A Study on Criticality Safety Parameters of New Fuel Storage Rack Design

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1. Introduction

The dry new fuel storage rack shall maintain the subcritical condition (i.e., k-eff < 0.95) when fully flooded with water and the k-eff will not exceed 0.98 even assuming that the optimum moderation causes the highest reactivity [1]. Thus, the design parameters of the new fuel rack are determined optimally by considering both the full density water flooding condition and the optimum moderation condition. The behavior of the k-eff as the variation of design parameter of the new fuel rack was investigated as the function of the moderating water density.

2. Methods and Results

2.1 Analysis Model

The basic model of this analysis is the APR+ new fuel storage rack loaded with PLUS7 fuel assembly [2]. Two 10x8 rack modules are located in the concrete cavity and stainless steel can of 6 mm thick plate forms the fuel storage cell. The pitch of the fuel storage cell is 350.0 mm and the inner dimension of the fuel storage can is 230.0 mm. The enrichment of U-235 in the fuel pellet is assumed to be 5.0 wt%.

2.2 Computer program and cross section library

The k-eff calculation of the various new fuel storage rack models was performed using the CSAS5 module and the V7-238 library of the SCALE6 code [3]. The CSAS5 is the control module for enhanced criticality safety analysis sequences with KENO V.a and the V7-238 is the 238-group neutron library based on the ENDF/B-VII Release 0 cross section data.

2.3 Analysis of the k-eff of the new fuel rack model

The k-effs of the new fuel storage rack for the APR+ were calculated at possible range of the moderating water densities and were given in Fig. 1. The optimum moderating water density which yields the maximum k-eff is unrealistically low (~0.14 g/cc) compared with normal water density. The second peak of k-eff occurs at the full density water. Usually the optimum moderation condition occurs at the water densities of 0.13 to 0.15 g/cc and the density causing the highest reactivity depends on the specific design characteristics of the new fuel rack. Throughout these analyses, the assumed water density for optimum moderation condition is 0.14 g/cc.

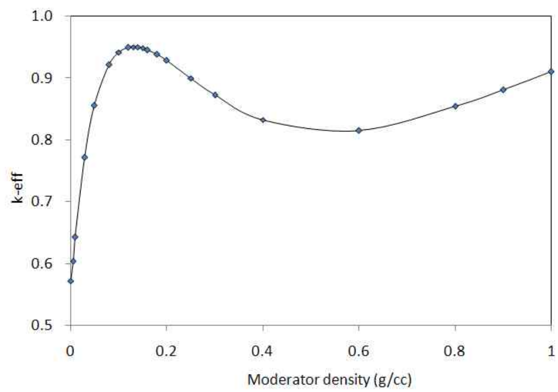

Fig.1. k-eff as the water density for the APR+ new fuel storage rack

To investigate the effect of the storage module size and shape, the following two models were prepared; a) model of square array storage module (1x1 ~ 20x20 array), and b) model of rectangular array storage module (1x144 ~ 12x12 array). In these models, the cell pitches of x and y-direction are both 350.0 mm (i.e., each fuel storage cell is a square).

At optimum moderation condition, the followings were found. The array size (i.e., storage capacity) of the rack module significantly affects on the k-eff (case a). And, even for same storage capacity, the array shape in the rectangular array also significantly affects on the k-eff (case b). However, at full flooding condition, the effects of array size and shape were very limited. Detailed behavior of k-eff was provided in Fig. 2. At the optimum moderation condition, the neutron leakage around the storage module boundary increases due to the low water density and it plays a role to reduce the k-eff. Thus, the k-eff at the optimum moderation condition is severely affected by the array size and the array shape of the storage module.

The model to analyze the effect of the cell pitch was prepared. In this model, the cell pitches of x- and y-direction varies but the cross sectional area of the cell is same. The calculated k-eff for various cell pitches of x- and y-direction was provided in Fig. 3. The cell pitch variation in x- and y-direction affects on the k-eff as directly opposite with the moderation density. The square pitch yields the lowest reactivity at the full density water but generates the highest reactivity at the optimum density water. This phenomenon is caused by the difference of the fuel to moderator ratio between adjacent cells in x- and y-direction and the degree of the moderation for entire model.

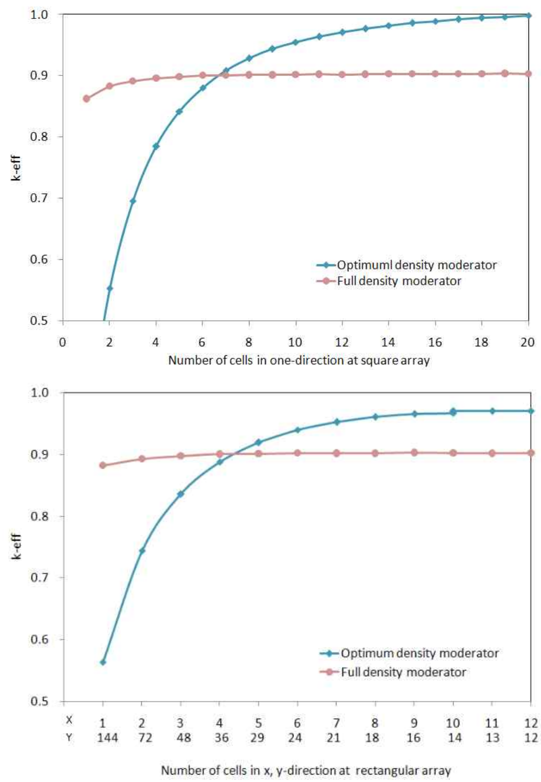

Fig.2. k-eff as the array size and the array shape of the new fuel storage rack

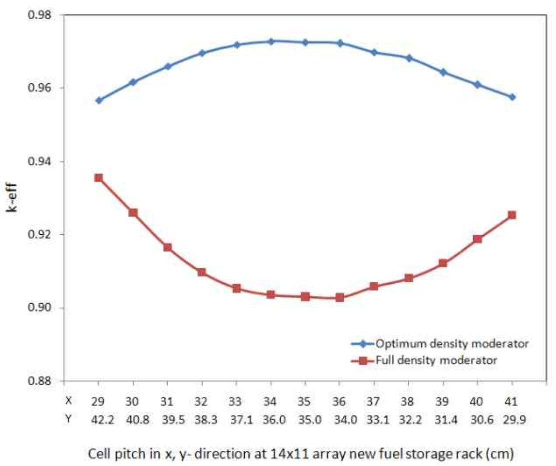

Fig.3. k-eff as the x- and y- direction cell pitch of the new fuel storage rack

The steel plate can of the fuel storage cell functions as the neutron absorber. Thus, the thin wall thickness yields the high reactivity for both water densities. However, the wall thickness very strongly affects at the optimum water density as can be seen in Table I. The inner dimension of the fuel storage can affects as directly opposite with the water density. The small inner dimension decreases the reactivity at full density water but increases the reactivity at optimum density water as can be seen in Table II. These are caused by the combination of the following two effects; a) the change of the neutron absorbing power of the steel plate, and b) the change of the neutron absorber (steel) material.

Table I: k-eff as the wall thickness of the fuel storage can

Can Inner dimension	Can Wall thickness	Optimum density	Full density
230.0 mm	6.0 mm	0.94985	0.91130
	5.0 mm	0.98883	0.91463
	Δk (5t–6t)	0.03898	0.00333
220.0 mm	6.0 mm	0.96155	0.90206
	5.0 mm	1.00247	0.90700
	Δk (5t–6t)	0.04092	0.00494

Table II: k-eff as the inner dimension of the fuel storage can

Can Wall thickness	Can Inner dimension	Optimum density	Full density
6.0 mm	230.0 mm	0.94985	0.91130
	220.0 mm	0.96155	0.90206
	Δk (220–230)	0.01170	-0.00924
5.0 mm	230.0 mm	0.98883	0.91463
	220.0 mm	1.00247	0.90700
	Δk (220–230)	0.01364	-0.00763

3. Conclusions

Many design parameters affect on the reactivity of the new fuel storage rack. The degree of impact of each design parameter is quite different and sometimes its trend is directly opposite as the moderator density. To achieve the optimized the new fuel storage rack design, therefore, the specific design requirements and design parameters should be analyzed for both the optimum density water and the full density water.

REFERENCES

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[3] ORNL/TM-2005/39, Version 6, "SCALE: Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation," Oak Ridge National Laboratory, 2009. 1.