Criticality Evaluation of Model UO_2 Fuel Concerning Voloxidation Process

Fanxing Gao, Won Il Ko, Chang Je Park
Korea Atomic Energy Research Institute, 1045, Daedeok-daero, Yuseoung-gu, Daejeon, 305-353, Korea
nwiko@kaeri.re.kr

1. Introduction

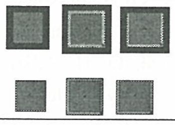
Criticality safety evaluation is of great importance in the design of voloxidation apparatus, the result of which determines the size of the apparatus as well as the capacity. However, there are fewer studies reported on the criticality evaluation of the voloxidation process. Based on the fundamental principles of the performance of criticality evaluation and assessment of methods used by other criticality evaluations concerning several related facilities such as transport container of nuclear fuel [1], the packaging of spent nuclear fuels [2], the spent fuel storage pool [3], the criticality evaluation of voloxidation process has been performed. The tool used is MCNPX code which is widely employed in the criticality safety evaluation [4]. The structure of a real voloxidation apparatus is complicated and difficult to be set as the input of the MCNPX code directly. The distribution of reactant in the cell is assumed to affect the results. So the selection of a proper geometry and optimization of the distribution of the reactants plays an important role in obtaining highly reliable results. In this paper, a simplified model in which the geometries of the reactant and container are both defined as cylinder has been adopted. As conservative results are always preferred in the criticality evaluation, the voloxidation apparatus is assumed to be surrounded by sufficiently thick water layer which functions as not only the neutron moderator but also the reflector [1, 5]. Fresh UO_2 fuel with an enrichment of 4.5 w% ^{235}U and a specified PWR spent fuel the initial enrichment of which is 4.5 w% ^{235}U with a burnup of 50GWd are adopted as the evaluation objects respectively. The reason for the employment of fresh UO_2 is that it contains almost no neutron poisons and offers a relatively conservative result.

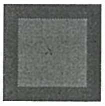
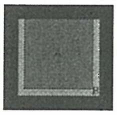
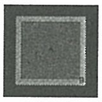
2. Setup of Evaluation Model

In this paper, the volume of the spent fuel is the summation of volumes of UO_2 and TRU oxides. Density of the spent PWR is calculated to be 10.97 g/cm^3. The main chemical reaction of the voloxidation process is $3UO_2+O_2=U_3O_8$, so the more O_2 charged, the more complete the UO_2 pellets converted into U_3O_8 powder. The density of the mixture, or UO_x powder uniformly mixed with O_2, during voloxidation operation was determined to be 1.10 g/cm^3 by the same method assuming the charge ratio of solid phase oxides to gas phase O_2 is 1 to 9.

In order to simulate most of the possibilities in regarding to not only normal but also abnormal situations, totally 6 cases were proposed for the determination of the final geometry used for evaluating criticality as illustrated in Table 1. Multiplication factors of a fresh UO_2 fuel was calculated employing these 6 geometries respectively shown in Table I as well. Finally #4 with the biggest K-effective value has been selected as the most conservative geometry to perform the criticality evaluation. The relationship between the multiplication factors of homogeneous case and solid-gas phase case depending on the increase of mass is not regular and the differences are negligible. Criticality evaluation of the fresh UO_2 and the spent fuel was carried out based on the #4 case with regarding fuel particulate system as a homogeneous phase substance.

Table 1 Model of 6 Cases

#3 Fuel	#2 Fuel & SS304 container without lid	#1 Fuel & SS304 container
		
K-effective=0.04889±0.00016	K-effective =0.05840±0.00041	K-effective =0.06066±0.000195

#4 Fuel surrounded by water	# 5 Fuel & SS304 container without lid surrounded by water	#6 Fuel & SS304 container surrounded by water
		
K-effective =0.42220±0.00347	K-effective =0.18649±0.00232	K-effective =0.08086±0.000875

*A stands for the fresh UO_2 fuel. B stands for the walls of the apparatus made of SS304. C stands for water. Thickness of water is 15 cm. Standard deviations are associated with 95% confidential.

3. Results and discussion

The values of the neutron multiplication factors obtained of 2000 kg UO_2 input scale is less than 0.7 which is smaller than the maximum permissible multiplication factor of 0.95 correspondingly no criticality risk. From mathematical point of view, the limit of the trend line equation is less than 0.8, so it seems there is no mass limitation of UO_2 concerning the criticality risk during the fresh UO_2 and PWR spent fuel voloxidation process.

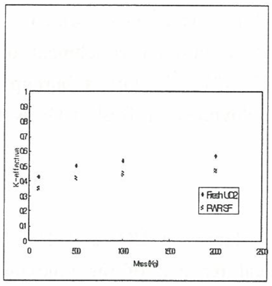


Fig.1. K-effective of fresh UO_2 and SF with Model #3.

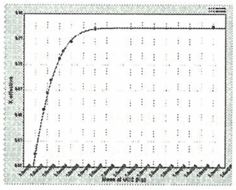


Fig.2. K-effective of UO_2 surrounded by water.

4. Conclusions

Fresh UO_2 with an enrichment of 4.5w% ^{235}U and a specified PWR spent fuel were adopted respectively as the reference fuels. 6 cases simulating the probable geometries of the apparatus was built and juel particles distribution in the apparatus was also estimated. It is proposed that there is no criticality risk concerning the voloxidation process. Based on the evaluation procedures and methods developed in this work, further work will be carried out to evaluate the criticality safety of other apparatus of pyroprocess such as electro-reducer, electro-refiner, and electro-winner etc.

References

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