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Impact of new evaluated nuclear data libraries on core characteristics of innovative reactor designs

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ABSTRACT

The impact of new evaluated nuclear data libraries (ENDF/B, JENDL and JEFF) on core characteristics of thermal and fast spectra innovative reactor designs was investigated. The innovative reactor design with thermal neutron spectrum is represented by small-sized, long-life CANDLE (**C**onstant **A**xial shape of **N**eutron flux, nuclide densities and power shape **D**uring **L**ife of **E**nergy producing reactors) HTGRs (High Temperature Gas-cooled Reactors) with uranium and thorium fuel cycles, while the one with the fast neutron spectrum is represented by compact, sodium-cooled B&BRs (**B**reed-and-**B**urn **R**eactors). The CANDLE HTGR core characteristics (i.e. kinf, keff, discharge burnup, burning region moving velocity, core life time and axial power peaking factor) were evaluated by a dedicated deterministic neutronics and depletion code based on few-group neutron diffusion theory in 2-D RZ geometry, while the required microscopic cross sections were prepared by using SRAC2006 with JENDL-4.0, ENDF/B-VI and JEFF-3.1 based new SRAC2006 libraries. The B&BR core characteristics were evaluated using a continuous energy Monte Carlo neutron transport code, SERPENT, with JENDL-4.0, ENDF/B-VII.0, ENDF/B-VII.1 and JEFF-3.1.1 nuclear data based new libraries. The impact of new evaluated nuclear data libraries for innovative CANDLE HTGR core characteristics was found significantly larger for thorium fuel cycle than the one for uranium fuel cycle, especially in the discharge burnup, burning region moving velocity which affected the core life time significantly. The findings indicated the needs of more accurate nuclear data libraries for nuclides involved in thorium fuel cycle. The impact of new evaluated nuclear data libraries for innovative B&BR core characteristics was found in a slightly large variation for keff evolution during burnup which in turn affected the estimated core life time. However, a good agreement within the statistical error on the integral kinetic parameters, Doppler reactivity coefficients, coolant density reactivity coefficients, axial and radial expansion reactivity coefficients, power density distributions can be observed among the libraries. In addition, the buildup of fission products and minor actinides were also similar.

1. Introduction

Recently pursued innovative reactor designs such as CANDLE (**C**onstant **A**xial shape of **N**eutron flux, nuclide densities and power shape **D**uring **L**ife of **E**nergy producing reactors) (Sekimoto et al., 2001) and B&BR (**B**reed-and-**B**urn **R**eactors) (Hartanto and Kim, 2012) require an assessment of the accuracy of their main reactor design parameters to determine properly the design feasibility, their safety margins, and in the future their economical margins. Innovative reactor designs often adopt a novel way of fuel burning scheme/scenario and initial fuel compositions which result in very heterogeneous core and/or blanket regions involving complex spatial power as well as different neutron spectra distributions across the reactor. In addition, the designs are commonly aimed at a very high discharged fuel burnup which require accurate reactor physics constants for nuclear transmutation whose accuracy is naturally rooted back to the high quality of the evaluated nuclear data used.

Several new evaluated nuclear data libraries have been released, namely the JENDL-4.0 (Shibata et al., 2011) (replacing the older version of JENDL-3.3 (Shibata et al., 2002)), ENDF/B-VII.1 (Chadwick

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et al., 2006) and JEFF-3.1 (Koning et al., 2006) etc, which cover more number of nuclides and have better agreement with integral measurement results. The release of the new evaluated nuclear data was followed by compilation works of code-specific working libraries for productive reactor design and analysis. For example, after Japan Atomic Energy Agency (JAEA) released the JENDL-4.0, the Agency also prepared, tested, verified and validated the JENDL-4.0 based SRAC2006 library (Okumura et al., 2007) and MVP-II library (Nagaya et al., 2005). SRAC2006 (Okumura et al., 2007) used in the present work is a comprehensive neutronics calculation code system which consists of many modules from neutron transport based cell calculation module to multidimensional neutron diffusion based whole core neutronics calculation module. For some other codes which are able to read directly the new evaluated nuclear data library (in ENDF format), such as SERPENT code (Leppänen, 2013), the compilation works are not needed. SERPENT code used in the present work is a continuous energy neutron transport Monte Carlo code dedicated for, and has unique features for, reactor physics analyses. Unlike other Monte Carlo code, SERPENT code's users are not burdened by complicated compilation works of converting the evaluated nuclear data library using for example the NJOY code system (Kahler, 2012).

In the present paper, the impact of new evaluated nuclear data libraries (JENDL, ENDF/B and JEFF) on the core characteristics the innovative CANDLE and B&BR reactor designs are investigated. Although the novel CANDLE burnup scheme can be applied both for fast and thermal reactors, in the present work, we consider block/prismatic type high temperature gas-cooled reactors (HTGR) which operate under thermal neutron spectra. Two fuel cycles are considered for the CANDLE HTGRs, namely the uranium and thorium fuel cycles. Thorium fuel cycle are not used presently, however in the future, the thorium potential would be utilized and investigation on the impact of the new evaluated nuclear data libraries on the thorium fuel cycle performance is of great interest. As for the innovative B&BR, compact sodium-cooled Breed-and-Burn fast reactors are considered. Naturally, this group of reactors is operated under fast neutron spectra. The fast reactors utilize, as one option, metallic low-enriched uranium (LEU) fuels for the initial core regions. The reactors are designed to burn spent nuclear fuels (SNF) from light water reactors (LWRs) after being metalized and put into the blanket regions. The burning and breeding mechanism to some extent is similar to CANDLE fast reactors. Both the thermal CANDLE HTGRs and fast B&BR reactors may reach much higher

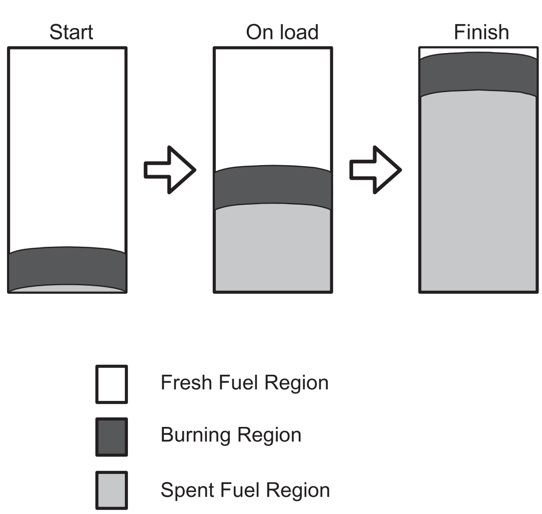

Fig. 1. CANDLE burnup concept.

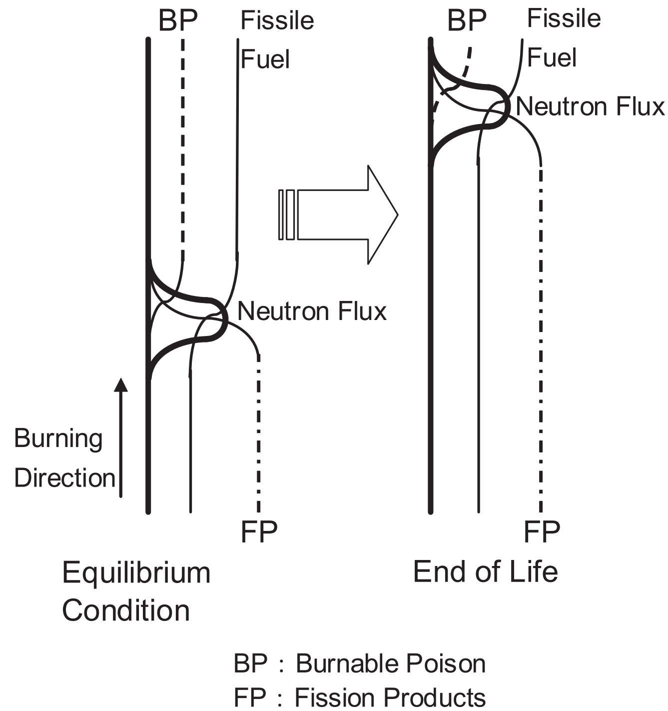

Fig. 2. CANDLE burnup application to HTGR.

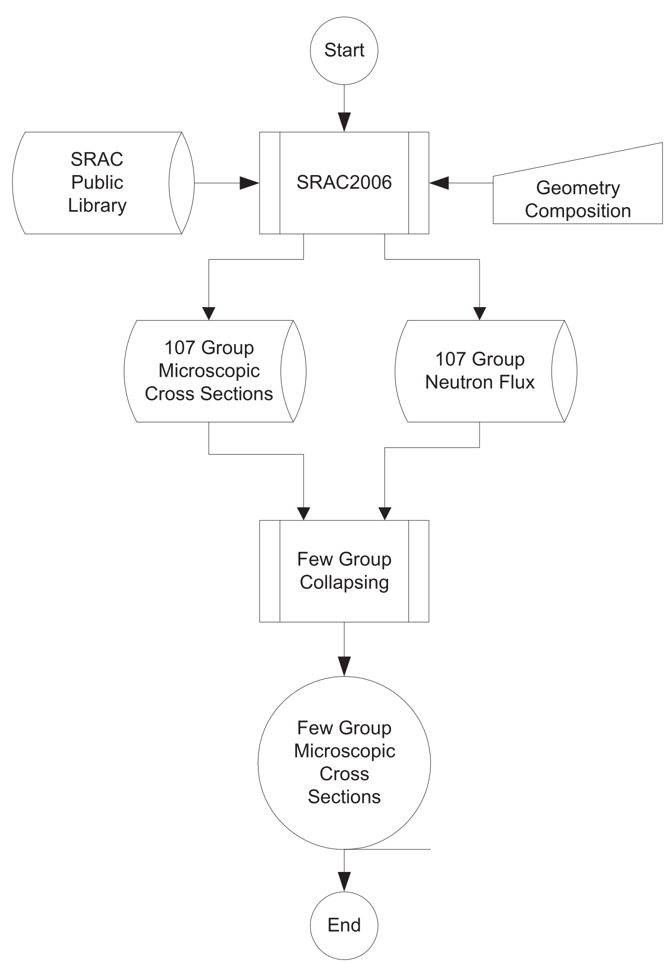

Fig. 3. Few group microscopic cross sections preparation using SRAC2006.