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Criticality Uncertainty Evaluation of New Fuel Storage Loaded with Accident Tolerance Fuel

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1. Introduction

After the Fukushima accident, accident tolerance fuel (ATF) is being developed to enhance the safety of nuclear power plant (NPP). Various concept of ATF (i.e. coating cladding, Fe based, SiC etc.) were suggested to achieve these goal. Among them, the concept of Chromium coating on zirconium-based alloy cladding was selected as a near term technology. In addition, additive fuel was used to reduce fission gas release and PCI failure.

Since change of fuel and cladding can cause criticality impact in terms of transportation and storage, it is necessary to verify criticality.

In this study, MCNP code [1] was used to criticality and uncertainty caused by design tolerance in case of ATF storage.

2.Geometry

In case of APR NPPs, there is two storage rack which has 7×8 array in new fuel storage (NFS). In normal conditions, new fuels are stored with dry condition, k_{eff} is very low. In this study, therefore, accident condition in which the NFS is flooded by pure water of the maximum density ($\rho = 1$ g/cm^3) is assumed.

It takes lots of time to model the entire NFS, so one cell was modeled and each surface was set as a reflective surface to assume infinite array (Fig. 1).

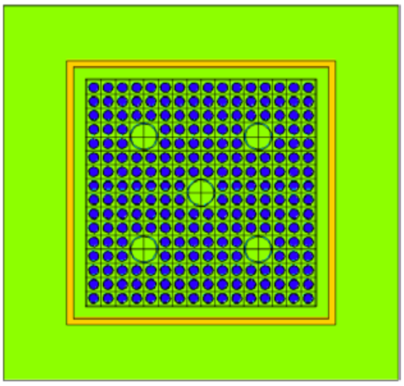

Fig. 1 Reference cell Model

In addition, for conservative assumptions, the grid was excluded from the model and upper and lower structure of fuel assembly except active region were replaced with water (Fig 2).

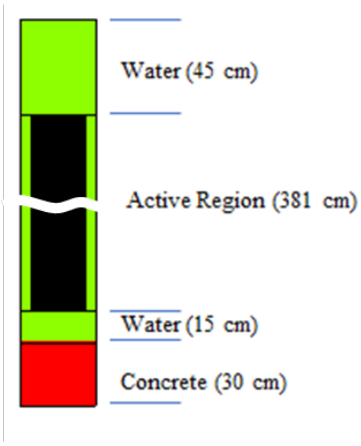

Fig. 2 Axial view of reference model

Major dimension and materials of fuel assembly and NFS is as below (Table. 1).

Table. 1 Design of fuel assembly and NFS rack

Input Data	Value
Fuel type	UO_2 or LAS
U-235 concentration	5.0 %
Pellet stack density	10.313 g/cm^3
Pellet diameter	0.81915 cm
Cladding type	HANA6
Cladding inner diameter	0.83566 cm
Cladding outer diameter	0.94996 cm
Coating thickness	15 µm
Guide tube type	HANA6
Guide tube inner diameter	2.2860 cm
Guide tube outer diameter	2.4890 cm
Fuel rod pitch	1.28524 cm
Assembly pitch	20.7772 cm
Active length	381 cm
Storage rack type	SS304[2]
Rack thickness	0.6 cm
Rack inner size	22.94 cm

3. Methods

Four type of fuel were considered in this study [Table 2]. This was set in consideration of the ATF under development of Korea. Type 1 is reference model which use standard UO_2 + zirconium alloy. Type 2 is standard UO_2 fuel + chromium coated cladding, type 3 is LAS fuel + standard zirconium alloy cladding and type 4 is LAS fuel + chromium coated cladding.

Table. 2 Type of fuel and cladding

Model	Type 1	Type 2	Type 3	Type 4
Fuel Material	UO_2	UO_2	LAS	LAS
Coating material	N/A	Cr	N/A	Cr
Enrichment	5.0%	5.0%	5.0%	5.0%
Coating Thickness	N/A	15 μm	N/A	15 μm

Uncertainty caused by 7 kinds of design tolerance of each types were evaluated. (i.e. (1) Min pitch, (2) Min rack thickness, (3) Max pellet density, (4) Max pellet diameter, (5) Max rod pitch, (6) Min cladding OD, (7) Assembly position eccentricity). Case (1) ~ (6) used the reference model and each design tolerance was change. Case (7) used a model that simulates the eccentricity of the fuel assembly.

Among the design tolerance, the maximum cladding outer diameter and cell thickness model were excluded from uncertainty analysis because these cases reduce the k_{eff}.

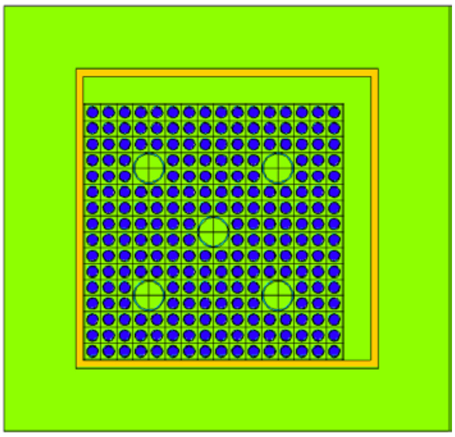

Fig. 3 Assembly position eccentricity model

Criticality analysis was performed using MCNP code [1] and ENDF/B-VII nuclear data was used as a cross section data [4]. 10,000 neutrons were used over 550 generations to minimized statistical uncertainty. In addition, initial 50 generations of k_{eff} value were ignored to exclude the influence of the bias caused by the initial value in the finial k_{eff} evaluations.

4. Results

Table.3 shows the reference k_{eff} and uncertainty of each fuel type. Uncertainties were derived by root mean square error for sum of $\triangle k_{eff}$. Uncertainty of type 1, standard UO_2 + zirconium alloy, was lower than other fuel types. It is because the Cr coating and LAS additives act as poison materials which absorb neutrons. According to criticality analysis, it seems that there is no criticality impact due to storage of ATF as a result of the criticality analysis. Although bias and uncertainty caused by monte carlo code verification was not considered, standard UO_2 + zirconium alloy case was already confirmed that final k_{eff} which consider all of uncertainty and bias.

Table. 3 Calculated k_{eff} of each cases.

Input Variable	k_{eff}			
	Type 1	Type 2	Type 3	Type 4
Reference	0.91424	0.91117	0.91354	0.91109
Min cell pitch	0.91505	0.91212	0.91478	0.91195
Min rack thickness	0.91550	0.91153	0.91591	0.91240
Max pellet density	0.91676	0.91302	0.91705	0.91328
Max pellet diameter	0.91544	0.91155	0.91476	0.91150
Max rod pitch	0.92233	0.91806	0.92140	0.91818
Min clad OD	0.91563	0.91319	0.91557	0.91208
Eccentricity	0.92003	0.91675	0.91933	0.91584
$\sqrt{\sum_i (\Delta k_i)^2}$	0.01053	0.00934	0.01097	0.00901

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