Effects of the Application of the New Nuclear Data Library ENDF/B to the Criticality Analysis of AP1000

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Abstract. Calculations of criticality of the AP1000 core due to the use of new edition of nuclear data library namely ENDF/B-VII and ENDF/B-VII.1 have been done. This work is aimed to know the accuracy of ENDF/B-VII.1 compared to ENDF/B-VII and ENDF/B-VI.8. in determining the criticality parameter of AP1000. Analysis was imposed to core at cold zero power (CZP) conditions. The calculations have been carried out by means of MCNP computer code for 3 dimension geometry. The results show that criticality parameter namely effective multiplication factor of the AP1000 core are higher than that ones resulted from ENDF/B-VI.8 with relative differences of 0.39% for application of ENDF/B-VII and of 0.34% for application of ENDF/B-VII.1.

Keywords: criticality analysis, AP1000, ENDF/B, MCNP

1. Introduction

For nuclear reactor, criticality is one of the most important parameter to be analyzed especially for reactor having high excess reactivity and a rather complicated of reactivity control system. PWR reactor core is loaded by big amount of fuel elements to produce high excess reactivity for providing a long period of operation with relatively efficient in operation cost. Besides that, the reactor is controlled by various modes namely, boron in moderator, burnable poison in fuel assembly such as Pyrex and IFBA.

AP1000 reactor is a PWR type of power reactor designed by Westinghouse Co. that can produce a nominal electric power of 1117 MWe or 3400 MW thermal generated by 157 fuel assemblies of UO2[1]. The fuel has 3 different enrichment 2.35 w/o, 3.40 w/o and 4.50 w/o. To control the reactivity, the AP1000 uses boric acid which is dissolved in moderator, Pyrex absorber rod and Integrated Fuel Burnable Absorber (IFBA). IFBA is a burnable absorber made from ZrB2 which is integrated in UO2 fuel, whereas Pyrex is an absorber rod made from B2O3 as control rod which is inserted into the guide tube.

Monte Carlo Method computer code, such as MCNP, performs very good analysis of criticality of AP1000 because it can make core model in detail in 3-dimension [2]. This MCNP code has been implemented to analyze criticality of AP1000 and gives results as compared to that of the design values[3]. Calculations were done by using ENDF/B-VI.8 library. Nowadays, MCNP version 6 uses newest evaluated nuclear data ENDF/B-VII.1[4-7]. It is reported in Ref. [4] that the ENDF/B-VII.1...
produces better accurate values of reactivity or multiplication factor in comparison to that resulted from older version of nuclear data ENDF/B.

The use of ENDF/B-VII.1 were also widely applied in criticality analysis for some reactor types and even adopted in several computer codes [8-10]. The results showed that there are also better accuracy using this new nuclear data library. It is therefore, necessary to study on effect of newest nuclear data library ENDF/B in calculation of criticality parameter of AP1000 core.

The objective of the research is to obtain the accuracy of ENDF/B-VII.1 compared to ENDF/B-VII and ENDF/B-VI.8. in determining the criticality parameter \( k_{\text{eff}} \) of AP1000 core by using Monte Carlo method. The results are intended to give contribution on the accuracy of using the latest version of ENDF data library for AP1000 core.

2. Methodology
Criticality parameter or effective multiplication factors \( k_{\text{eff}} \) are calculated for 3-dimensional X-Y-Z geometry of AP1000 core. The calculation object is the AP1000 core at cold zero power (CZP) conditions what means at temperature of 200 \( ^{\circ}\)C, zero power and free xenon poisoning. The calculation is principally done in 2 (two) steps namely model preparation and then core calculation. The cross section view of the AP1000 core is described in the Fig.1.

![Core configuration of AP1000](image)

**Figure 1.** Core configuration of the AP1000 with PYREX and IFBA [3]

The 3-dimensional core models of AP1000 used are the models resulted by T. Sembiring [3] that gave a good agreement to the design values of reactivity of AP 1000. The models are again shown in Fig. 2 and 3 as 3-dimensional model of AP1000 core for radial and axial directions. They were generated by MCNP6 code for XY (radial) and XZ (axial) directions. The model are representing the core configuration of AP1000 as shown in Fig. 1.
Figure 2. Three dimension model of AP1000 core in XY (radial) direction

Figure 3. Three dimension model of AP1000 core in R-Z (axial) direction

Core calculations are then carried out by Monte Carlo computer code, MCNP6 version 1[2]. The code shows a very good accuracy for effective multiplication calculation for PWR reactor as
validated by several research [5,11]. The calculations are done for two core conditions namely with and without boron.

3. Results and discussion
The calculation results of core reactivity of AP 1000 for conditions with and without boron are presented in Table 1 and Table 2. Table 1 shows that using new libraries either ENDF/B-VII or ENDF/B-VII.1 gives higher values of multiplication factor or reactivity of core. It means that reaction rate is higher as the libraries newer. The relative differences compared to those resulted by ENDF/B-VI are shown in Table2. For core without boron conditions, the relative differences of core multiplication factor are consecutively 0.39% and 0.35% for ENDF/B-VII and ENDF/B-VII.1. Whereas for core with boron conditions, those values are 0.39% and 0.33%.

| Core condition | ENDF/B-VI.8 | ENDF/B-VII | ENDF/B-VII.1 |
|----------------|-------------|------------|--------------|
|                 | \( k_{\text{eff}} \) | Standard deviation | \( k_{\text{eff}} \) | Standard deviation | \( k_{\text{eff}} \) | Standard deviation |
| without boron   | 1.20535     | 0.00010    | 1.21004      | 0.00010    | 1.21015    | 0.00010    |
| with boron      | 0.97813     | 0.00010    | 0.98160      | 0.00010    | 0.98138    | 0.00010    |

Table 2. The relative difference of \( k_{\text{eff}} \) of the AP1000 core for with and with boron conditions

| Core condition | ENDF/B-VI.8 \( k_{\text{eff}} \) | ENDF/B-VII \( k_{\text{eff}} \) | Rel. diff % | ENDF/B-VII.1 \( k_{\text{eff}} \) | Rel. diff % |
|----------------|-------------------------------|-------------------------------|-------------|-------------------------------|-------------|
| without boron   | 1.20535                       | 1.21004                       | 0.39        | 1.21015                       | 0.35        |
| with boron      | 0.97813                       | 0.98160                       | 0.39        | 0.98138                       | 0.33        |

The reasons of the increase those \( k_{\text{eff}} \) values as from ENDF/B-VII.1 can be followed from Fig. 4. This figure shows that there is differences in absorption rate in the energy region surrounding 0 – 0.02 eV and \( > 6.06 \) MeV. It tells us that the increase of that \( k_{\text{eff}} \) from ENDF/B-VII and VII.1 are caused by lower absorption rate in the energy region \( > 6.06 \) MeV in comparison to that of from ENDF/B-VI.8.

![Figure 4. Neutron absorption rate as a function of energy for core without boron.](image)
Fig. 5 shows in more detail the relative differences in using the ENDF/B-VII and ENDF/B-VII.1 compared to that of ENDF/B-VI.8. It is clearly shown that nuclear data ENDF/B-VII.1 has a significant differences in comparison with that of ENDF/B-VI.8 for the whole neutron energy. Whereas for ENDF/B-VII there is a relatively small difference in the region 0.0025 eV – 3.8 MeV. These relative differences for ENDF/B-VII and ENDF/B-VII.1 are in the range of -37% - 18% and -60% - 75% respectively. In comparison to Fig. 5, neutron absorption rate in the region > 6.06 MeV has relative difference of -30% and 60% for ENDF/B-VII and ENDF/B-VII.1. Figure 5 shows a proof that the differences of nuclear data in the energy region > 6.06 MeV cause the change of effective multiplication factor $k_{\text{eff}}$ values while using ENDF/B-VII and ENDF/B-VII.1 nuclear data library.

![Graph showing relative difference in neutron absorption rate](image)

**Figure 5.** The relative difference of neutron absorption rate to the ENDF/B-VI.8 for without boron condition

Fig. 6 shows the neutron absorption rate for core with boron. It is similar to that one of core without boron that neutron energy in the region of 0 – 0.02 eV and > 6.06 MeV become the cause of producing difference $k_{\text{eff}}$ from difference nuclear data library. For analyzing the neutron energy region that effects in producing the $k_{\text{eff}}$ values, it is necessary to calculate the relative difference of neutron absorption rate and those are then compared to ENDF/B-VI.8 as presented in Fig. 7.

Fig. 7 illustrates a shift of relative difference distribution of absorption rate especially for ENDF/B-VII.1 in the energy region of 3.68 – 6.06 MeV, where the relative difference drops to 0% compared to that of in Fig. 5. This case shows that boron has a role in the decrease of relative difference of the absorption rate. Similarly, for core without boron, the neutron energy region > 6.06 MeV effect the effective multiplication factor due to the difference of nuclear data library.

From the above discussions it can be summarized that the differences of calculated core reactivities are dependently on the status of nuclear data library. Nowadays, improvement of ENDF/B-VII is apparently of lower neutron absorption rate mainly in the energy region higher than 6.06 MeV. It cause higher value of core reactivity that give accuracy of about 0.39% and 0.34% for ENDF/B-VII and ENDF/B-VII. These numbers are proposed to be the corrent factors for multiplication values resulted from the former ENDF/BV-VL8.
Figure 6. Neutron absorption rate as a function of energy for core with boron condition

Figure 7. The relative difference of neutron absorption rate to the ENDF/B-VI.8 for with boron condition

4. Conclusions
Application of newer edition of nuclear data library ENDF/B-VII and ENDF/B-VII.1 in the calculation of core reactivity of AP 1000 reactor, produces higher value of multiplication factor compared to that of resulted from ENDF/B-VI.8. The relative difference values is of 0.39% for application of ENDF/B-VII and of about 0.34% for application of ENDF/B-VII.1.

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References

[1] Schulz T L 2006 Westinghouse AP1000 Advanced Passive Plant Nucl. Eng. Des. 236 1547–57

[2] Goorley T, James M, Booth T, Brown F, Bull J, Cox L J, Durkee J, Elson J, Fesin M, Forster R A, Hendricks J, Hughes H G, Johns R, Kiedrowski B, Marts R, Mashnik S, Mckinney G, Pelowitz D, Prael R, Sweezy J, Waters L, Wilcox T and Zukaitis T 2016 Features of MCNP6 Ann. Nucl. Energy 87 772–83

[3] Semiring T M 2011 Analysis of the 3-Dimensional Core Model for Evaluation of Criticality Parameters of the Advanced PWR 100 MW Class Tri Dasa Mega13 78-95

[4] Mosteller R 2014 Comparison of ENDF / B-VII . 1 and ENDF / B-VII . 0 Results for the Expanded Criticality Validation Suite for MCNP and for Selected Additional Criticality Benchmarks Nucl. Data Sheets 118 442–5

[5] Kahler A C, Macfarlane R E, Mosteller R D, Kiedrowski B C, Frankle S C, Chadwick M B, Mcknight R D, Lell R M, Palmiotti G, Hiruta H, Herman M, Arcilla R, Mughabghab S F, Sublet J C, Trkov A, Trumbull T H and Dunn M 2011 ENDF / B-VII . 1 Neutron Cross Section Data Testing with Critical Assembly Benchmarks and Reactor Experiments Nucl. Data Sheets 112 2997–3036

[6] van der Marck S C 2012 Calculations Shielding Benchmarks Calculations Nucl. Data Sheets 113 2935–3005

[7] Chadwick M B, Herman M, Oblo´ P, Pritychenko B, Arbanas G, Arcilla R, Brewer R, Brown D A, Capote R, Carlson A D, Cho Y S, Derrien H, Guber K, Hale G M, Hoblit S, Holloway S, Johnson T D, Kawano T, Kiedrowski B C, Kim H, Kunieda S, Larson N M, Leal L, Lestone J P, Little R C, Mccutchan E A, Macfarlane R E, Macinnes M, Mattoon C M, Mcknight R D, Mughabghab S F, Nobre G P A, Palmiotti G, Palumbo A, Pigni M T, Pronyaev V G, Vogt R L, Marck S C Van Der, Wallner A, White M C, Wiarda D and Young P G 2011 ENDF / B-VII . 1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data Nucl. Data Sheets 112 2887–996

[8] Quan H, Honda Y, Goto M and Takada S 2017 Numerical investigation of the random arrangement effect of coated fuel particles on the criticality of HTTR fuel compact using MCNP6 Ann. Nucl. Energy 103 114–21

[9] Zu T, Wan C, Cao L, Wu H and Shen W 2016 Total Uncertainty Analysis for PWR Assembly Based on the Statistical Sampling Method Nuclear Science and Engineering 183 371-86

[10] Jin H, Seog K, Gi S and Seung J 2017 An improved DeCART library generation procedure with explicit resonance interference using continuous energy Monte Carlo calculation Ann. Nucl. Energy 105 95–105

[11] Douglass S, Rahnema F and Margulies J 2010 A stylized three dimensional PWR whole-core benchmark problem with Gadolinium Ann. Nucl. Energy 37 1384–403