Establishment of Criticality Limit Curve for PWR Spent Fuel Loading into KDC-1 Disposal Canister

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Ⅰ. Introduction

Technology related to a deep geological disposal as a long-term spent nuclear fuel management strategy has been under development at the Korea Atomic Energy Research Institute (KAERI) since 1997. The main purpose of this program is to establish a Korean reference HLW repository system by the end of 2006. As a preliminary result, a disposal system design including a canister and disposal hole was proposed through thermal and mechanical analyses. The proposed canister, however, still has the potential to be modified, if one of the safety criteria can't be satisfied. For a safe storage of spent nuclear fuel the requirement concerning a normal criticality safety described in 10CFR60.131(h), as one of the criteria, should be met. Therefore, the criticality limit curve satisfying the criticality safety limit was established to ascertain how many spent fuels can be loaded into the proposed canister by considering the domestic spent PWR nuclear fuels and disposal system developed up to now. From this result, it was eventually ascertained whether the proposed canister design, KDC-1[1], is reasonable or not.

Ⅱ. Procedure and Scope

The scopes performed throughout this study are as follows. (i) Current status and upcoming trends for a domestic spent fuel were investigated and predicted comprehensively to obtain the basic data needed for a criticality analysis. The inventory, and the characteristics such as the physical dimensions, fuel rod array, weight, initial ^{235}U enrichment and discharge burnup of the spent fuel from existing and planned nuclear power reactors were investigated and projected. And then, a set of the representative spent fuels was proposed. (ii) The isotopic compositions over the range of the initial ^{235}U enrichments (Korean Standard Fuel Assembly and Vantage 5H with a initial enrichment of 3.2 wt.%, 4.0 wt.%, and 4.5 wt.% were considered) and burnups of each representative spent fuel were estimated for the subsequent criticality analysis. Because the fuel is burned faster near the center of the fuel than at the ends as the fuel is irradiated, the fuel was modeled with seven axial segments with corresponding burnups. A "bounding" axial-burnup profile was applied to construct the axially varying brunup model. Depletion calculations for an isotopic composition were undertaken by using the SAS2 sequence of the SCALE 5 code system[2] up to a burnup corresponding to each axial segment by considering the fuel geometry and the specified irradiation history. Different sets of actinides and fission products were created, which will eventually provied the results to ascertain how many spent fuels can be loaded depending on the different levels of a burnup credit. (iii) Effective multiplication factor was calculated by the CSAS25 (KENO V.a) module as a function of the burnup, enrichment, and a burnup nuclide set for each representative fuel. The calculations were performed with the built-in 44-group library. Nominal condition was considered for this physics calculation. Repository model was explicitly set up with a disposal canister, KDC-1, containing 4 PWR spent fuels. The isotopic specification calculated through a depletion calculation was applied to each axial segment built in the 2nd step. The depletion and criticality calculation procedure is depicted in detail in Fig. 1. (iv) Uncertainties inherent in a physics model and a computation tool were evaluated in detail to establish the criticality limit curve. The uncertainty parameters were defined, and then their quantification was performed. To define the parameters, the overall conditions during the model development and the depletion calculation were examined in detail. (v) The results produced in the previous step were used to establish the criticality limit curves representing K_{eff}=0.95 as functions of the initial enrichment and the discharge burnup for different sets of actinides and fission products. The limit curves were superimposed onto the spent fuel inventory map to asceratin how many fuels could be loaded into the disposal canister.

Ⅲ. Results and Discussions

The criticality limit curve for each different level of burnup credit is described in Fig. 2. The spent fuel in the above region beyond the limit curve can be put into the KDC-1 canister in the figure. Set 1 only considers the actinide burnup credit, which contains only ^{234}U, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, and ^{241}Am. Set 2 considers the actinide and the major fission product burnup credit, which contains ^{243}Am, ^{237}Np, ^{143}Nd, ^{147}Sm, ^{149}Sm, ^{150}Sm, ^{151}Sm, ^{152}Sm, and ^{151}Eu in addition to set 1. Nuclides in Set 3 includes ^{99}Tc and ^{103}Rh in addition to set 2. These nuclides were chosen based on their contribution to the reactivity decrease, confidence of the nuclear data, stability of a nuclide form, and the possibility of a verification of the calculated isotopic content. The results obtained through this study are as follows. Minimum required burnups to ensure a criticality safety were shown to be 27 GWD/MTU for 3.2 wt.%, 38 GWD/MTU for 4.0 wt.%, and 44 GWD/MTU for 4.5 wt.%, respectively, when the actinide burnup credit (set 1) was considered for V5H. For KSFA, the minimum required burnps were about 5 MWD/MTU lower than those for V5H. The overall uncertainty inherent in a depletion calculation, the fabrication and encapsulation tolerance, and a code bias was revealed to be 0.92 Δk. The portions of spent fuel which could be loaded into the KDC-1 disposal canister with an ensured criticality safety were shown to be 88% for an actinide burnup credit, and 99% for an actinide and fission product burnup credit. Therefore, it can be concluded that the disposal system including the KDC-1 canister developed in Korea is reasonable in terms of a criticality safety.

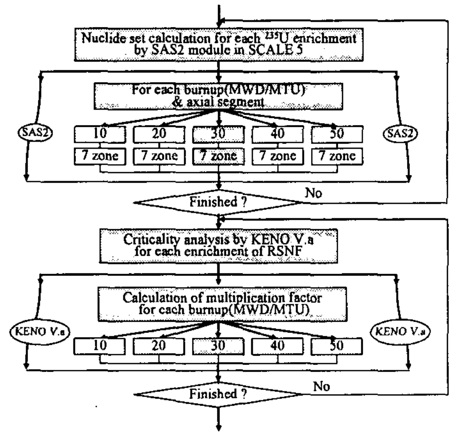

Fig. 1. Depletion and criticality calculation procedure

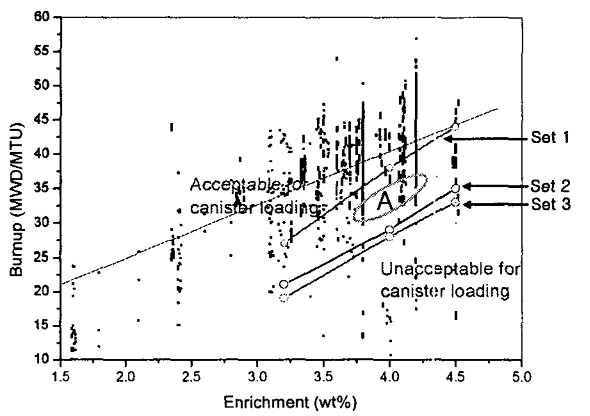

Fig. 2. Criticality limit curve for a spent fuel loading into the KDC-1 canister

References

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