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Current Status of R&D on Erbia-Bearing Super High-Burnup Fuel

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1. Introduction

Utilization of high-burnup fuel is effective to reduce the number of spent fuel from nuclear power plant. The most straightforward way to realize a high-burnup fuel is to increase the uranium enrichment[1]. However, the current upper limitation of the fuel enrichment is 5wt% in Japan, and the increase of uranium enrichment over 5wt% requires considerable investment in fuel fabrication, transport and storage process, namely, design modification, reconstruction, re-licensing etc., to cope for the possible issues especially in critical safety. Such investments may be a serious barrier for the introduction of future high-burnup fuels with higher enrichment.

The erbia-bearing super high-burnup fuel (hereafter referred as "Er-SHB")[2], currently being studied by the authors, is an alternate pathway for realizing the high-burnup fuels with higher enrichment. In this concept, low content (>0.2wt%) of erbia (Er_2O_3) is added in the UO_2 powder with high enrichment (>5wt%) immediately after the re-conversion process. The addition of erbia acts to suppress the reactivity of the high-enrichment fuel, so that the criticality safety will be equivalent to the uranium fuel with enrichment of 5wt% or less; this idea for suppressing the reactivity is named as "erbia credit".

The concept of Er-SHB is rather different from the current LWR fuel loaded with erbia as burnable absorber, where erbia is loaded partially in certain fuel rods in the fuel assembly to control in-core power distribution and moderator temperature coefficient. Contrary to such usage, erbia is added in all fuel rods to meet the criticality safety requirements in the Er-SHB fuels.

In order to conduct a comprehensive R&D on the Er-SHB fuel, the authors have launched a four-year development program[3] in 2005 under the support project of Ministry of Economy, Trade and Industry (METI) for Innovative and Viable Nuclear Energy Technologies (IVNET). Our program covers a wide aspect of the fuel fabrication as follows;

(1) critical experiments,
(2) development of uncertainty reduction methodology for neutronics parameters,
(3) criticality safety analysis,
(4) fabrication test of erbia-bearing fuel pellet,
(5) core design of Er-SHB loaded cores,
(6) source term estimation for heat load and shielding analysis, and
(7) applicability of burnup credit for the Er-SHB fuels.

2. Current status of the project

The results of the project obtained until the end of 2006 fiscal year are the critical experiments at KUCA, theoretical studies of the generalized bias factor to improve prediction accuracy, criticality safety analysis for fuel fabrication facilities, nuclear design parameter survey by the core calculation of equilibrium cycle, fabrication tests of erbia-bearing fuel and numerical evaluation of burnup credit of the Er-SHB fuel.

2.1 Critical Experiments at KUCA

Critical experiments of erbia-loaded thermal spectrum cores are being conducted using the solid moderated cores of Kyoto University Critical Assembly (KUCA). Highly-enriched U-Al alloy fuel plates are combined with natural uranium metal, polyethylene and erbia-coated graphite plates (Fig.1) to simulate the design specifications of Er-SHB fuel under various conditions by varying the H/U ratio, average enrichment and erbia content.

Fig. 1 Erbia-coated graphite plates

Following the preliminary experiments in FY2005, the first critical experiment of the erbia-loaded whole core was successfully conducted in December 2006. The average enrichment and erbia content of the core is 5.4wt% and 0.3wt%, respectively, which corresponds to the basic design of the Er-SHB fuel. Criticality, control rod worth, erbia worth and prompt neutron decay constant have been measured in the experiment.

Preliminary analysis of the criticality using MVP and JENDL-3.3 shows that the calculated k-effective and reactivity worth of erbia plates showed satisfactory agreement with the experimental values. More detailed analysis of the experiments is underway.

2.2. Theoretical study on the generalized bias factor

The generalized bias factor utilizes covariance data of the cross sections and sensitivity coefficients to improve the prediction accuracy of neutronic parameters for the actual system by using the results of critical experiments. Theoretical improvements have been carried out in FY2006 to improve the prediction accuracy. Covariance data for erbium cross sections were also prepared.

2.3. Criticality safety analysis for fuel fabrication facilities

Parametric survey has been conducted to determine the subcritical conditions of erbia-loaded fuel with enrichment higher than 5wt% in various simple geometries. Based on the analysis, relation between erbia content and enrichment has been determined so that the subcriticality of Er-SHB fuel is equivalent to 5wt% UO_2.

2.4. Neutronics design of Er-SHB loaded cores

Feasibility studies of the Er-SHB fuel loaded cores have been carried out with major specifications shown below;

- 4-loop type PWR with 17 x 17 assembly,
- maximum assembly burnup of 70GWt/d,
- cycle length of 13.7, 18.5 and 24.0 EFPM,
- average uranium enrichment of 5.6 to 6.0 wt%,
- erbia content of 0.4 to 1.0 wt%, and
- number of fuel assemblies of 48 to 92.

The equilibrium cycle analysis show that the utilization of the Er-SHB fuel in PWR is feasible and has a significant impact on reducing the number of feed assemblies by about 20% compared to the conventional 4.95wt% UO_2-Gd fuel. Neutronics design of the fuel assembly has also been performed to improve the anti-PCI property based on the transient analysis.

2.5. Fuel fabrication test

Er-SHB fuel pellets are simulated by adding erbia of low content to fuel powder with natural uranium composition. Based on the sintering test results for the fabricated fuel samples, the productivity of Er-SHB fuel is confirmed to be feasible as ordinary fuel.

2.6. Numerical evaluation of burnup credit of the Er-SHB fuel

Criticality safety analysis for PWR spent fuel cask containing Er-SHB fuel assemblies are carried out in consideration of fuel depletion, and the erbia content required to give reactivity equivalent or less than 5wt% enrichment has been determined.

3. Future works

Further critical experiments using KUCA are scheduled from FY2007. Through these experiments, systematic investigation of uranium enrichment, erbia content and moderation ratio will be accomplished. Based on the experiment results, prediction accuracy of the actual Er-SHB core will be evaluated using the generalized bias factor. Core design of Er-SHB loaded cores including safety analysis, as well as source term estimation for heat load and shielding analysis will further be conducted. Evaluation of optimum scheme for introducing Er-SHB fuel to present LWR cycle will also be conducted. Finally, based on these results, the feasibility of Er-SHB concept will be quantitatively established.

4. Summary

The present paper summarizes the current R&D status of Er-SHB fuel for LWRs. Under the four-year project conducted by the authors, comprehensive knowledge on erbia-loaded uranium fuel and its application to PWR are being accumulated both in front-end and back-end of LWR fuel cycle, both experimentally and theoretically.

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