Nuclear data libraries assessment for modelling a small fluoride salt-cooled, high-temperature reactor

Cite as: AIP Conference Proceedings **1799**, 020007 (2017); https://doi.org/10.1063/1.4972905
Published Online: 06 January 2017

Hassan Mohamed, Benjamin Lindley, and Geoffrey Parks

Nuclear Data Libraries Assessment For Modelling A Small Fluoride Salt-Cooled, High-Temperature Reactor

Hassan Mohamed[1, 2, a)], Benjamin Lindley[2, b)] and Geoffrey Parks[2, c)]

[1]*Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia.*
[2]*Department of Engineering, University of Cambridge, UK.*

[a)]Corresponding author: mhassan@uniten.com.my
[b)]bal29@cam.ac.uk
[c)]gtp10@cam.ac.uk

Abstract. Nuclear data consists of measured or evaluated probabilities of various fundamental physical interactions involving the nuclei of atoms and their properties. Most fluoride salt-cooled high-temperature reactor (FHR) studies that were reviewed do not give detailed information on the data libraries used in their assessments. Therefore, the main objective of this data libraries comparison study is to investigate whether there are any significant discrepancies between main data libraries, namely ENDF/B-VII, JEFF-3.1 and JEF-2.2. Knowing the discrepancies, especially its magnitude, is important and relevant for readers as to whether further cautions are necessary for any future verification or validation processes when modelling an FHR. The study is performed using AMEC's reactor physics software tool, WIMS. The WIMS calculation is simply a 2-D infinite lattice of fuel assembly calculation. The comparison between the data libraries in terms of infinite multiplication factor, k_{inf} and pin power map are presented. Results show that the discrepancy between JEFF-3.1 and ENDF/B-VII libraries is reasonably small but increases as the fuel depletes due to the data libraries uncertainties that are accumulated at each burnup step. Additionally, there are large discrepancies between JEF-2.2 and ENDF/B-VII because of the inadequacy of the JEF-2.2 library.

INTRODUCTION

Nuclear data is widely used in various energy applications such as fission reactor design, nuclear fuel cycles, nuclear safety and waste disposal and many others as it stores important information on cross sections, half-lives, γ-rays from radionuclides, decay modes and decay radiation properties. Additionally, it has also been used for non-energy applications, including production of radioisotopes for medical and industrial applications, radiation safety, cancer radiotherapy and many more. The nuclear data is gathered and compiled into various data libraries. International Atomic Energy Agency (IAEA) plays important roles in handling about 100 nuclear data libraries and giving convenient access to this global collection of nuclear data libraries[1]. Under IAEA monitoring, an international network to coordinate the worldwide collection, compilation and distribution of nuclear reaction data was established. This international collaboration is known as the Nuclear Reaction Data Centres Network (NRDC), forming a worldwide cooperation of nuclear data centres. Core centres are the US National Nuclear Data Center at the Brookhaven National Laboratory, OECD NEA Data Bank in France, IAEA Nuclear Data Section in Austria and Russian Nuclear Data Center in Obninsk [2].

Some examples of the frequently used data libraries are the Europe Joint Evaluated Fission and Fusion File (JEFF) and the US Evaluated Nuclear Data File (ENDF/B). The JEFF library is an evaluated library created through a collaboration between NEA Data Bank member countries, joining the efforts of the JEFF and EFF/EAF (European Fusion File/European Activation File) working groups in order to create a common sets of evaluated nuclear data, not only for fission but also for fusion applications. For ENDF/B, the library is produced via collaboration of the national laboratories, industry, and universities in the United States and Canada, under the auspices of the Cross Section Evaluation Working Group (CSEWG). These general purpose libraries basically contain neutron reaction

Advancing Nuclear Science and Engineering for Sustainable Nuclear Energy Knowledge
AIP Conf. Proc. 1799, 020007-1–020007-5; doi: 10.1063/1.4972905
Published by AIP Publishing. 978-0-7354-1467-9/$30.00

data, thermal neutron scattering law data, and incident proton data for transport calculations, as well as special purpose files with radioactive decay data, fission yields data, and activation data [3].

Data libraries that are available to use in our local repository are JEFF-3.1, JEF-2.2 and ENDF/B-VII. Historically, the JEF-2.2 was released in 1992 [4] and since then, continuous improvement of the library has been carried out. From experimental validation of the JEF-2.2 library and based from the feedback provided by evaluators, a much improved JEFF-3.0 data library with ENDF-6 format was available in April 2002 [5] and later JEFF-3.1 was released in May 2005 [6]. The most used JEFF library is the updated JEFF-3.1.1 (released in 2007). It is commonly used for PWR and BWR calculations as well as used in ERANOS2 for Generation IV reactor designs. It has also been extensively validated for fast breeder reactors. A slightly improved JEFF-3.1.2 library was released in February 2012 with an updated neutron file and identical sublibraries to JEFF-3.1.1 [7]. It is also important to note, although not being used in the study here, the latest JEFF library is JEFF-3.2 as it was released on March 5, 2014. The ENDF/B-VII was first released in 2006. The ENDF/B library was typically used by researchers in the United States. On 22th December 2011, an updated ENDF/B-VII.1 library was released. This latest ENDF/B library has new fission product yields and greatly expanded decay data and neutron sublibraries [8].

We choose ENDF/B-VII as our main cross sections library instead of JEFF-3.1 or JEF-2.2, because it is the latest version of all our available data libraries. Majority of reviewed fluoride salt-cooled high-temperature reactor (FHR) studies, including the Small modular Advanced High-Temperature Reactor (SmAHTR) pre-conceptual report [9], do not provide sufficient details on the data libraries used in their analyses. Only few of them clearly explain the data libraries used such as Ingersoll et al. [10], Clarno et al. [11] and Szakaly et al. [12] in their Liquid-Salt-Cooled Very High-Temperature Reactor (LS-VHTR) studies. They used ENDF/B-VI instead of ENDF/B-VII for their assessments, which might be because ENDF/B-VII was relatively new at the time and ENDF/B-VI had been widely used before. Most importantly, ENDF/B-VII is primarily chosen because many studies related to FHR (or AHTR, LS-VHTR) originate from the United States and highly likely their analyses are based on ENDF/B data libraries. Thus, it has been extremely useful for us to perform validation and verification processes against other FHR studies, which are mostly carried out by FHR researchers at Oak Ridge National Laboratory (ORNL), Idaho National Laboratory (INL), Massachusetts Institute of Technology (MIT) and University of California Berkeley (UCB).

Even though ENDF/B-VII has been commonly selected as the main library for FHR analysis, the main objective of this data libraries comparison study is to investigate whether there are any significant discrepancies between data libraries. Knowing the discrepancies, especially their magnitudes, is important and relevant for us and the readers as to whether further cautions are necessary for any future verification or validation processes. For example, if the discrepancies are extremely large, one might need to ensure results are taken with attentiveness when comparing our results with other analyses or experiments. Whereas, if the discrepancies are extremely small, they can be simply neglected and the results can be safely accepted.

METHOD

A small FHR pin-type fuel assembly design is taken from the SmAHTR study [9][13] as shown in Figure 1. The fuel assembly design with 19.75 wt.% UO_2 fuels is run with a 172-group calculation in WIMS with the JEF-2.2, JEFF-3.1 and ENDF/B-VII data libraries. WIMS is a reactor physics software tool developed by ANSWERS, Amec Foster Wheeler. It is a deterministic code that can solve problems such as fuel depletion analysis and multiplication factor, k, calculations[14]. The WIMS calculation is simply a 2-D infinite lattice of fuel assembly calculation. The comparison between the data libraries in terms of infinite multiplication factor, k_{inf} and power map are presented in the Results and Discussion section.

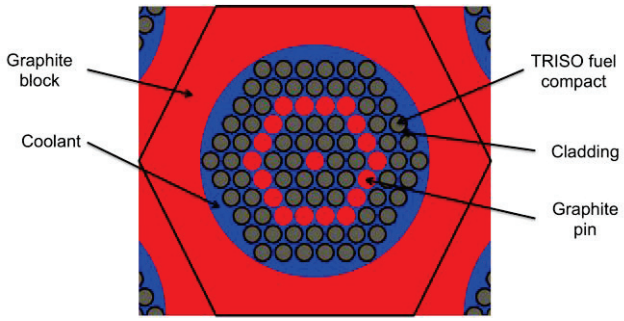


FIGURE 1. SmAHTR fuel assembly design with cylindrical fuel pins [13].

RESULTS AND DISCUSSION

Figures 2 and 3 show the comparison of infinite multiplication factor, k_{inf} and power map between the data libraries, respectively. The differences in k_{inf} and power map are calculated relative to ENDF/B-VII.

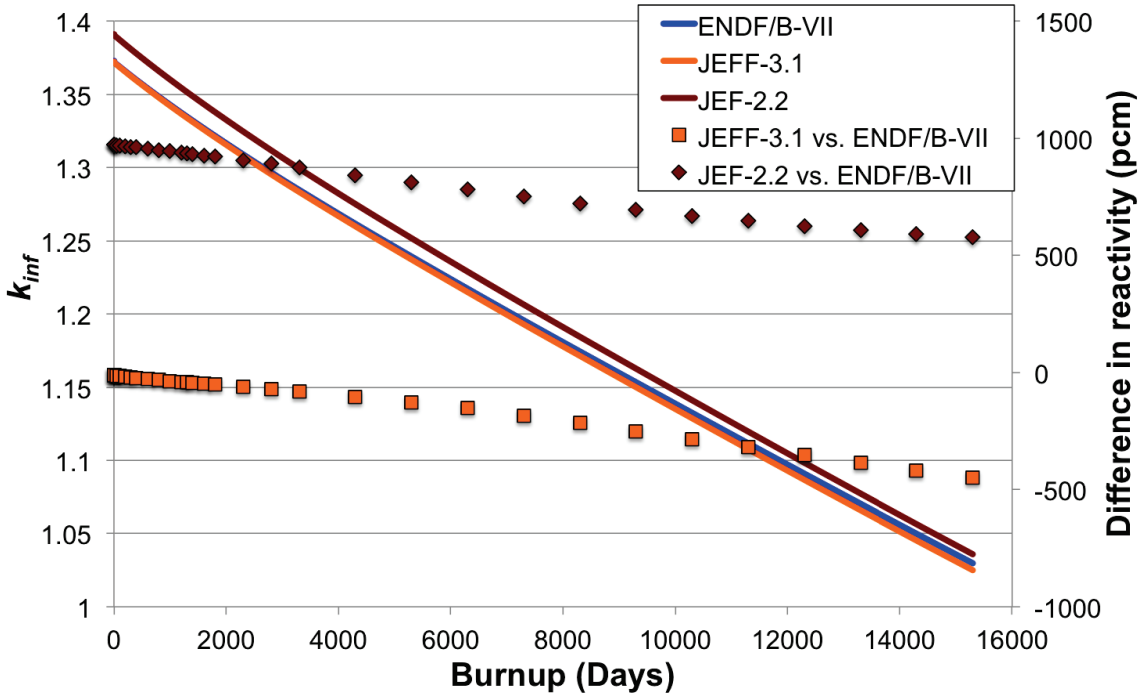
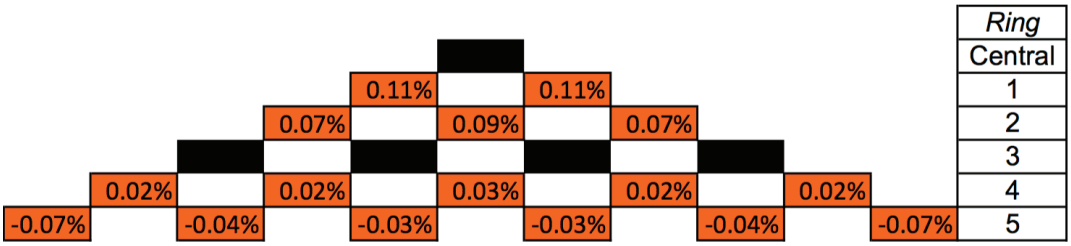
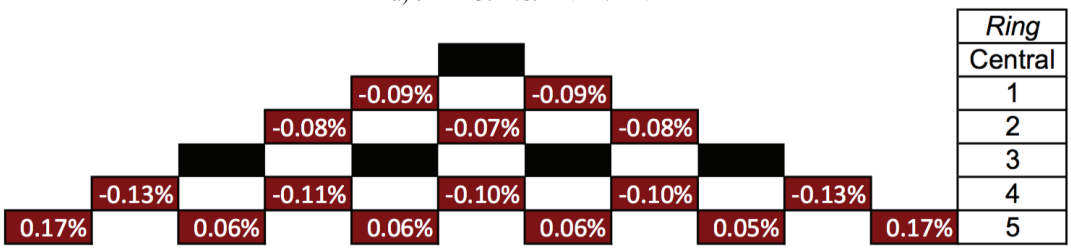


FIGURE 2. (Left) Infinite multiplication factor, k_{inf}, for three different data libraries and (right) the difference in reactivity with respect to ENDF/B-VII.



a) JEFF-3.1 vs. ENDF/B-VII



b) JEF-2.2 vs. ENDF/B-VII

FIGURE 3. Percentage difference of normalised pin power map relative to ENDF/B-VII in a 1/6th of a fuel assembly. Black boxes represent the graphite pins.

Larger discrepancies are observed between the JEF-2.2 and ENDF/B-VII, as the JEF-2.2 overestimates the infinite multiplication factor of the system, k_{inf} by 971 pcm at BOL. On average, the difference is approximately 850.34 pcm throughout the cycle period, which is relatively high and undesirable. This large discrepancy may be due to the fact that the JEF-2.2 is an old and obsolete data library for fluoride salt coolant. As a result, very large discrepancies are found. In addition, The ENDF/B-VII data library includes the reaction chain [15] for ^{6}Li to capture neutrons and to create ^{3}H, then for ^{3}H to decay to ^{3}He. This chain was not present in earlier libraries such as JEF-2.2 [16]. Hence, Li depletion is not taken into account in the JEF-2.2 run as it assumes the unchanged presence of ^{6}Li that may add negative reactivity. Consequently, it can be observed that the difference between the JEF-2.2 and ENDF/B-VII gradually decreases during fuel depletion because in the JEF-2.2 run, the undepleted ^{6}Li provides negative reactivity. Whereas, in the ENDF/B-VII run, positive reactivity is achieved because of the depletion of ^{6}Li.

The JEFF-3.1 library, on the other hand, tends to slightly underestimate the k_{inf} in comparison to ENDF/B-VII, but still agrees relatively well with a very small difference, approximately −10 pcm at BOL. But caution needs to be taken when using the results at higher burnup steps as the reactivity difference gradually increases up to −417 pcm (average difference is −122 pcm). These increased discrepancies between JEFF-3.1 and ENDF/B-VII data libraries during burnup are expected as they may be contributed by the data library uncertainties. Any uncertainties will propagate through depletion steps in a manner that is difficult to predict. In regard to the power map comparison at BOL, all libraries tend to agree with very small percentage differences, approximately less than 0.17% relative to the ENDF/B-VII. The JEFF-3.1 data clearly has the closest match to the ENDF/B-VII with even smaller percentage difference, which is less than 0.11%.

CONCLUSION

Results obtained from JEFF-3.1 and ENDF/B-VII libraries are generally in a good agreement, in which at BOL, the difference in k_{inf} is −10 pcm. Additionally, the average reactivity difference throughout the burnup period is approximately −122 pcm. In regard to normalised power, the percentage difference is extremely small, which is less than 0.11%. The discrepancy between JEFF-3.1 and ENDF/B-VII libraries, however, increases as the fuel depletes due to the data libraries uncertainties that are accumulated at each burnup step. On the other hand, there are large discrepancies between JEF-2.2 and ENDF/B-VII because of the inadequacy of the JEF-2.2 library, as it is missing the ^{6}Li (n,α) and (n,p) reactions. Thus, the use of JEF-2.2 is not highly recommended when performing a neutronic analysis on FHRs.

ACKNOWLEDGMENTS

The first author would like to acknowledge support received from the ANSWERS team at AMEC, providing access to and invaluable assistance on the use of WIMS 10.

REFERENCES

1. O. Schwerer, Nuclear Data Libraries and Services Provided by the IAEA, Technical Presentation, Nuclear Data Section, International Atomic Energy Agency (IAEA), Vienna, Austria (September 2001).
2. Nuclear Data Services, International Network of Nuclear Reaction Data Centres (NRDC) [online], 2015. URL: https://www-nds.iaea.org/nrdc/ (cited 1 September 2015).
3. Nuclear Energy Agency, JEFF-3.1.1 evaluated data library [online], 2015. URL: https: //www.oecd-nea.org/dbforms/data/eva/evatapes/jeff_31/index-JEFF3.1.1.html (cited 20 September 2015).
4. A. Santamarina, D. Bernard, P. Blaise, M. Coste, A. Courcelle, T. D. Huynh, C. Jouanne, P. Leconte, O. Litaize, S. Mengelle, G. Noguere, J-M. Ruggieri, O. Serot, J. Tommasi, C. Vaglio, and J. F. Vidal, JEFF Report 22: The JEFF-3.1.1 Nuclear Data Library, Number 6807, ISBN 978-92-64-99074-6, OECD (2009).
5. Nuclear Energy Agency, JEFF Report 19: The JEFF-3.0 Nuclear Data Library, Number 3711 ISBN 92-64-01046-7, OECD (2005).
6. Nuclear Energy Agency, JEFF Report 21: The JEFF-3.1 Nuclear Data Library, Number 6190, ISBN 92-64-02314-3, OECD (2006).
7. Nuclear Energy Agency, Evaluated Nuclear Data Library Descriptions [online], URL: https://www.oecd-nea.org/dbdata/data/nds_eval_libs.htm (cited 20 September 2015).
8. National Nuclear Data Center, ENDF/B-VII.1 Evaluated Nuclear Data Library [online], 2015. URL: http://www.nndc.bnl.gov/endf/b7.1/ (cited 1 September 2015).
9. S. R. Greene, "Pre-Conceptual Design of a Fluoride-Salt-Cooled Small Modular Advanced High-Temperature Reactor (SmAHTR)" in *Technical Report ORNL/TM-2010/199* (Oak Ridge National Laboratory, December 2010).
10. D. T. Ingersoll, K. T. Clarno, C. W. Forsberg, J. C. Gehin, R. W. Christensen, C. B. Davis, G. L. Hawkes, J. Sterbentz, T. K. Kim, T. A. Taiwo, and W. S. Yang, "Status of Physics and Safety Analyses for the Liquid-Salt-Cooled Very High-Temperature Reactor (LS-VHTR)" in *Report ORNL/TM-2005/218* (Oak Ridge National Laboratory, Oak Ridge, TN 37831, December 2005).
11. K. T. Clarno and J. C. Gehin, "Physics Analysis of the LS-VHTR: Salt Coolant and Fuel Block Design" in *Proceedings of PHYSOR '06*, Vancouver, BC, Canada (2006).
12. F. J. Szakaly, T. K. Kim, and T. A. Taiwo, "Neutronics Assessment of Stringer Fuel Assembly Designs for the Liquid-Salt-Cooled Very High Temperature Reactor (LS-VHTR)" in *Proceedings of Joint International Topical Meeting on Mathematics & Computation and Supercomputing in Nuclear Applications (M&C + SNA 2007)* (2007).
13. H. Mohamed, G. T. Parks, and E. Shwageraus, "The Effects of Variations of UO_2 Fuel, FLiBe and Graphite Moderator Composition and Proportions on a Small Fluoride Salt-Cooled, High-Temperature Reactor" in *Proc. Int. Congress on Advances in Nuclear Power Plants ICAPP*, Number 15073, pages 403–411, Nice, France (May 2015).
14. ANSWERS, WIMS User Guide for Version 11 (Ed. Amec Foster Wheeler 11th edition) (2015).
15. M. Chadwick, M. Herman, P. Obložinský, M. Dunn, Y. Danon, A. Kahler, D. Smith, B. Pritychenko, G. Arbanas, R. Arcilla, R. Brewer, D. Brown, R. Capote, A. Carlson, Y. Cho, H. Derrien, K. Guber, G. Hale, S. Hoblit, S. Holloway, T. Johnson, T. Kawano, B. Kiedrowski, H. Kim, S. Kunieda, N. Larson, L. Leal, J. Lestone, R. Little, E. Mc-Cutchan, R. MacFarlane, M. MacInnes, C. Mattoon, R. McKnight, S. Mughabghab, G. Nobre, G. Palmiotti, A. Palumbo, M. Pigni, V. Pronyaev, R. Sayer, A. Sonzogni, N. Summers, P. Talou, I. Thompson, A. Trkov, R. Vogt, S. van der Marck, A. Wallner, M. White, D. Wiarda, and P. Young, "ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data" in *Nuclear Data Sheets*, 112(12):2887 – 2996, Special Issue on ENDF/B-VII.1 Library, doi:http://dx.doi.org/10.1016/j.nds.2011.11.002 (2011).
16. G. Hosking, Amec Foster Wheeler, 7th November 2014 (private communication).