The Effectiveness of Gd Contents of Fuel Basket Wall in UNF Shipping & Storage Cask – 16598

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ABSTRACT

A more effective basket structure, which employs the single wall basket structure and more effective neutron absorbing materials compared to the conventional 3 wall structure with boron neutron absorber, is under development. The criticality of the cask was evaluated as a function of the Gd and B contents in the plate and the Gd-containing SS plate thickness while maintaining the basic geometry the same as the reference cask which uses boron compound as neutron absorber. The KENO-VI code in SCALE with the data library ENDF/B-VII 238-group was used. In all the range of interest, the keff values are below 0.4 which is much lower than licensing limit of 0.95. As Gd content increases, the keff exponentially decreases. The Gd added SS shows higher performance than B added case in low atomic percent region. The B case curve showed less steep slope than the Gd case. The results of the wall thickness effect calculation indicated that the keff decreases with thickness increase until ~6 mm and it increases as thickness increases over ~7 mm.

INTRODUCTION

The used nuclear fuel (UNF) storage could become one of the most important issues for the future of nuclear energy. The storage capacities of UNF pool in nuclear power plants (NPP) are getting full so it should be moved or stored in other facilities. Therefore, there are growing needs for better UNF shipping and storage cask and, in this regard, a study is underway to develop a material which can offer better neutron absorbing capability and act both structural material and neutron absorbing material at the same time.

Boron has been widely used as the neutron absorber in the cask. However, boron produces helium bubbles as it absorbs neutron and this could cause problems especially after long time use when it is combined with materials degradation.[1] The neutron absorption cross section of gadolinium is about 80 times higher than B in thermal energy region [2] and also, gadolinium isotopes remain as gadolinium after it absorbs neutron and thus does not cause materials problem even up to high neutron fluence.

Currently most casks have stainless steel (SS) plate fuel basket structure, on which boron compounds are encapsulated and welded to the SS plate.[3] If we can add neutron absorbing material into the SS, we can simplify the structure and its manufacturing process. In this regard, the effectiveness of increasing Gd contents in the SS fuel basket, while maintaining the cask structure the same as the case where boron compound is used as the neutron absorber material, is studied.

The stainless steel with neutron absorbing materials is under development and it has better corrosion resistance and higher strength than stainless steel.[4] The possibility to use of Gd stainless steel in spent fuel rack was studied as the function of Gd content, Gd with other neutron absorbers and thickness of basket cell.[5, 6]

The criticality calculation method was firstly verified for reference model calculation, which has 3 wall structure described below.

In this paper, the criticality of the cask is evaluated as a function of the Gd and B contents in the plate and the Gd-containing SS plate thickness while maintaining the basic geometry the same as the reference cask which uses boron compound as neutron absorber.

METHOD

Computer Program

The criticality calculations are performed by CSAS6 module from Keno-VI code in SCALE 6.1 code system which was developed by Oak Ridge National Laboratory at the request of the U.S. Nuclear Regulatory Commission.[7] The ENDF/B-VII 238-Group of a multi-group library was used for the nuclear cross section library.[8] The total cycle is 2000 and the number of neutrons per cycle is 8000. The average standard deviation is about 0.00008-0.00009.

MODEL

Fuel assembly modeling

The Westinghouse 17X17 Optimized Fuel Assembly (OFA) with 4.5 enriched U-235 was used for criticality calculation. The fuel is UO_2 and its density is 95.25%. Cladding, guide thimble and instrumentation tube are made of Zircaloy-4. The number of fuel rods is 264 and the number of guide thimble and instrumentation tube is 25 in total. The dimensions of fuel assembly are summarized in Table I. For conservative calculation, following assumptions are made:

- Fresh fuel with initial enrichment and composition
- No burnable absorber material in the fuel assembly
- Ignore the supplementary structures such as spacer grid, top and bottom nozzle

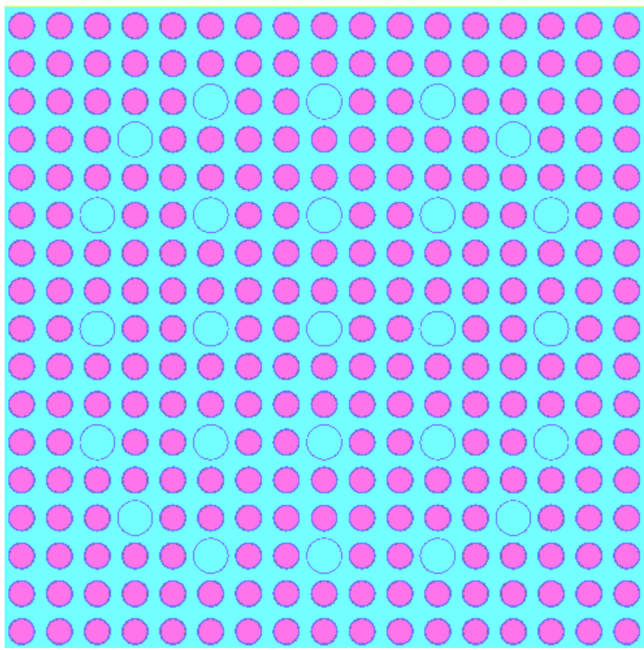

Fig. 1. Fuel assembly model

Table I. Fuel assembly dimension [9]

Component		Dimension [mm]
UO_2 fuel	Diameter	7.84
	Height	3658
	Pitch	12.6
Cladding	Thickness	0.57
	Outer diameter	9.14
Guide thimble / Instrumentation tube	Inner diameter	11.23
	Outer diameter	12.04

Cask Modeling

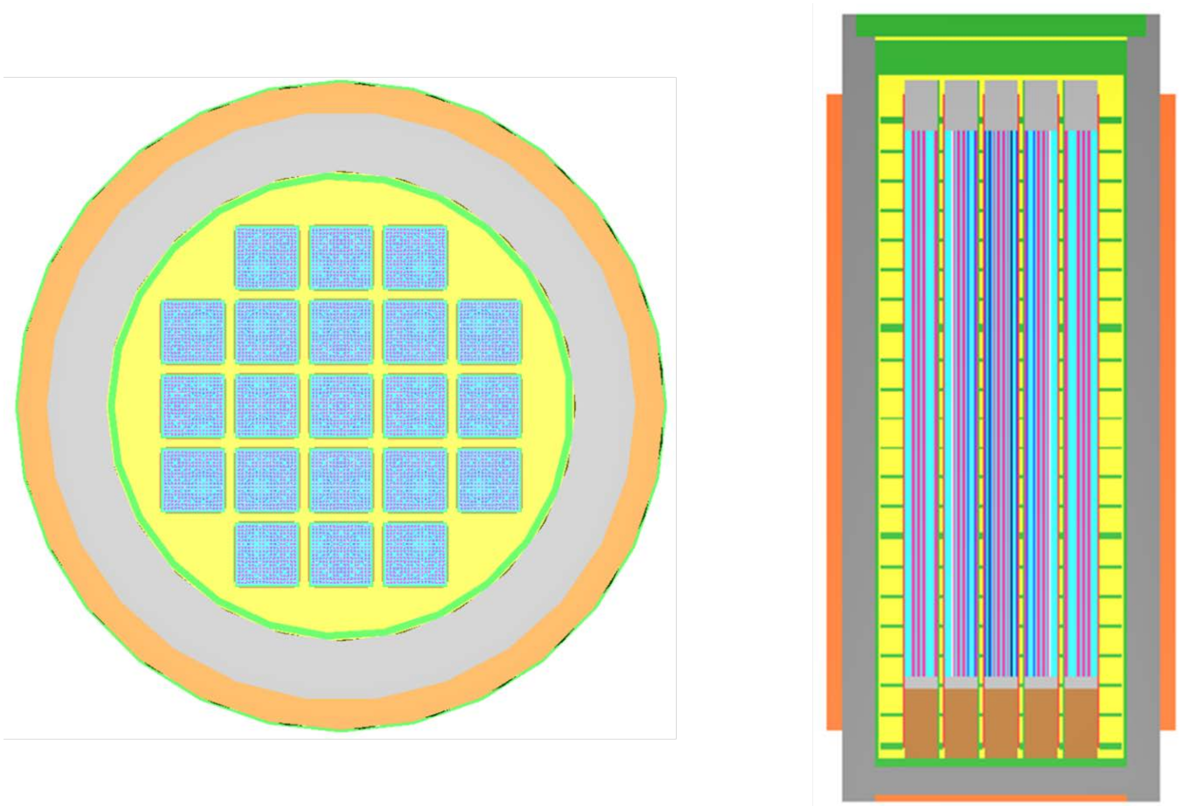

Fig. 2. Cask model

The cask model used in the calculation is metal shipping and storage cask. It can accommodate 21 fuel assemblies at maximum as shown in Fig. 2. The cask body is carbon steel and it is surrounded by resin neutron shield. In the canister, there is a basket assembly which is composed of basket cells, support disks and disk support rods. 22 support disks are located in axial direction. Flux traps are installed between nearby fuel assemblies which enhances the thermalization of fast neutrons.

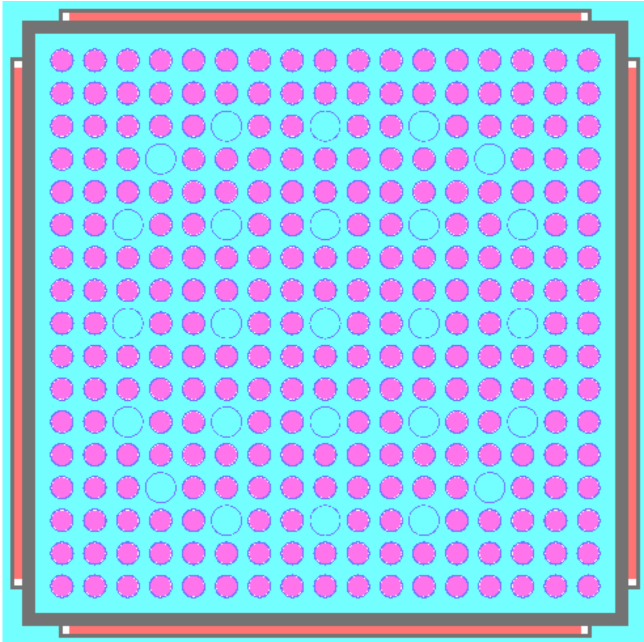

Fig. 3. Reference model

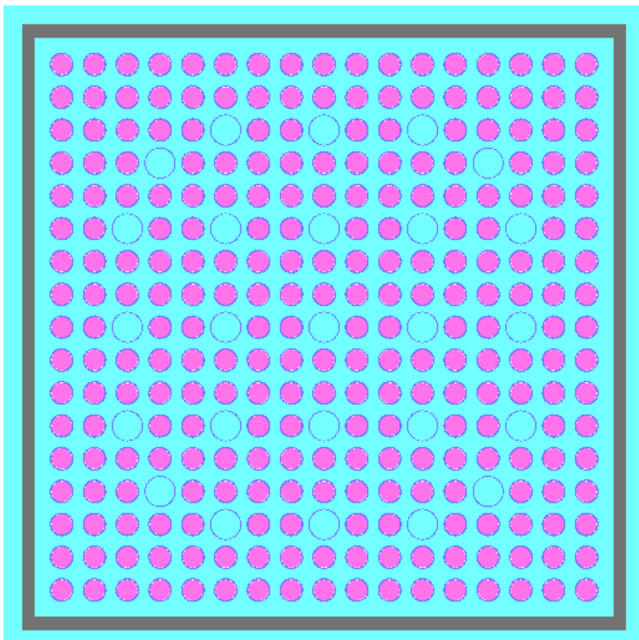

Fig. 4. Integral model

Both reference model and the integral model has same cask dimensions and materials of the cask except the basket design. The reference model used the boron carbide composite material for neutron absorber and it is described in Fig. 3. The basket wall has 3 layers; the wall, neutron absorber and sheathing. The wall and sheathing were made of stainless steel and their thickness is 5 mm and 1.5 mm, respectively. The neutron absorber is the metal matrix composite (MMC) with boron carbide particles dispersed in aluminum powder (28.5 wt% of B_4C) and its thickness is 3 mm.

The integral model has single layer of wall without separate neutron absorber and sheath as shown in Fig. 4. This wall acts as both structural component and neutron absorber at the same time. The wall is composed of stainless steel with neutron absorbing material and its thickness is 5 mm.

Fuel assemblies are stored at the center of the basket and the rack wall surrounds it in four sides of the fuel assemblies. Inner and outer side of cask is dry air condition for normal operation.

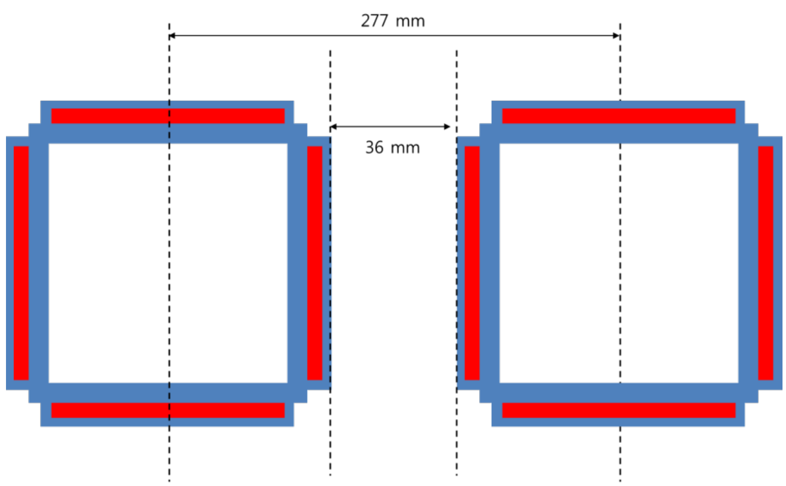

Fig. 5. Dimensions of basket pitch and flux trap for reference model

The dimensions of basket pitch and flux trap is described in Fig. 5. The pitch is 277 mm and the flux trap between neutron absorbers is 36 mm.

RESULTS

The criticality of the cask was evaluated as a function of the Gd and B contents in the plate and the Gd-containing SS plate thickness while maintaining the basic geometry, such as cell pitch, number of UNFs and the basic structure, the same as reference cask which uses boron compound as neutron absorber.

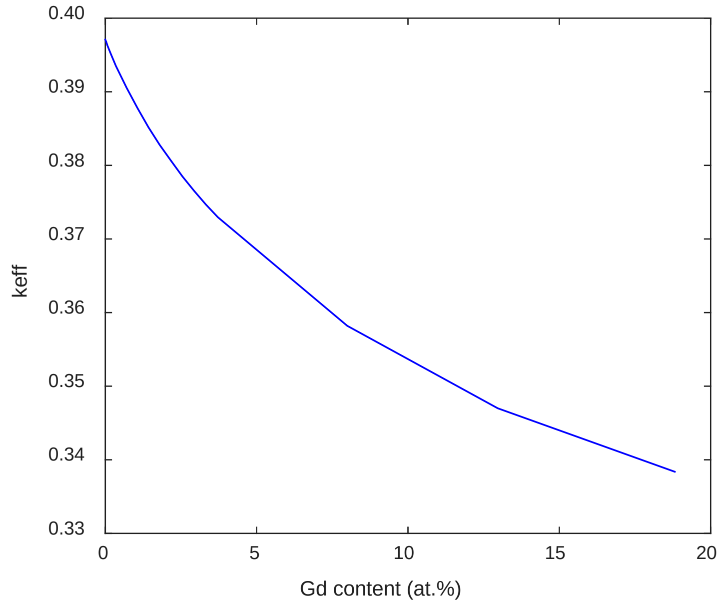

Fig. 6. Change of keff as Gd content increases

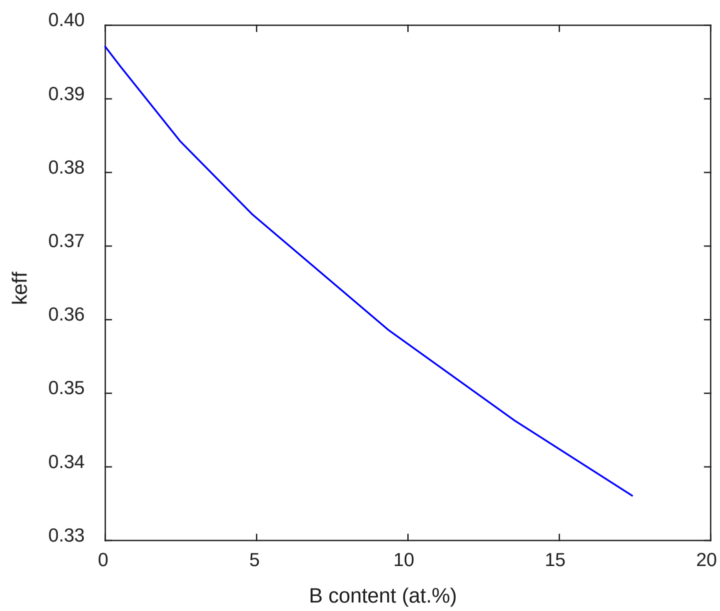

Fig. 7. Change of keff as B content increases

The effectiveness of Gd content is described in Fig. 6. In all the range of interest, the keff values are below 0.4 which is much lower than licensing limit of 0.95. As Gd content increases, the keff exponentially decreases.

Fig. 7 presents the change of keff with B content increase. The keff decreases as B content increases. The B case curve shows less steep slope than Gd case. In lower atomic percent range of neutron absorber in SS, Gd addition shows stronger effect than B addition.

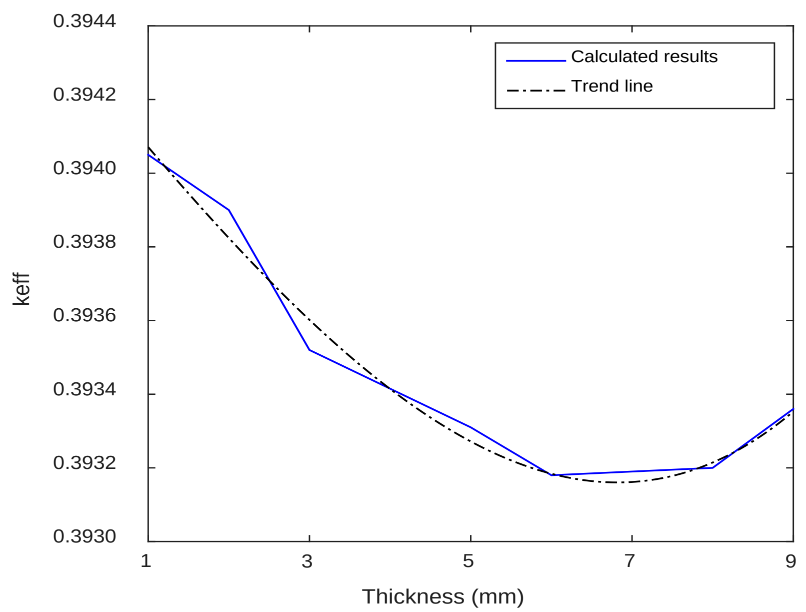

Fig. 8. Effect of wall thickness increase on keff for the 1 wt.% Gd addition case

The effective multiplication factor was calculated for different basket cell thickness with 1 weight percent Gd as shown in Fig. 8. Some scattering of the results within normal standard deviation range was observed. And therefore, the change of keff values with thickness increase could be shown by the trend line. One could notice that the keff decreases with thickness increase until ~6 mm and it increases as thickness increases over ~7 mm.

CONCLUSION

A more effective basket structure, which employs the single wall basket structure and more effective neutron absorbing materials compared to the conventional 3 wall structure with boron neutron absorber, is under development.

The criticality of the cask was evaluated as a function of the Gd and B contents in the plate and the Gd-containing SS plate thickness while maintaining the basic geometry the same as the reference cask which uses boron compound as neutron absorber.

All the calculated keff values for dry air condition were in the range of 0.39 and well below the regulatory limit of 0.95.

The Gd added integral model showed exponential decreases of keff values as Gd content increases. The B case curve shows less steep slope than Gd case. In lower atomic percent range of neutron absorber in SS, Gd addition shows stronger effect than B addition.

The results of the wall thickness effect calculation indicated that the keff decreases with thickness increase until ~6 mm and it increases as thickness increases over ~7 mm.

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