Condensed Neutron Energy Group Structure for Core Analysis of Material Test Reactor

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Keywords: group structure, cross-section library, research reactor

1. Introduction

The Korea Atomic Energy Research Institute has developed a reactor core code based on the discrete ordinate method. To facilitate the core design of the KJRR (Ki-Jang Research Reactor) by using the code, its performance validation is currently undergoing through various benchmark calculations [1]. For reactor core analysis, a nuclear data library is used to calculate the reactor core parameters. To ensure computational efficiency, it is necessary to condense the detailed nuclear data into a few representative group structures. In addition, since the accuracy of the calculations depends on the chosen group structure [2], it is also necessary that a suitable group structure is appropriately derived for the reactor core analysis of the KJRR.

2. Methods

The KJRR, with a 15 MWt capacity, operates using low-enriched uranium (LEU) fuel with an enrichment level of 20wt% or less. This reactor will be used for the production of medical-grade Mo-99, as well as industrial semiconductor materials. Additionally, it will be utilized for developing and validating innovative technologies using research applications [3]. Within this context, the previous studies conducted on the analogous research reactor are investigated to identify an appropriate group structure for core analysis in the KJRR.

3. Results and Discussions

Data were collected and analyzed from international collaborative research programs targeting research reactors such as the RERTR project. The cases of core analysis that were investigated mainly focused on IAEA's 10 MWt MTR benchmark. Additionally, core analysis cases targeting research reactors from various countries such as OPAL, Saphir, KURR, FNR, and others were included in the scope of the investigation [4-7]. In these programs, the energy group structures are ranged from two to ten group structures. Particularly, most of the energy group structures are concentrated in a range of three to five-group structures, as shown in Fig. 1. Fig. 1 shows the group structures used for research reactor core analysis across multiple research institutions, displayed on a log-scale vertical line. The horizontal axis indicates the neutron energy and the red lines indicate the energy boundaries.

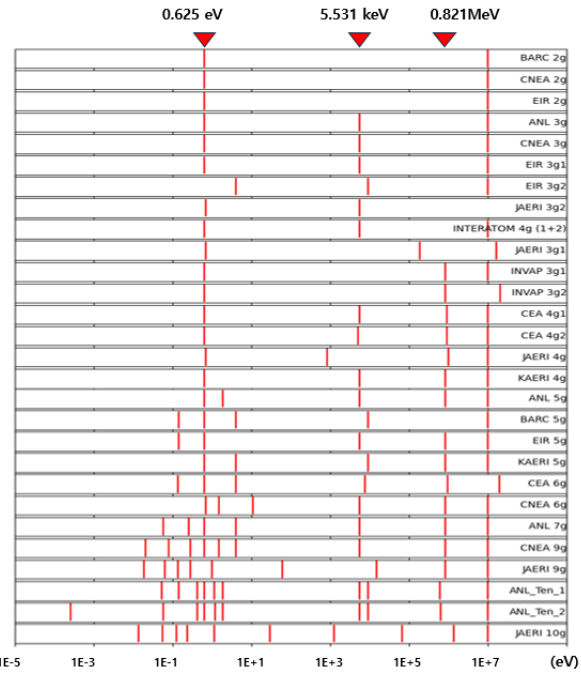

Fig. 1. Comparison graph of neutron group structure used in the research reactor core analysis

As shown in Fig. 1, the key energy boundaries used for the group structures were 0.625 eV, 5.531 keV, 0.821 MeV, and 10 MeV. The characteristics of the four energies used for the analysis of research reactors are as follows:

0.625 eV: This energy is mainly considered as a group boundary when using group structures of two or more groups. In two-group structure with this energy, as a middle of group boundary, it distinguishes neutron energy into the fast and thermal regions. In three and more group structures, this energy also selected major group boundary for distinguishes thermal region and resonance region. Therefore, it is considered the major energy boundary to decision group structures.

5.531 keV: This energy is major energy boundary following 0.625 eV. It is not used well for two-group structure, but it has been used three or more group structures. In case of using this energy in three-group

structure, it has been used for divide to fast region and resonance region. The fission cross-sections of fissile materials, such as U-235 and Pu-239, are resonated between this energy and 0.625 eV. And many neutron absorbers, like Hf-176, and Gd-155, have a resonance of capture cross-section in same energy range. This is not the same for all nuclides, but this energy is chosen as a valid group boundary.

0.821 MeV: Same as the 5.531 keV, this energy is importance when using group structures of three or more groups. In three-group structures, it has been considered competitively with 5.531 keV as a group boundary for divide fast and resonance region. It seems to be reflected that the cross-sections of some nucleus such as Fe-56 resonate above the 5.531 keV. In four and more group structure, 0.821 MeV has been used for divided to fast region and slowing down region.

10 MeV: This energy is in range of fast region. This is the commonly chosen as the highest energy group boundary for performing core analysis. Energy regions higher than this value are less considered in core analysis of material test reactors. At energies above 10 MeV, the cross-section of most nuclides decreases rapidly. So, nuclear reaction occurring in the higher energy range than this are expected to correspond to a very small fraction of the overall total reaction of research reactor. It is inferred that this is the reason why 10 MeV has been considered for the highest boundary of the group structure.

The four-group structure, consisting all the four energies discussed above, has been used to core analysis of research reactors. Other energy group structures which have less than four-group, have been employed in the analysis of research reactor cores. However, EIR (a participant in the RERTR program) highlighted the necessity of utilizing at least a four-group structure for accurate analysis results that closely match experimental outcomes in research reactor core calculations [4].

While direct comparisons might be complex, according to the research by Sicheng Wang et al, a four-group structure substantially reduces eigenvalue errors in core calculations without significant increases in computational time compared to a two-group structure. When compared to a seven-group structure, the error rates were only slightly higher [8].

In study of T. Surbakti et al, they used four-group structure, similar to the one proposed in this study, for core analysis of MTR reactor. And they obtained Consistent results across various fuel conditions [9].

Based on the data from these experiences, it is expected that this group structure will also effectively operate in the core analysis of KJRR.

4. Conclusion

In this study, a group structure for the core analysis of the KJRR is recommended. By analyzing energy group boundaries utilized in the various research reactors, an optimal selection of energy groups is proposed to reflect the appropriate neutron behavior within the reactor core. A four-group structure, consisted by energy boundaries of 0.625 eV, 5.531 keV, 0.821 MeV, and 10 MeV, will be deemed suitable for core analysis of the material test reactor. Furthermore, there is potential to extend the analysis up to a five-group structure by considering additional energy boundaries of 0.140 eV or 4 eV, accounting for the thermal neutron region.

It is expected that the proposed group structure enhances the precision of calculation and contributes to the design and operation of the KJRR. However, further research and validation efforts are recommended to ensure the applicability and effectiveness of the proposed group structure.

Acknowledgment

This research was conducted with the support of the Korea Research Foundation funded by the Ministry of Science and ICT, Republic of Korea (Grant No. 2023M2D5A1009866).

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