FEASIBILITY STUDY FOR BURNUP CREDIT IN SPENT-FUEL STORAGE FOR NUCLEAR POWER STATION

Xue Xiaogang Liu Zhenhua Shen Leisheng Yang Lijun
China Institute of Atomic Energy
P.O.Box 275<45>, Biejing 102413, P.R.China
Fax. 86-10-69357008 Tel. 86-10-69357520
E-mail: xiaogang@iris.ciae.ac.cn

ABSTRACT

Criticality and heat residual power analyses were performed for three improved schemes of Daya Bay Nuclear Power Station spent fuel storage pool. The effects of actinide and combined actinide and fission product poisons on criticality safety were evaluated respectively. Using burnup credit technique in the design of future storage pool can result in increased pool capacities.

1. INTRODUCTION

The spent-fuel storage becomes an important problem with the development of nuclear power in China. One of the primary considerations in fuel storage facilities design is criticality control. Traditional criticality analyses for storage pool have assumed the package to be loaded with fresh, unirradiated fuel, that is also the requirements of the current national rule. This assumption provides considerable criticality safety margin, in fact, the capacity of the storage pool could be increased by taking credit for fuel burnup, i.e. depletion of fissile material and buildup of fission product and actinide absorbers.

The purpose of our analysis was to evaluate the criticality safety and heat residual by taking burnup credit technique for improved schemes of Daya Bay Nuclear Power Station spent-fuel storage pool. The calculation of depletion and isotopic contents within the fuel assembly analyses was performed with standardized computer code: ORIGEN-2. The criticality analyses was performed with a Monte Carlo n-particle transport code MCFR, that was developed by Monte Carlo method research group at China Institute of Atomic Energy, and its function is similar to the well-known criticality calculation code MCNP. The point Cross section data was taken from ENDF/B-V cross section database.

2. ANALYSIS MODELS

Principles of all the analyses are based on the facts of Daya Bay Nuclear Power Station. So any approximation about storage pool geometric description wasn't made, and all the fuel assemblies with various discharge burnup and different enrichment that could be loaded in the storage pool were considered in criticality calculation. Full core discharge adopted by Daya Bay Nuclear Power Station was also considered in our analyses.

2.1 SPENT-FUEL STORAGE POOL

The capacity of current spent-fuel storage pool is 695 fuel assemblies. Our analyses of spent-fuel storage pool dealt with the three improved schemes (the capacity is 1287, 1455, 1520 fuel assemblies respectively) of Daya Bay Nuclear Power Station spent fuel storage pool. The construction of three new storage pool is similar each other. In order to allow high-density rankings, it is necessary to consider a storage in two regions. Cadmium was adopted as the absorbers wrapped with 304 stainless steel in the basically racks for the fresh fuel, the pitch is 280 mm. The second type of racks is the borated steel as the absorbers for the spent fuel assemblies, the pitch is 232 mm. Faulted fuel assembly storage racks was the same as that adopted cadmium .

2.2 FUEL ASSEMBILIES

Our analyses were based on the actual discharge fuel assemblies of Daya Bay Nuclear Power Station. Unit 1 and unit 2 employed fuel assemblies with different enrichment. During the first 8 cycle for both unit, unit 1 employed the fuel assemblies with 1.8%, 2.4%, 3.1%, 3.2%, 3.7% enrichment, and unit 2 employed the fuel assemblies with 1.8%, 2.4%, 3.1%, 3.2% enrichment. After that, the 4.45% fuel assembly is the only choice because the 18 month fuel management will be adopted. The discharge burnup of the 4.45% fuel assembly is about 45000MWD/TU expectedly. The fuel assembly was made in 17517 rods array.

Table I. The quantity and discharge burnup of fuel assemblies with different enrichment

Unit 1	1.8%	2.4%	3.1%	3.2%	3.7%
No.	53	52	60	256	100
Burnup	23064	23587	29802	29892	42000
Unit 2	1.8%	2.4%	3.1%	3.2%	
No.	53	52	56	264	
Burnup	23064	23587	29802	29892	

Burnup: MWD/TU

2.3 BASIC ASSUMPTION

In our analysis, We taken the following assumptions:

- The last fuel assembly being unloaded 7 days after reactor shutdown.
- Pure water in the spent fuel pit (more than 20000 pcm negative reactivity due to the borated water is not considered).
- Criticality safety criteria to be respected : $k_{eff}<0.95$
- After the 8th cycle for both Unit 1 and Unit 2, every 1.5 year discharge of 52 fuel assemblies with 45000MWD/TU discharge burnup.
- 72 new fuel assemblies with 4.45% enrichment being loaded
- Except the position occupied by spent-fuel assemblies from the first 8 cycle, others were fully filled by spent-fuel assemblies with 4.45% enrichment.

3. ANALYSES OF SPENT-FUEL COMPOSITION AND HEAT RESIDUAL POWER

After the termination of each burnup history, ORIGEN-2 was used to calculate the inventories of radioactive actinides, fission products and decay heat power within a total of 25 year.

Although nearly 1700 nuclides were included in the output result, only the most important 12 nongaseous fission products and 13 actinides were considered in our criticality analysis according to the reference [1] and our calculation results. The 12 fission products were ^{99}Tc, ^{103}Rh, ^{131}Xe, ^{133}Cs, ^{143}Nd, ^{145}Nd, ^{147}Sm, ^{149}Sm, ^{150}Sm, ^{152}Sm, ^{153}Eu, ^{155}Gd. The 13 actinides were ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{243}Am, ^{244}Cm.

These fission products provide about 70% contributions to the total fractional neutron absorption rates of all the fission products, and this rates were increasing with the extend of the cooling time. The above was a popular conclusion for fuel assemblies with difference enrichment and different discharge burnup. Here we only given the calculation result for the fuel assembly with 4.45% enrichment and 45000 MWD/TU discharge burnup as an example (see Table II).

Based on the calculation results of heat residual power, the actual quantities and the time loaded in the storage pool for every type assembly, we obtained the maximum heat residual power of the pool. Considering full core discharge condition:

Heat residual power =8.8 MW

No considering full core discharge condition:

Heat residual power =3.5 MW

4. CRITICALITY ANALYSIS OF SPENT-FUEL STORAGE POOL

Three improved schemes of unit 1 and unit 2 were analyzed for both fresh fuel and irradiated fuel. The effect of actinides only and the combined effect of actinides and fission products were considered separately.

In our analysis, the following principle for assembly configuration was abided by. New fuel assemblies with 4.45% enrichment were arranged in the original rack region of the pool. Different types of spent-fuel assemblies were arranged in the new rack region from the periphery to the core as the fissionable nuclides concentration within spent-fuel assemblies, while assemblies with a same enrichment were arranged in the same rack as far as possible. So that spent-fuel management and actual operation of nuclear power station are easier, while the k_{eff} value of the pool is lower. The results were summarized in Table III.

In addition, we analyzed the k_{eff} sensitivity at various burnup of 4.45% enrichment assemblies, because of uncertainty of discharge burnup in the future. The results are given in Figure 1.

CONCLUSIONS

The analysis results for Daya Bay Nuclear Power Station three improved schemes of spent-fuel storage pool demonstrated that use of burnup credit in the criticality analysis and design of spent fuel storage pool could result in considerable benefits. The k_{eff} of the storage pool could be decreased about 20% if we only consider the effect of main actinide, and decreased about 30% if we consider the combinative effect of actinide and the major fission product poisons. The capacity of the Daya Bay Nuclear Power Station spent fuel storage pool could be increased about one times, such as the using time of storage pool for loading spent-fuel assemblies could be extended to 25 years. However it is worth to pay more attention on the discharge burnup of 4.45% enrichment assemblies. From Figure 1, the k_{eff} will be great than the criticality criteria 0.95 if the discharge burnup is less than about 32000MWD/TU.

REFERENCES

1. Thomas L. Sanders, R. Michael Westfall, "Feasibility and Incentives for Burnup Credit in Spent-Fuel Transport Casks" ,Nuclear Science and Engineering, Vol. 104 (1990).

2. Xue Xiaogang, Shen Leisheng, Ruan Keqiang, "Study on Reactivity Charge Due to Burnup Effect in Spent Fuel Storage for Nuclear Power Plant", Chinese Journal of Nuclear Science and Engineering, Vol. 16, No. 4 (1996).

3. Methods for Expanding the Capacity of the Swedish a Way from Reactor Storage Facility. CLAB, IAEA-TECDOC-559, 1990

Table II. The fraction of neutron absorption due to fission products at various cooling times for one ton uranium with 4.45% enrichment and 45000MWD/TU discharge burnup

Unit: %

Nuclides	Time at shutdown	5 day	0.5 year	1 year	2 year	3 year	5 year	8 year	12 year	16 year	20 year
Tc-99	4.915	5.653	5.644	5.631	5.602	5.571	5.509	5.427	5.351	5.303	5.276
Rh-103	9.676	11.19	12.19	12.21	12.15	12.08	11.94	11.77	11.60	11.50	11.44
Xe-131	6.06	6.989	7.049	7.032	6.996	6.958	6.880	6.778	6.682	6.624	6.589
Cs-133	6.747	7.767	7.783	7.765	7.725	7.682	7.596	7.484	7.378	7.314	7.275
Nd-143	9.06	10.44	10.62	10.59	10.54	10.48	10.36	10.21	10.07	9.978	9.926
Nd-145	2.842	3.260	3.251	3.243	3.226	3.208	3.173	3.126	3.082	3.055	3.039
Sm-147	0.0638	0.0737	0.0918	1.081	1.346	1.544	1.804	1.991	2.077	2.098	2.101
Sm-149	4.154	7.265	7.903	7.884	7.844	7.800	7.713	7.599	7.492	7.462	7.387
Sm-150	1.832	2.100	2.095	2.090	2.079	2.068	2.044	2.014	1.986	1.968	1.958
Sm-152	3.997	4.582	4.569	4.559	4.535	4.510	4.460	4.394	4.332	4.294	4.272
Eu-153	3.235	3.737	3.733	3.724	3.705	3.685	3.644	3.590	3.539	3.508	3.490
Ed-155	9.187E-2	0.14	1.326	2.459	4.483	6.220	8.981	11.81	14.05	15.28	15.98
Total	52.68	63.20	66.25	68.25	70.27	71.81	74.10	76.20	77.64	78.38	78.74

Table III. k_{eff} of criticality calculation for three improved schemes

Unit	Fuel condition	Scheme 1	Scheme 2	Scheme 3
	fresh fuel	1.2095±0.0011	102091±0.0010	1.2094±0.0012
1	actinide only	0.9285±0.0014	0.9315±0.0013	0.9274±0.0014
	actinide+fission product	0.8694±0.0016	0.8680±0.0015	0.8731±0.0017
2	actinide only	0.9268±0.0014	0.9327±0.0013	0.9320±0.0016
	actinide+fission product	0.8715±0.0016	0.8680±0.0015	0.8702±0.0018

Results were based on 3000 neutrons/generation, 100 generations. 10 generations were skipped.

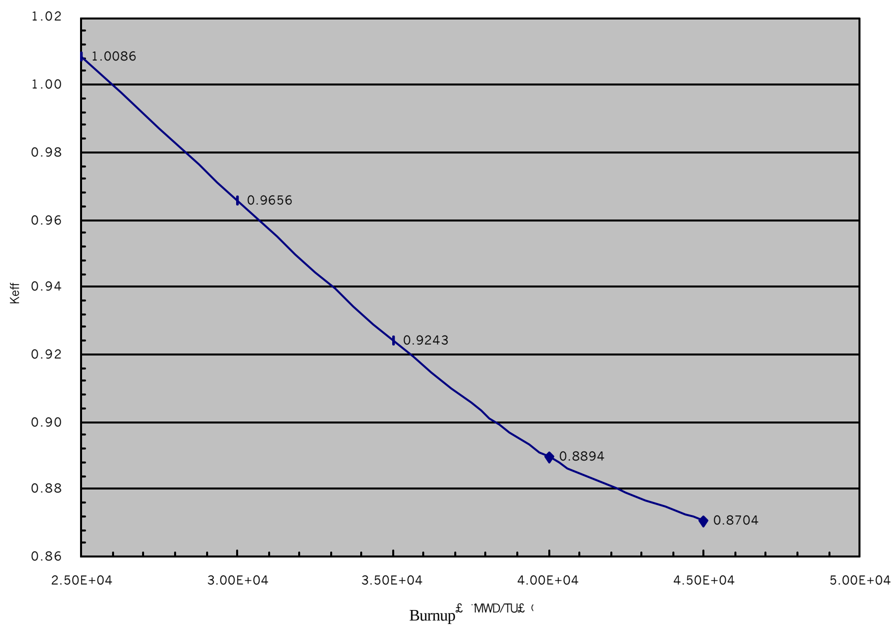

Figure 1. The k_{eff} at various discharge burnup of assemblies with 4.45%enrichment