDL4U 4.4% and finally the JEFF3.2 8.17%.

Table 8: Comparisons for total cross-section sensitivities coefficient for the MIX-MET-FAST-001 using MCNP6.2 code

Isotope	ENDFVII.0	ENDFVII.1		ENDFVIII.0		JEFF3.2		JENDL4U	
	MCNP6.2 $S_{k,x}$	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %	MCNP6.2 $S_{k,x}$	diff %
U-235	0,227286 +/- 0,000680	0,227053 +/- 0,000666	**-0,10**	0,227230 +/- 0,000725	**-0,02**	0,226708 +/- 0,000648	**-0,25**	0,225943 +/- 0,000738	**-0,59**
U-238	0,010289 +/- 0,000182	0,010346 +/- 0,000159	**0,55**	0,009925 +/- 0,000146	**-3,53**	0,010142 +/- 0,000152	**-1,43**	0,010013 +/- 0,000186	**-2,69**
Pu-239	0,619814 +/- 0,001024	0,620691 +/- 0,001140	**0,14**	0,616934 +/- 0,001234	**-0,46**	0,620890 +/- 0,001096	**0,17**	0,618379 +/- 0,001182	**-0,23**
Pu-240	0,022742 +/- 0,000252	0,022434 +/- 0,000242	**-1,35**	0,022244 +/- 0,000241	**-2,19**	0,022678 +/- 0,000251	**-0,28**	0,021994 +/- 0,000265	**-3,29**
Pu-241	0,001810 +/- 0,000053	0,001868 +/- 0,000058	**3,22**	0,001868 +/- 0,000061	**3,22**	0,001958 +/- 0,000068	**8,17**	0,001889 +/- 0,000062	**4,40**

4. Conclusion

The determination of the keff using library ENDFVII.0, ENDFVII.1 and ENDFVIII.0 generally have the lowest deviation. But, in another hand, the JENDL4U library has the highest deviation, where the JEFF3.2 has only 1pcm of deviation for U233-MET-FAST-001 and 268pcm for PU-MET-FAST-002. The sensitivity coefficient for total cross-section data gives information about the impact of every isotope in the calculation of the keff. These values were changed from the cross-section data to another with some percent.

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