MANAGEMENT OF THE STORAGE AND TRANSPORTATION OF PWR SPENT FUEL CASK IN NORMAL AND ACCIDENT CONDITION

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Abstract

MCNPX computer code is used to model the general cask GBC-32 which contain 32 typical PWR spent fuel assemblies. For Safe storage and transportation of the cask, factors that affect the criticality were studied using the concept of burn up credit. Several parameters such as initial fuel enrichment, fuel burnup, cooling time, and axial burnup profile were analysed. The analysis was performed in two different steps, first burn the fuel assembly at different burnup and storage conditions, secondly, incorporate the details of the assemblies into the cask and perform a criticality calculations for the cask. Several cases of unnormal storage conditions are considered. The results are compared with similar GBC-32 benchmark.

1. INTRODUCTION

Criticality Safety is one of the most important task in the safety demonstration of the storage and transportation of the spent fuel package. The spent fuel package should remain subcritical during storage and transportation under normal and accident conditions. There are many factors affecting criticality of the package such as cask design, fuel type, and burn up of the spent fuel. Burn up credit describes the reduction in reactivity of the fuel due to the production of radioactive isotopes during fuel burn up. Burn up credit plays an important role in nuclear fuel cycle criticality safety studies. The decrease of the irradiated fuel reactivity is taken into account in order to optimize safety margins and to avoid oversizing of nuclear facilities [1–3].

In this research, MCNPX code package, based on Monte Carlo method, is used to model a PWR spent fuel transportation cask. The Cask contains 32 spent PWR Fuel assemblies [4, 5]. The concept of burnup credit is applied and the axial burnup of the assemblies, actinides and fission product are calculated and incorporated in MCNPX model. The multiplication factor for the cask is determined in normal conditions. Factors that affect multiplication factors such as Fuel enrichment, fuel burn up, cooling time are studied under the concept of burnup credit. Accident conditions in which fuel assembly is placed in an incorrect positions or low burnup assembly are considered [6–8].

In the following section 2 describes the computational MCNPX model, section 3 contains the results and discussions, section 4 conclusion, and the references are given at the end of the paper.

2. COMPUTATIONAL BENCHMARK PROBLEM

The generic cask design, GBC-32 [4,5], accommodate 32 typical spent PWR fuel assemblies. Dimensions for the GBC-32 cask and fuel assemblies are listed in Table 1. The assembly is equipped with a layer of thickness 0.2565 cm of boron carbide along the active height of the assembly to reduce the criticality during storage. Borated panel is composed of three different layers. The outer layers are aluminum and form a sandwich with the central layer composed of boron carbide [5].

The fuel assembly is typical PWR of size 17 × 17 fuel rod positions. The assembly contains 20 burnable poison rods, 5 water channels and 264 fuel rods as illustrated in Figure 1. The full dimensions and compositions of fuel, clad and burnable poison rods can be found in reference [5]. MCNPX computer code are used to model the burnup of the assembly in a typical operating condition of PWR reactor, the power assigned to the assembly is 17.1 MW. The Discharge burnup is 60 000 MWd/T with decay cooling times extended up to 100 years after discharge from the reactor.

The axial fuel rod height is divided into 20 zones to take into consideration the axial fuel burn up in each zone. The concentration of actinides and fission product are calculated at every time step. Fig. 1 shows a typical MCNPX model of the a PWR assembly. In the assembly model The tallies are calculated with 600 000 neutron histories which are divided into 60 cycle with 10 000 neutron each and 10 cycles are skipped. The burnup step are adjusted to be calculated every 10 000 Mwd/T. The depletion calculations were performed using reasonably conservative cycle average operational parameters for fuel temperature (900 K), clad temperature (600 K), moderator temperature (570 K), soluble boron concentration (0 ppm) and specific power (36.22 MW/MTU).

Fig. 2 shows MCNPX model for GBC-32 canister (cask). The canister (or cask) contains 32 similar fuel assemblies. Table 1 contains the date for the canister dimensions. In the model of the cask (canister) the axial concentrations of burned fuel in the assembly model which contains actinides and fission product are incorporated in the material composition of the cask model.

In determining which additional nuclides to include for the estimation of the additional reactivity margin, MCNPX computer codes calculates in this model a total of 100 isotopes (15 actinides and 85 fission product) .

TABLE 1. DIMENSIONS OF GBC-32 CASK [5]

Parameter	Dimension (cm)
Cask inside diameter	175.0
Cask outside diameter	215.0
Cell inside dimension	22
Cell outside dimension	23.5
Cell wall thickness	0.75
Boral panel thickness	0.2565
Boral central thickness	0.2057
Boral aluminum plate thickness	0.0254
Cell pitch	23.7565
Boral panel width	19.05
Cell height	365.76
Top assembly hardware thickness	30.0
Bottom assembly hardware thickness	15.0
Cask radial thickness	20.0
Base plate thickness	30.0
Cask lid thickness	30.0
Active fuel height and boral panel height	365.76
Cask inside height	410.76

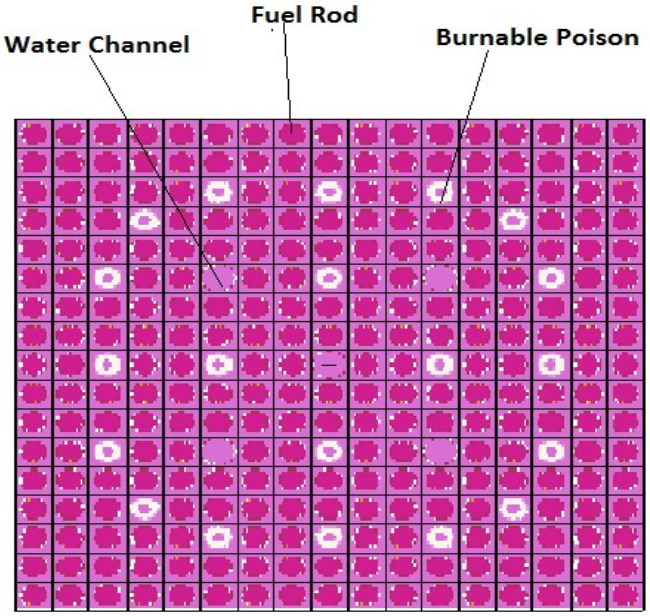

FIG. 1. Cross Section of MCNPX model for fuel Assembly

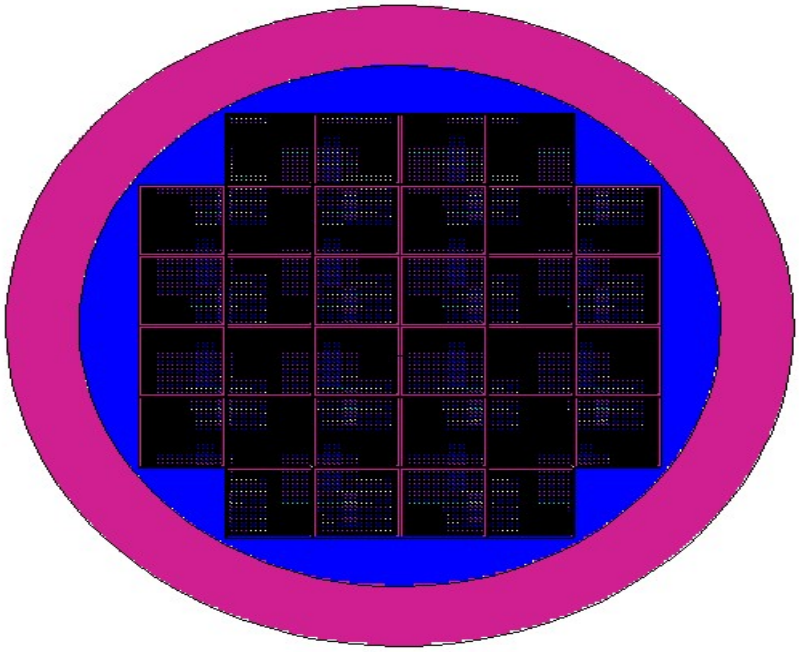

FIG. 2. MCNPX cross sectional view of GBC-32 cask model

3. RESULTS AND DISCUSSIONS

The computational methods necessary for this benchmark analysis include two steps, the first step depletion of the assembly under different conditions such as fuel enrichment, cooling time and fuel burn up. The second step is to incorporate the full conditions of the assembly in cask GBC-32 and perform criticality calculations. It is assumed that all assemblies in the cask are stored under the same conditions.

Fig. 3 shows the axial fuel burnup (GWd/T) versus axial fuel distance for different fuel enrichments 2, 3, 4, and 5%. The axial burn up illustrates cosine shape and peak at the fuel center, the minimum burnup at fuel bottom is 36 GWd/T while the maximum value approach 84 GWd/T with ratio 2.33.

Fig. 4 shows the concentration of U-235 and Np-237 (atom/barn·cm) versus axial fuel distance (cm) for fuel of initial enrichment 4% at burnup 60 GWd/T and 5 years cooling. The results indicate that U-235 are consumed higher in the middle zones. While Np-237 remains constant along the axial distance.

Fig. 5 shows Pu- isotopes concentration (atom/barn·cm) versus axial fuel distance (cm) for fuel of initial enrichment 4 % at burnup 60 GWd/T and 5 years cooling. The concentration of Pu-239 after 60 GWd/T is 2.0 E-4 (atom/barn·cm) and higher than other isotopes.

Fig. 6 shows the concentration of four fission products - Mo-95, Nd-145, Nd-143 and Tc-99 (atom/barn·cm) versus axial distance for assembly of initial enrichment 4 % at burnup 60 GWd/T and 5 years cooling. The results of both Nd-143 and Tc-99 coincide with each other.

Fig. 7 shows the concentration of 3 fission products Sm-149, Gd-155 and Ag-109 ((atom/barn.cm) versus axial distance for assembly of initial enrichment 4 % and 60 GWd/T and 5 years cooling. The results of both Sm-149 and Gd-155 coincide with each other.

Based on the nuclide sets identified in the previous section, calculated k_{eff} values are provided as a function of initial enrichment,fuel bumup, and cooling time, within the ranges relevant to storage and transportation. Table 2 shows K_{eff} for GBC-32 cask if the cask is filled with similar 32 assemblies. The results indicate that K_{eff} is higher than 1.0 for fresh storage except for enrichment 2% which equal 0.93568. The results of the present MCNPX model are compared with reference [5]. The maximum difference occurs at enrichment 5% equal $\Delta K\%$= 0.0128837, this difference due to MCNPX model consider a total of 100 actinides and fission products while the results of reference [5] based on SCALE code consider 27 isotopes only. Also SCALE code uses different neutron cross section library with 44 neutron group while MCNPX used contanious cross section library.

Table 3 shows K_{eff} for cask GBC-32 loaded with assemblies with different burn up fresh, 5000, 30 000, 40 000 MWd/T for fuel with initial enrichment 5% without cooling (0.0 cooling time). The results indicate that ($K_{eff} < 1$) the cask is subcritical only for storage of 40 000 MWd/T.

Table 4 shows K_{eff} for a cask of different initial enrichment 2, 3, 4, and 5% with all having discharge burnup 60 000 Mwd/T and cooling time 5 years, the results indicate that the cask is subcritical in all conditions. The difference between the present results and reference [5] is due to the number of actinides and fission products considered in the two methods.

Table 5 shows cask multiplication factor (K_{eff}) loaded with 32 fuel assemblies with initial enrichment 5%, discharge burnup 60000 MWd/T and different cooling times 0.0, 5, 20,30, 50, 100 years. The results indicate that K_{eff} for the cask decrease as cooling time increase.

Unnormal conditions: Three cases of unnormal storage are considered :

- Loss of water cooling inside the cask;
- The cask is immersed totally in water;
- 4 fresh casks are misloaded into the cask which is filled with high burned fuel.

Table 6 shows K_{eff} for cask GBC-32 loaded with fuel with initial enrichment 5 % and burnup 40 000 MDd/T and in the second case water cooling is lost from the cask. The results show that K_{eff} decrease from 0.96186 to 0.38497 in the case of loss of water cooling inside the cask.

Table 7 shows K_{eff} for cask GBC-32 loaded with fuel with initial enrichment 5% and burnup 40 000 MWd/T, the second case if the cask is totally immersed in water, the results show that K_{eff} increase slightly from 0.96186 to 0.96215 in the case of cask drops in water.

Table 8 shows K_{eff} for cask GBC-32 loaded with fuel initial enrichment 5% and burnup 40 000 MWd/T in the case of misloading with 4 fresh fuel assemblies. the results show that K_{eff} increase from 0.96186 to 0.99432 in the case of 4 casks with fresh fuel are misloaded.

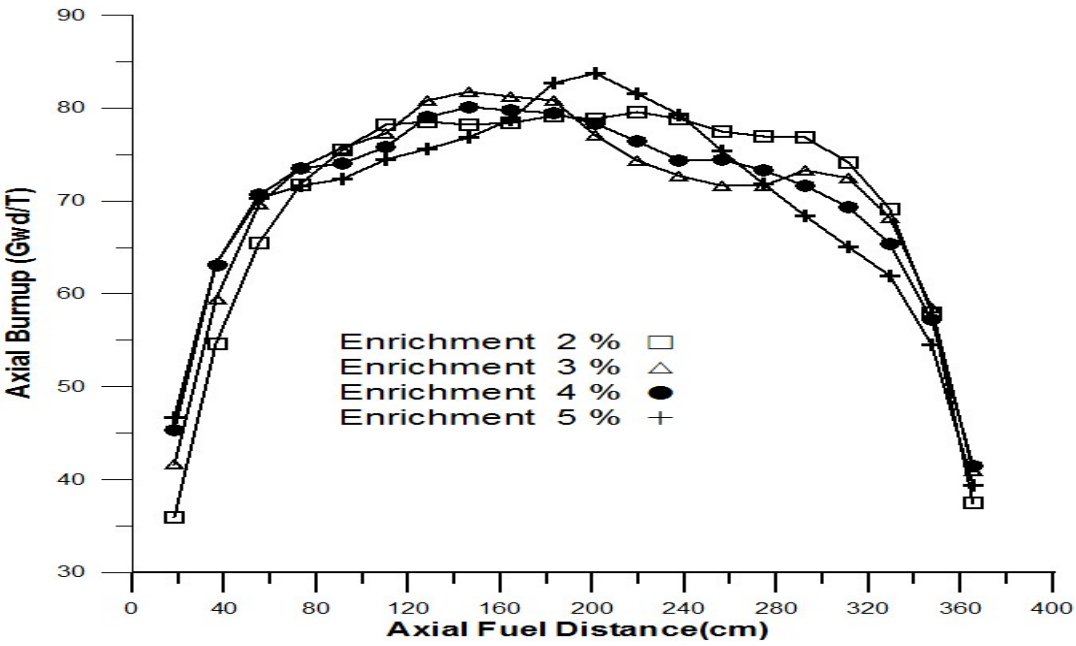

FIG. 3. Axial Burnup (Gwd/T) versus axial fuel distance (cm)

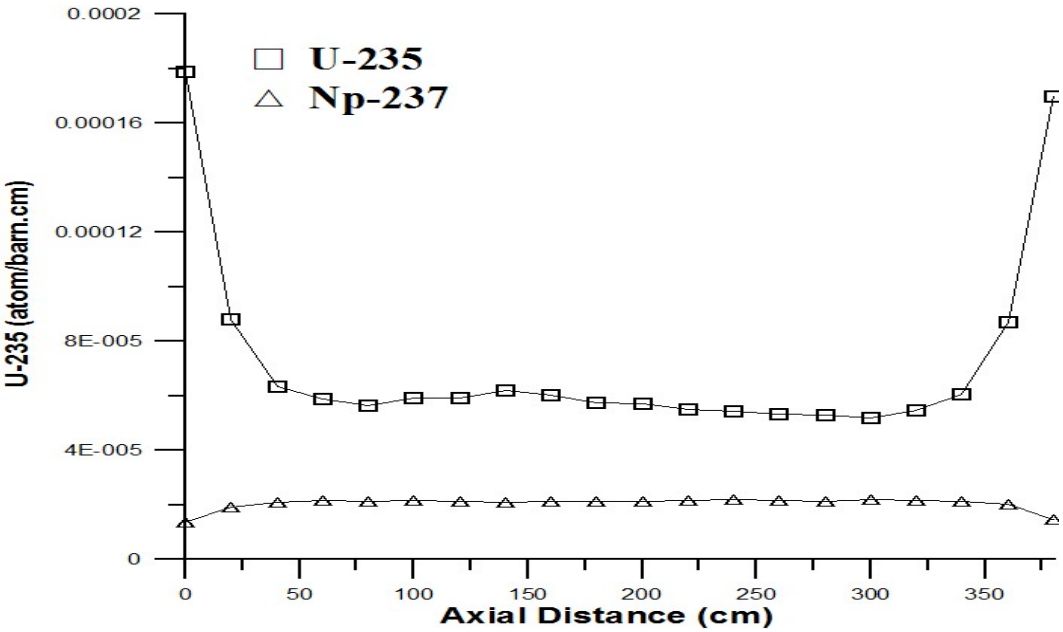

FIG. 4. U-235 and Np-237 versus Axial core distance (cm) for 4% Enrichment at discharge burnup 60 GWd/T and 5 year cooling.

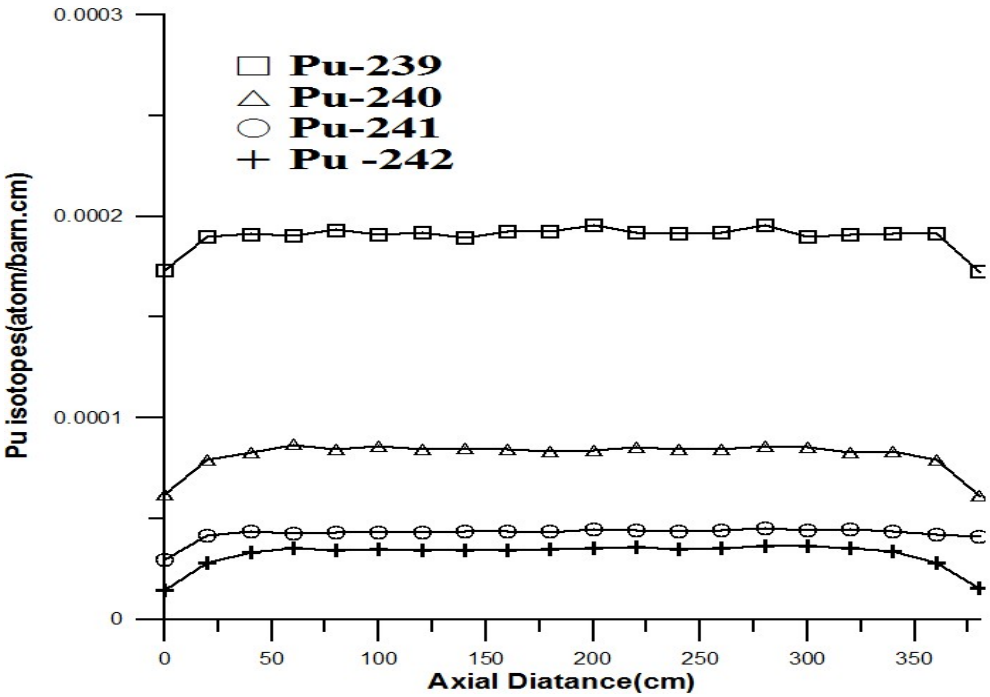

FIG. 5. Pu isotopes versus Axial core distance (cm) for 4% Enrichment at discharge burnup 60 GWd/T and 5 year cooling.

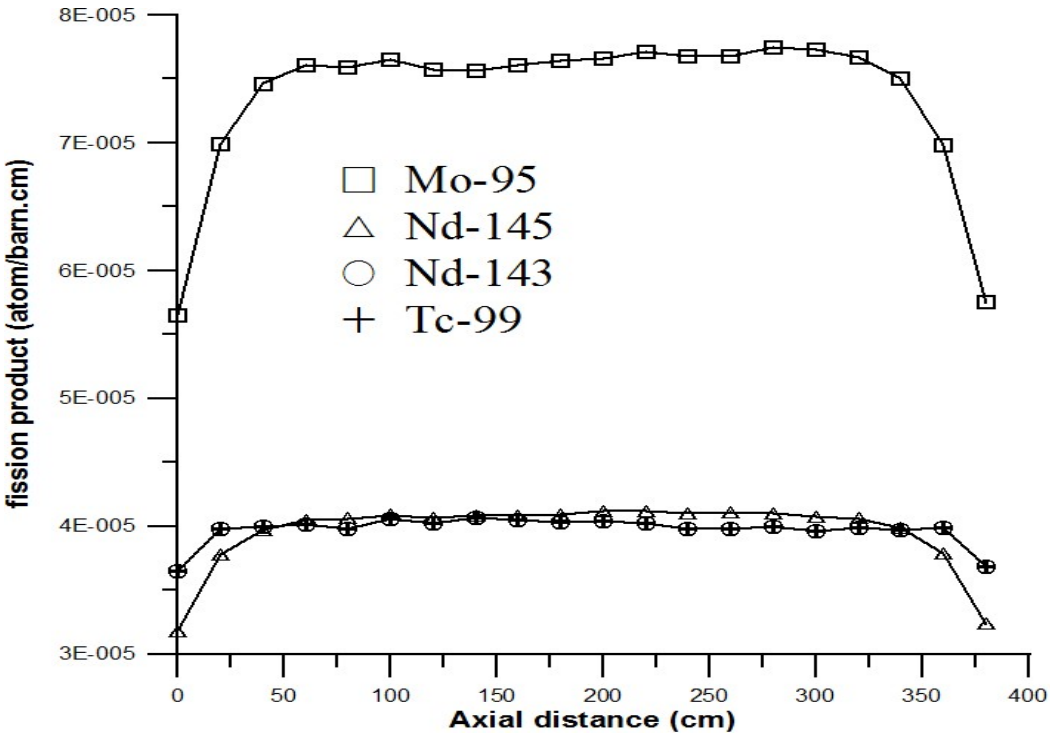

FIG. 6. Fission product versus Axial core distance (cm) for 4% Enrichment at discharge burnup 60 GWd/T and 5 year cooling.

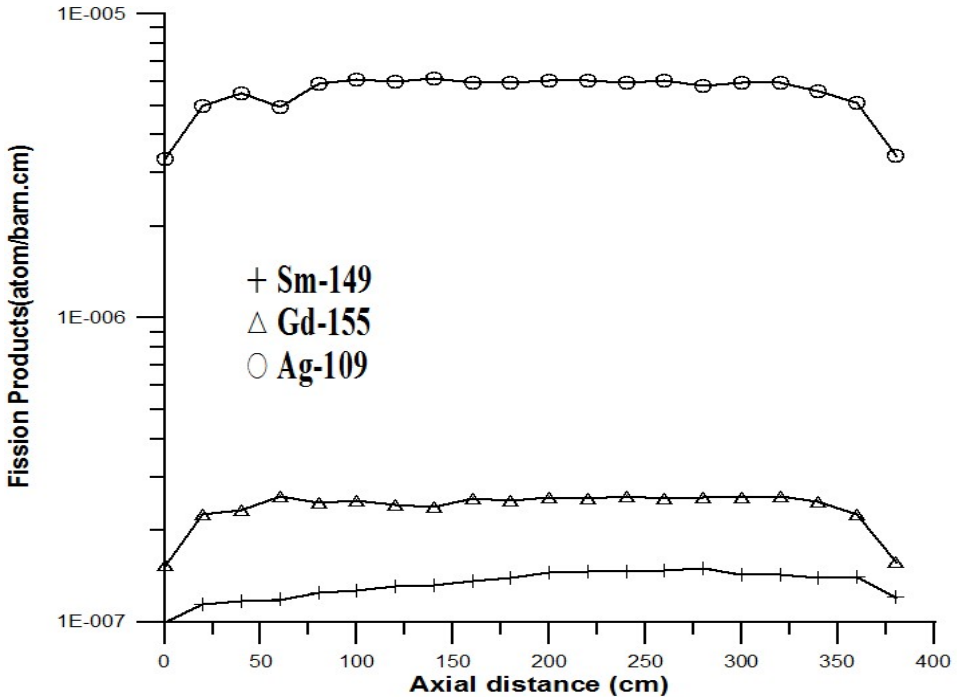

FIG. 7. Fission product versus Axial core distance (cm) for 4 % Enrichment at discharge burnup 60 GWd/T and 5 year cooling.

TABLE 2. K_{EFF} FOR FRESH STORAGE FOR CASK GBC-32 WITH DIFFERENT FUEL ENRICHMENT

Enrichment	2 %	3 %	4 %	5%
MCNPX model	0.93568±0.00084	1.05226±0.00088	1.12678±0.00086	1.17607±0.00098
Reference [5]	0.94797±0.00078	1.06633±0.00059	1.13983±0.00065	1.19142±0.00056

TABLE 3. KEFF FOR CASK GBC-32 WITH DIFFERENT BURNUP AND ZERO COOLING TIME OF INITIAL FUEL 5 % ENRICHMENT

Burnup MWd/T	0.0	5000	30 000	40 000
MCNP Model	1.17607±0.00098	1.13908±0.00097	1.04691±0.00068	0.96186±0.00079
Reference [5]	1.19142±0.00056	----------	----------	----------

TABLE 4. K_{EFF} FOR CASK GBC-32 WITH DIFFERENT FUEL ENRICHMENT AT BURNUP 60 000 MWD/T AND 5 YEARS COOLING

Enrichment	2%	3%	4%	5%
MCNPX model	0.73828±0.00064	0.77057±0.00067	0.81418±0.00067	0.87433±0.00052
Reference [5]	0.64783±0.00047	0.71563±0.0.00051	0.79043±0.00056	0.85549 ±0.00052

TABLE 5. K_{EFF} FOR CASK GBC-32 WITH BURNUP 60 000 MWD/T AND DIFFERENT COOLING TIME

Cooling Time (years)	0.0	5	20	30	50	100
MCNP Model	0.88563 ±0.00059	0.87433 ±0.00052	0.85642 ±0.00062	0.85549 ±0.00048	0.84133 ±0.0005	0.83738 ±0.00042
Reference [5]	0.88140 ±0.00048	0.85549 ±0.00048	0.82850 ±0.0005	------	-------	-------

TABLE 6. K_{EFF} FOR GBC-32 CASK WITH FUEL INITIAL 5% ENRICHMENT AND 40 000 MWD/T,

	Normal	Loss of cooling
MCNP Results	0.96186±0.00079	0.38497±0.00015

TABLE 7. K_{EFF} FOR GBC-32 CASK WITH FUEL INITIAL 5% ENRICHMENT AND 40 000 MWD/T

	Normal	Over moderated
MCNPX results	0.96186±0.00079	0.96215±0.00079

TABLE 8. K_{EFF} FOR GBC-32 CASK WITH FUEL INITIAL 5% ENRICHMENT AND 40 000 MWD/T

	Normal	Misloading 4 fresh assemblies
MCNPX results	0.96186±0.00079	0.99432±0.00121

4. CONCLUSION

- MCNPX computer code is used to model GBC-32 cask which contains 32 similar spent fuel assemblies. The calculations are performed in two steps burning the fuel assembly in a typical operating conditions of PWR reactor and in the second step calculates criticality calculations for the cask;
- Several parameters that affect the safety of the storage such as fuel enrichment, burn up history, cooling time are analyzed;
- The results indicated that the most important factor that affect the safety and criticality of the cask is the burn up of the fuel if 4 fresh assemblies are misloaded into the storage cask that contains spent fuel, K_{eff} approach to unity (criticality).

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