FOR UTILIZATATION AND PROMOTION OF COVARIANCE DATA OF NUCLEAR DATA

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Background

- A lot of works on uncertainty quantification of various parameters of nuclear systems have been actively carried out in recent years, and importance of covariance data of nuclear data have been recognized in the nuclear engineering community.

- In order to promote covariance data application to actual problems such as design studies and safety assessments of nuclear systems, the Covariance Data Use Promotion Working Group was established under the JENDL committee in FY2018.

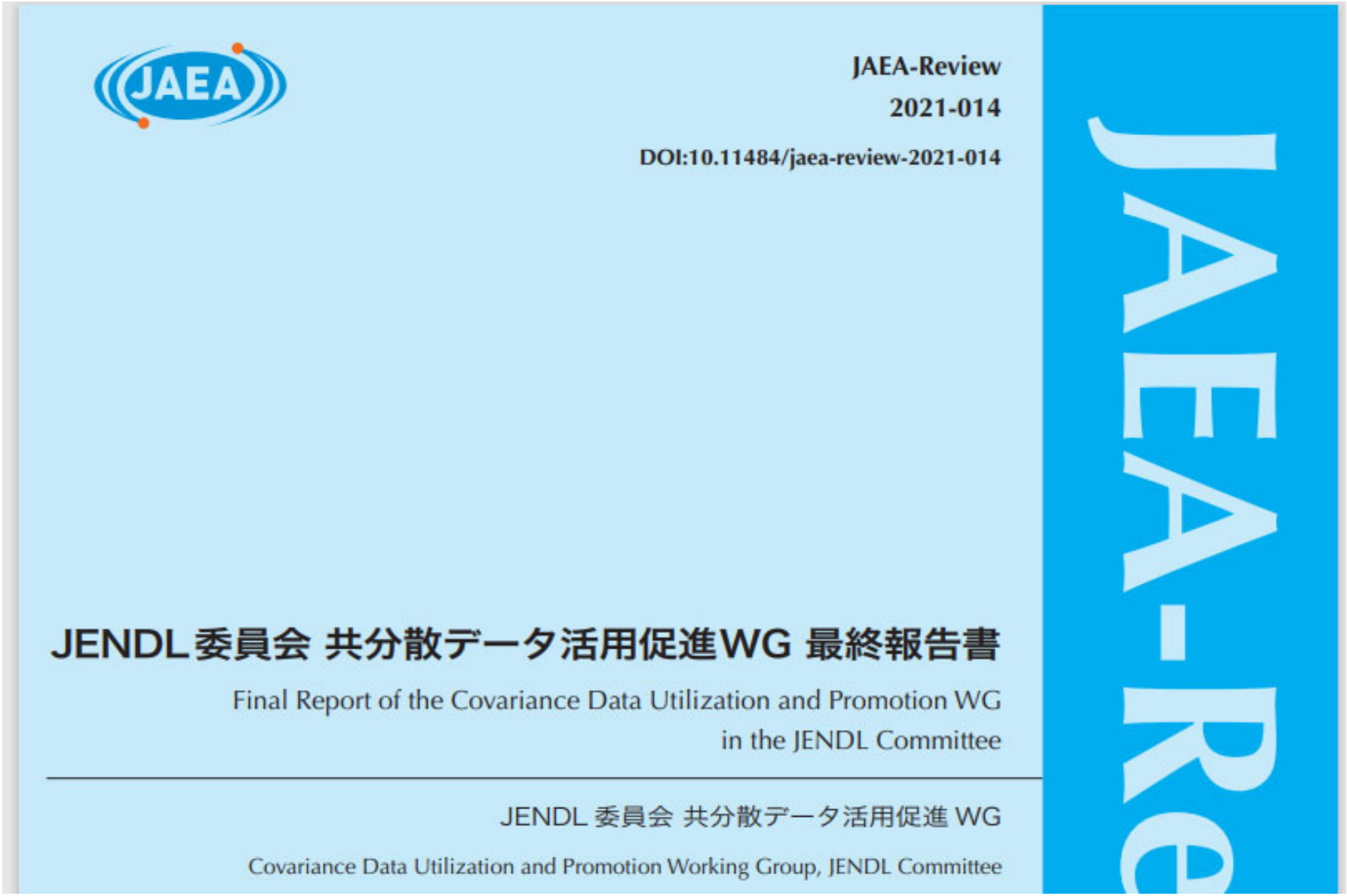
Background

- Information exchanges, discussions, and setting of required future works had been done among domestic experts on the nuclear data measurement/evaluation /application fields through the activities of this working group.

- A final report has been published this year as an official JAEA report[1].

[1] "Final report of the Covariance Data Utilization and Promotion Working Group in the JENDL Committee," JAEA-Review 2021-014 (2021).

Background



[1] "Final report of the Covariance Data Utilization and Promotion Working Group in the JENDL Committee," JAEA-Review 2021-014 (2021).

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A method for the data consistency check is proposed by Tokashiki of NFI, and its detail is described in this section. This method utilizes the extended bias factor method proposed by Kugo of JAEA, and the quartile deviation is used to moderate the influence of outliers of data. A good example of its application to actual problems is also presented.

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- Data adjustment method can be derived with several ways: the Lagrange multiplier method, the generalized linear least-square method (GLLS), and the multivariate statistical theory. In this section, a method based on the GLLS is presented by Maruyama of JAEA from a different point of view from the conventional ones, especially in the covariance matrix treatment.

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- Problems in very uncertain data

- Review of sensitivity analysis, uncertainty quantification, and data assimilation

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- Is nuclear data a random variable?

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Is evaluated nuclear data a random variable?

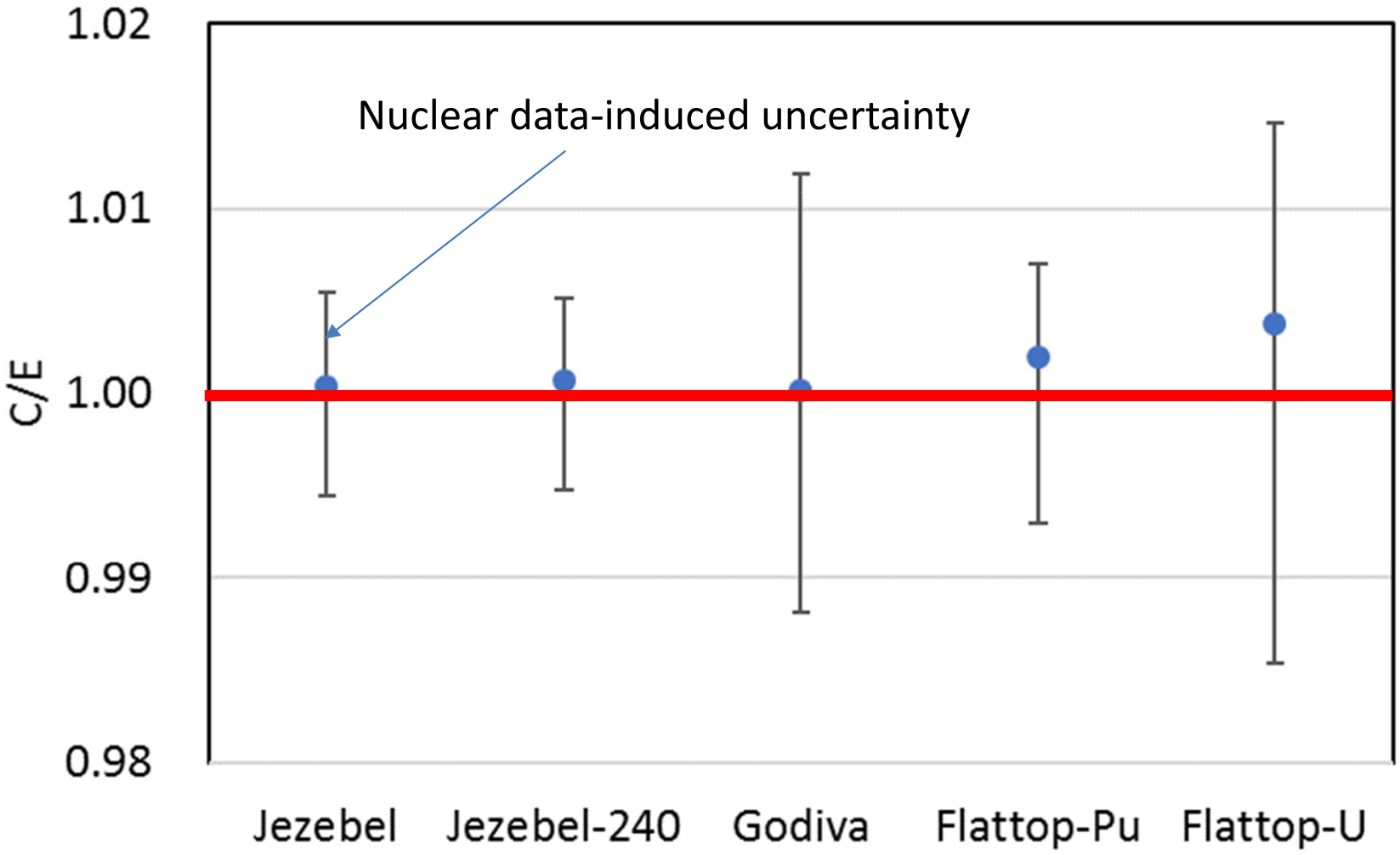
- Nuclear data itself is a physical constant and is NOT a random variable.

- EVALUATED nuclear data should depend on some measurable quantities which are random variables. Even though most part of the evaluation is conducted with the theoretical model, used parameters in the model would be determined from the measurable quantities which are random variables.

- Thus, the evaluated nuclear data should be considered as a random variable and should be represented by a specific probability density function.

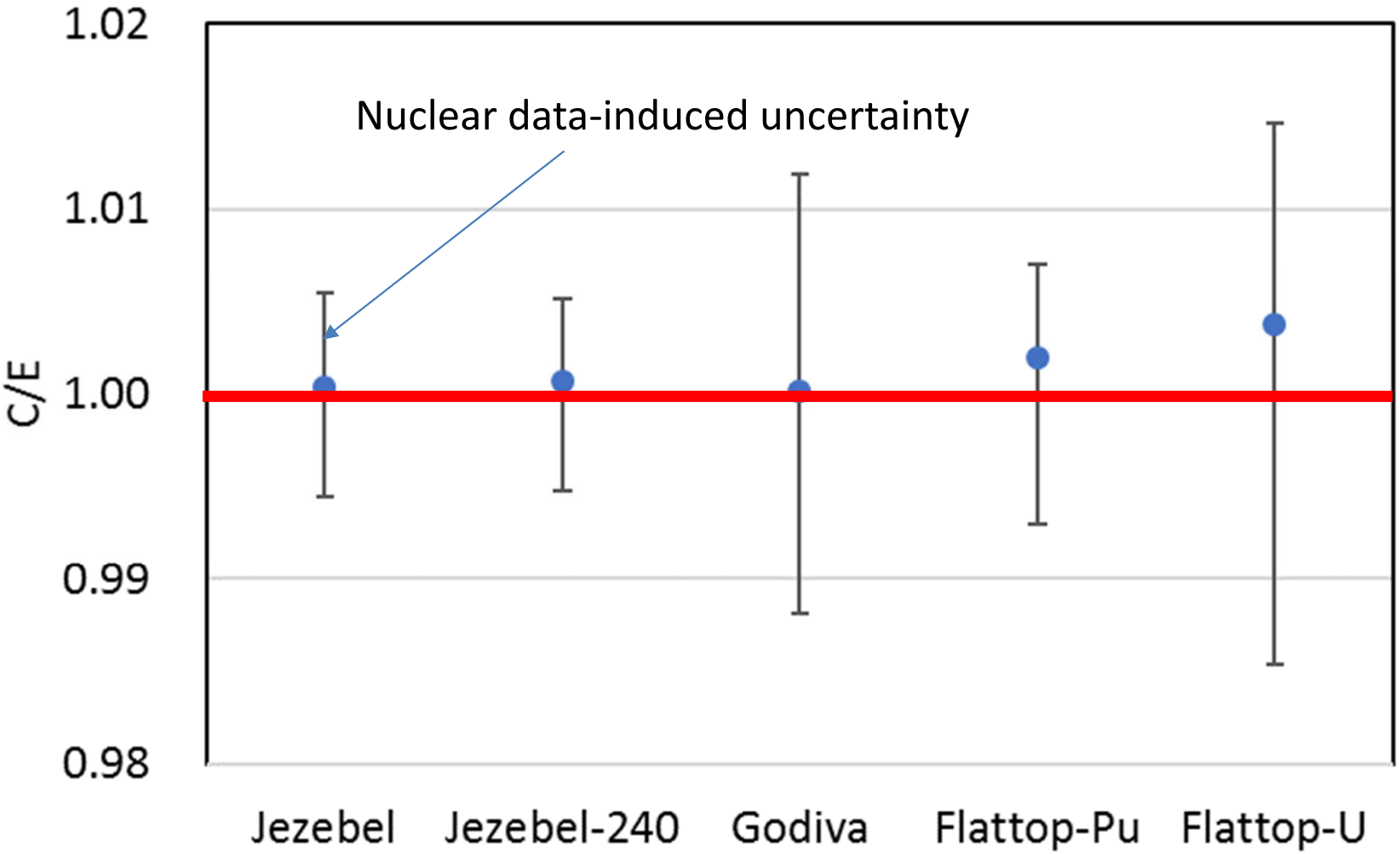
- If not, further discussions would be impossible.

Performance of the evaluated data against reactor calculations



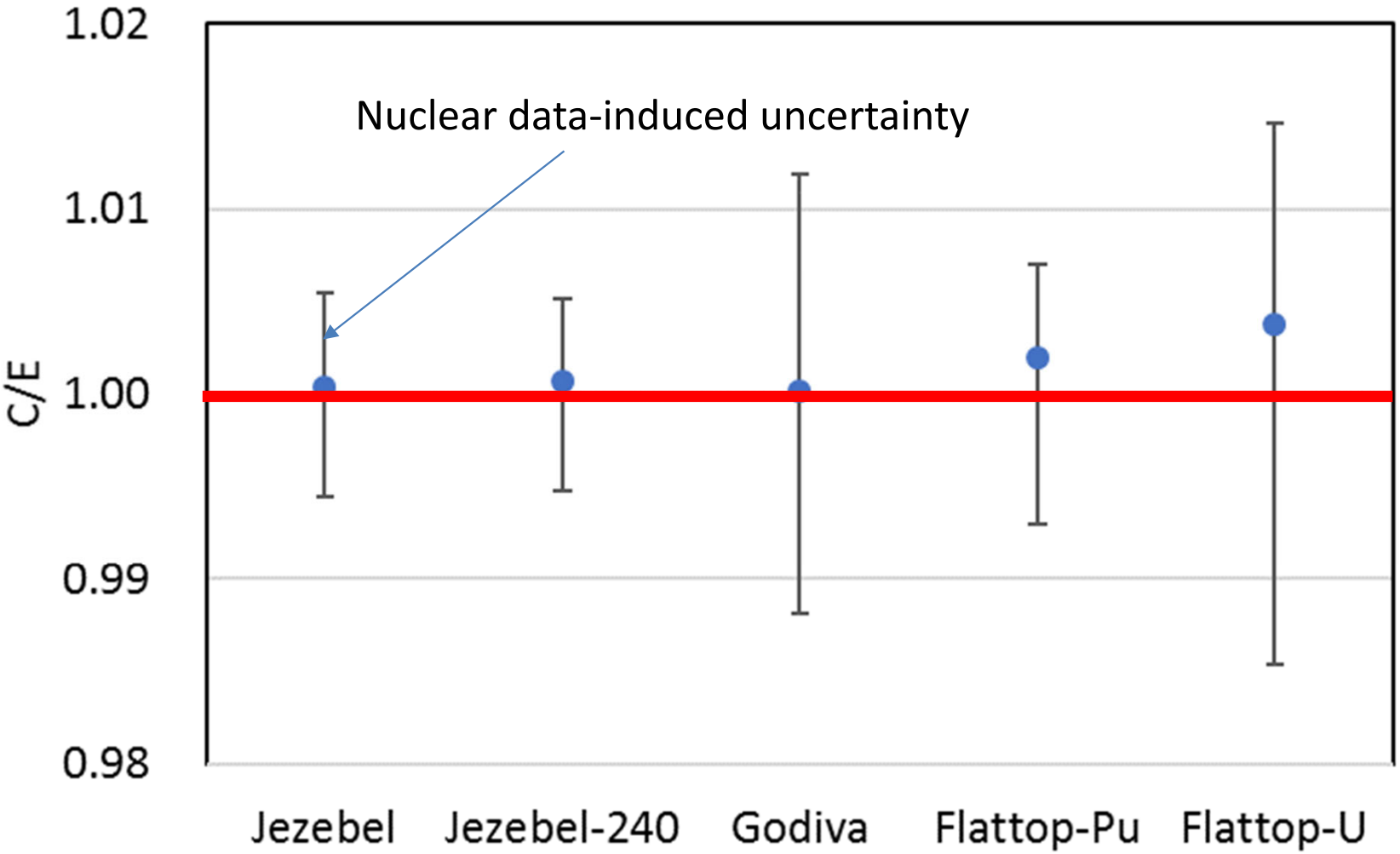
Do we have to say that these C/E values and their uncertainties are inconsistent with each other from the statistical point of view?

Performance of the evaluated data against reactor calculations



Uncertainties of nuclear data have been estimated WITHOUT any knowledge on these reactor data. What we should do is to update the covariance data with this new information.

Performance of the evaluated data against reactor calculations



However, if nuclear data are random variables, this result can be obtained with almost zero probability. If so, we have to say something like that the uncertainty of nuclear data would be “overestimated”.

Is evaluated nuclear data a random variable?

- Nuclear data evaluation is NOT a simple statistical and mathematical process, and it should implicitly include various professional knowledge of evaluators.

- Covariance data of the nuclear data present just the “degree of uncertainty” for the evaluator, so we have to say that evaluated nuclear data would NOT be random variables.

- If evaluated nuclear data are NOT random variables, further discussions based on the statistics would be impossible…

Is evaluated nuclear data a random variable?

- If nuclear data evaluation becomes a simple (or even complicated) statistical and mathematical process, “reasonable” covariance data would be obtained.

- The problem is how to develop a concrete evaluation method/procedure including the various professional knowledge of evaluators.

- This may be one of the future directions in the nuclear data evaluation research?

Contents of this presentation

- Is nuclear data a random variable?

- Problems in very uncertain data

- Review of sensitivity analysis, uncertainty quantification, and data assimilation

Problems in very uncertain nuclear data

- In uncertainty propagation calculations from nuclear data to reactor parameters, random sampling method is generally used now.

- The normal distributions are often assumed to nuclear data.

- Importance of the sensitivity of the assumed probability density function of the inputs to the results was recognized in the past, and several practical techniques were proposed.[1] Nowadays, direct evaluation of this sensitivity becomes possible.

[1] M. D. McKay, "Sensitivity and uncertainty analysis using a statistical sample of input values," Chap. 4, Uncertainty Analysis (Ed. Y. Ronen), CRC press (1988).

Problems in very uncertain nuclear data

- Sometimes, relative standard deviation of over 50% is given to nuclear data. If we assume the normal distribution to this nuclear data, this means that this nuclear data can take negative values with non-negligible probability.

- For such nuclear data, we can insist to use other density functions in which positivity is assured.

Problems in very uncertain nuclear data

- If the positivity should be assured, the truncated normal distribution is chosen from the maximum entropy principle.

- Practical sampling method for the truncated normal has not yet been developed.

- Positivity is assured also in the log-normal distribution, but possible range of the correlation coefficients is limited.

- We have to assume the probability density function for nuclear data in random sampling calculations, but is it meaningful to do this for very uncertain nuclear data? "Very uncertain" means that there are almost no information including the probability distribution.

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Review in SA, UQ, and DA

- In order to identify important nuclear data for accurate predictions of reactor parameters, sensitivities of the reactor parameters with respect to the nuclear data are very useful quantities.

- Since the number of nuclear data is huge, direct numerical differentiation to calculate sensitivities is impractical. Several techniques to reduce the number of input variables had been developed[1].

- The perturbation theory has been developed and advanced in the field of reactor physics, and it has become possible to calculate sensitivity of various kinds of reactor parameters.

[1] M. D. McKay, "Sensitivity and uncertainty analysis using a statistical sample of input values," Chap. 4, Uncertainty Analysis (Ed. Y. Ronen), CRC press (1988).

Review in SA, UQ, and DA

- If the covariance data of the nuclear data are available, it becomes possible to quantify the uncertainty in the reactor parameters caused by the input nuclear data uncertainty with the sensitivities.

- Uncertainty quantification calculations with the covariance data and sensitivities have been conducted in the past.

- As far as the author knows, large-scale uncertainty quantification calculations have been initially carried out in Japan for fast reactor analyses using JENDL-3.3 since JENDL-3.3 is the first evaluated library which contains the covariance data for many nuclides.

- Nowadays, most nuclear data files contain the covariance data, and UQ calculations have been conducted everywhere.

Review in SA, UQ, and DA

- By virtue of the rapid increase of the computer ability, sampling procedure has become practical, and for every reactor parameters which can be numerically calculated, UQ calculations become possible.

- The total Monte Carlo which calculates uncertainty propagation from the basic nuclear parameters to the reactor parameters would be a good example of this.[1]

- The possibility of the uncertainty propagation calculations from the basic nuclear parameters to the reactor parameters was discussed before.[2]

[1] A.J. Koning, D. Rochman, "Towards sustainable nuclear energy: putting nuclear physics to work," Ann. Nucl. Energy., 35, p.2024-2030 (2008).
[2] A. Gandini, "Uncertainty analysis and experimental data transposition methods based on perturbation theory," Chap. 6, Uncertainty Analysis (Ed. Y. Ronen), CRC press (1988).

Review in SA, UQ, and DA: Data assimilation

- Use of the information on measured reactor parameters (integral data) to improve the prediction accuracy has been attempted. The approaches can be categorized into the following: the bias factor method, the bias operator method, and the data adjustment method.[1]

- Data adjustment is known as the data assimilation at present. The history of the nuclear data adjustment is very old[2].

- Japanese experts also contributed to this field, and they pointed out that undetected uncertainty can result in not chi-squared distribution but non-central chi-squared distribution, and this can be utilized to identify the undetected uncertainty[3].

- The adjusted library applicable to fast reactor analyses has been developed by JAEA known as the “ADJ” libraries.

[1] Y. Ronen, “Uncertainty analysis based on sensitivity analysis,” Chap. 2, Uncertainty Analysis (Ed. Y. Ronen), CRC press (1988).
[2] A. Gandini, et al., “Nuclear data and integral measurement correlation for fast reactors, part 1: statistical formulation,” CNEN Rep. RT/FI(73)5, Rome, (1973).
[3] H. Mitani, H. Kuroi, “Adjustment of group cross-sections by means of integral data,” J. Nucl. Sci. Technol., 9[7], p.383, (1972).

Review in SA, UQ, and DA: Data assimilation

- Consistency check for the original nuclear data and added integral data can be carried out by observing the chi-square/DOF of the adjusted data. Changes in cross section data through the adjustment can be compared with the standard deviations of the original data[1].

- If the existence of undetected uncertainty is suspicious, chi-square values can be useful indicators: the integral data causing large chi-square value can be identified. Observation of the changes in cross section data is also important to identify undetected uncertainty in evaluated nuclear data[2].

[1] Y. Ronen, "Uncertainty analysis based on sensitivity analysis," Chap. 2, Uncertainty Analysis (Ed. Y. Ronen), CRC press (1988).
[2] A. Gandini, "Uncertainty analysis and experimental data transposition methods based on perturbation theory," Chap. 6, Uncertainty Analysis (Ed. Y. Ronen), CRC press (1988).

Review in SA, UQ, and DA: shielding calculations

- Fundamental theory for the shielding calculations is essentially same as that for the reactor calculations, and it is possible to find the relevant works in the old literature[0].

- A code dedicated for the shielding problems has been developed and advanced[1-2].

- Several papers have been published based on the perturbation theory. [3-4].

- Recently the sampling method has been adopted[5].

[0] NEA Specialist Meeting on sensitivity studies and shielding benchmarks, Paris. November 17, (1977).
[1] K. Furuta, et al., "SUSD: a computer code for cross section sensitivity and uncertainty analysis including secondary neutron energy and angular distributions," UTNL-R-0185, University of Tokyo, (1986).
[2] I. Kodeli, "A multidimensional deterministic nuclear data sensitivity and uncertainty code system: method and application," Nucl. Sci. Eng., 138, 45-66 (2001).
[3] I. Kodeli, "Cross-section sensitivity and uncertainty analysis of the FNG copper benchmark experiment," Fusion Eng. Design, 109-111, 1222-1226 (2016).
[4] G. Chiba, "Sensitivity and uncertainty analysis of fusion neutronics benchmark problem with deterministic code system CBZ," 85-90, JAEA-Conf 2017-001 (2017).
[5] D. Rochman, et al., "Exact nuclear data uncertainty propagation for fusion neutronics calculations," Fusion Eng. Design, 85, 669-682 (2010).

Summary of the presentation

- The final report of the Covariance Data Use Promotion Working Group has been briefly reviewed.

- Two relevant topics have been presented.

- Reviews for SA, UA, and DA have been provided.