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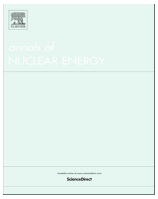

The effect of eccentric loading in spent fuel pool criticality safety analyses

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ABSTRACT

Eccentric fuel loading is one of the studies performed in a spent nuclear fuel criticality safety analysis. The study normally considers fuel assemblies placed at one side or corner in the rack cell. The purpose of this work is to study the effect of random placement of fuel assemblies on reactivity. MCNP was used to model the high density spent fuel pool and the depleted PLUS7 fuel. A total of 1400 cases with randomly displaced fuel assemblies in the rack cells, with and without neutron absorbers, were prepared. The results showed that none of the k-effective values from the random displacement cases exceed that of the base case where the fuel assemblies were centered in the rack cell. This suggests that eccentric fuel loading studies may not be needed in all criticality safety analyses with randomly displaced fuel assemblies.

1. Introduction

Criticality safety analyses are part of the licensing procedure required by the regulatory body. The approach, methodologies, tools, limitations and considerations have changed significantly in this field throughout the years. For example, early NRC guidance required that the spent fuel must be conservatively modeled as fresh fuel (NRC, 1978). As such, nuclear power plant designs incorporated low-density fuel storage pools that can accommodate spent fuel assemblies discharged from the reactor. However, the large amounts of discharged spent fuel, and the lack of a clear solution for permanent storage, led to the re-racking of the fuel storage pools through the incorporation of neutron absorbers (Lambert and Lambert, 2007). After re-racking, several issues needed to be addressed such as the chemical stability of neutron absorbers and additional uncertainties. Given that the early fuel pool designs had a large rack cell pitch, the reactivity effect due to fuel assembly position within each cell was negligible. However, the reduced pitch in the re-racked fuel storage pools introduced a new uncertainty due to assembly position to be accounted for in criticality safety analyses (ANS, 1983; Kopp, 1998). Criticality safety reports dated in the early 1990's started to include a discussion about eccentric loading (Westinghouse, 1993). Nowadays, it is mandatory to consider the effect of the assemblies' position within the fuel storage rack cells (NRC, 2011; NEI, 2014). For this purpose, the assembly position is normally modeled in an extreme location in the corner or side of the rack cell. This displacement is commonly known as eccentric loading, asymmetric assembly positioning, or off-centered assembly positioning and the positive reactivity effect from this displacement is considered as an uncertainty term (Xcel Energy, 2017). In reality the fuel assemblies are positioned in the rack using fuel handlers. The handlers do not necessarily position the assemblies in the center of the rack cell and may randomly offset them. Thus it is highly unlikely that a group of assemblies are positioned in extreme locations.

While several studies have been performed to investigate the effect of manufacturing tolerances in criticality analyses (Han et al., 2013; Li et al., 2015; Pecchia et al., 2015) and one study briefly discussed the impact of eccentric fuel loading on reactivity (EPRI, 2014), there is a need to thoroughly investigate the random placement of fuel assemblies in the spent fuel pool rack cell. The purpose of this work is to study the random displacement of fuel assemblies caused by eccentric loading and its effect on reactivity.

2. Case study

PLUS 7 fuel assemblies (KEPCO/KHNP, 2014a) were used in this study with a fresh fuel U-235 enrichment of 5 w/o. The cladding and guide tube material used were ZIRLO (Westinghouse, 2006). Some of the PLUS 7 design data (KEPCO/KHNP, 2014a) can be found in Table 1.

After generating a burn up-dependent cross-section library using a one-quarter PLUS7 assembly by TRITON-NEWT of the

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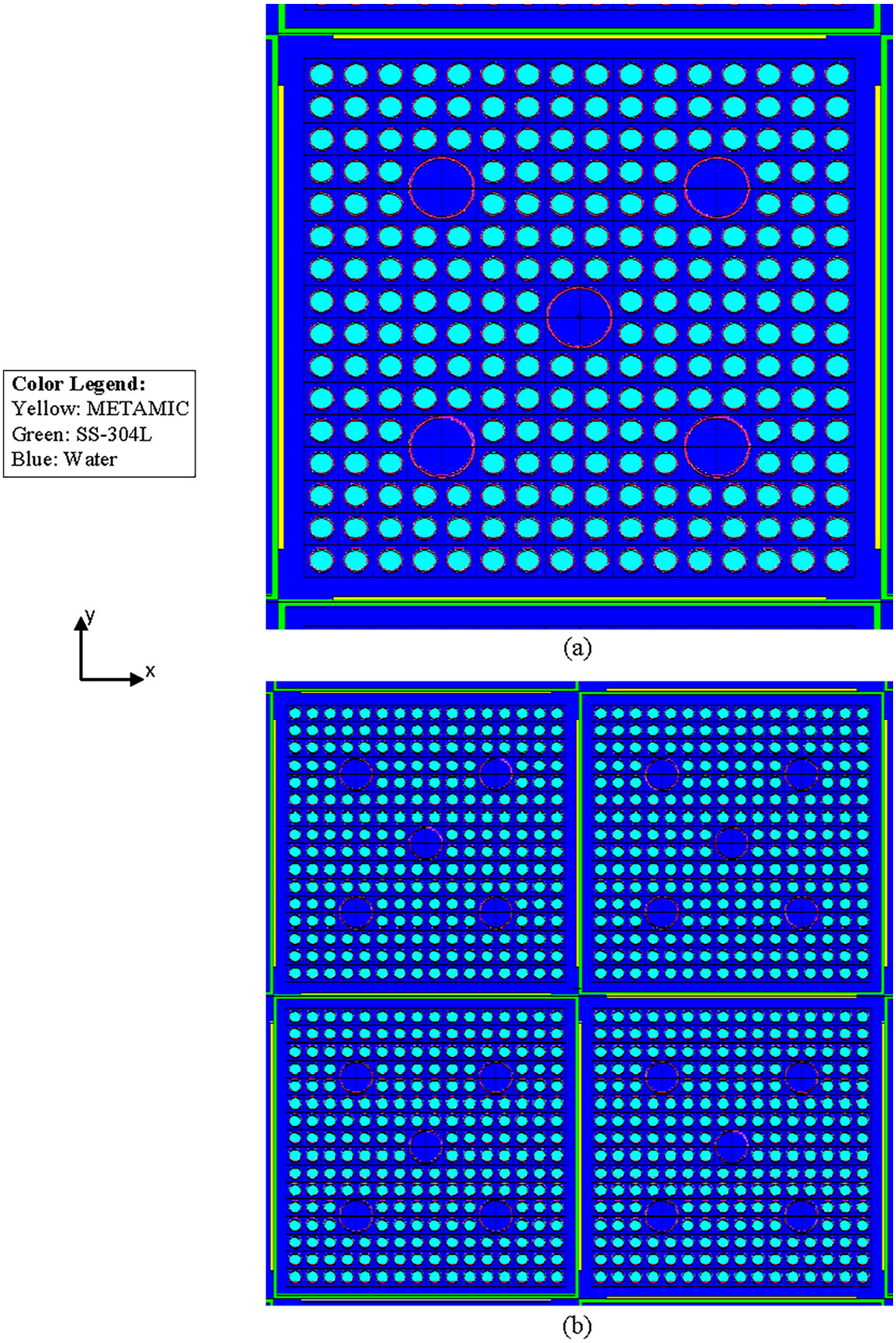
Table.1
PLUS7 fuel assembly design data.

Number of fuel rods	236
Array	16 × 16
Number of guide tubes	5
Fuel pellet diameter	0.8192 cm
Fuel rod inner diameter	0. 8357 cm
Fuel rod outer diameter	0.95 cm
Rod-to-Rod pitch	1.2852 cm
Assembly width	20.229 cm
Guide thimble inner radius	1.1430 cm
Guide thimble outer radius	1.2445 cm
Fuel active height	381.0 cm

SCALE package, the spent fuel composition was obtained by ORIGEN-ARP (ORNL, 2011). Limiting reactor operating conditions were adapted in the depletion process. The depletion process was performed in 1.06 GWd/MTU burn up steps in order to sufficiently capture the change in cross-sections with burn-up (ORNL, 2011). The maximum operating power of 53 MW/MTU was used in the depletion and the assembly average burn-up was 49.0 GWd/MTU. The spent fuel composition consisted of 28 isotopes. The selected isotopes for the analysis were based on their chemical and nuclear stability and as recommended by the NRC (NRC, 2012).

Holtec high density racks were used to accommodate the spent fuel assemblies. The rack and sheathing material used was stainless steel 304L and the neutron absorber was METAMIC (HOLTEC,



(a)

(b)

Fig. 1. a) One fuel assembly in the pool b) The four center fuel assemblies in the base model.