Journal of the Korean Nuclear Society
Volume 20, Number 3, September, 1988

Estimation of Discharged Amounts of U and Pu Nuclides from the PWR Spent Fuels in Korea

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(Received March 18, 1988)

국내 가압 경수형 원자로의 사용후 핵연료에서 잔류하는 U과 Pu핵종의 발생량 추정

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(1988. 3. 18 접수)

Abstract

As a part of tandem fuel cycle feasibility study, the residual U and Pu nuclide contents of PWR spent fuels are computed using ORIGEN2 code for each Korea Nuclear Unit and batch to investigate the potential of utilizing them as CANDU fuels. The annual and accumulated discharged amounts of U and Pu nuclides are computed for the PWRs from KNU 1 through KNU 10.

The results of computation show that the spent fuels having 0.7-0.8 w/o U-235 are dominant and considerable amounts of fissile Pu are produced. The enrichment of U-235 is less than the expected 0.8-0.9 w/o U-235 since the burnups offered by KEPCO are higher than those of other PWRs.

요　　약

Tandem 핵연료 주기에 관한 연구의 일부로써 CANDU 원자로에 활용할 수 있는 우라늄과 플루토늄의 양을 추정하기 위해 국내 가압경수형 원자력 발전로에서 발생되는 사용후 핵연료속의 이들 핵종의 잔존량을 ORIGEN2 코드를 사용하여 각 호기별 각 batch별로 계산하여 연도별 발생량과 누적량을 구하였다. 1호기부터 10호기까지의 가압경수형 원자력 발전소를 대상으로 하였다.

계산 결과 0.7 내지 0.8 w/o의 U-235가 주종을 이루며 또한 핵분열성 플루토늄도 상당량 배출되고 있다. 이것은 처음에 예상했던 0.8 내지 0.9 w/o보다 적은 값인데 이는 한전에서 제공한 연소도가 일반적인 경우보다 다소 높은 값을 나타내기 때문이다.

Table 1. Nuclear Design Data of Each KNU.

	1		2	5 & 6		7 & 8	9 & 10
Rod array	14*14		16*16	17*17		17*17	17*17
No. of ass./core	121		121	157		157	157
Ass. design parameters	STD	OFA	STD	STD	OFA	OFA	STD
Total weight *1	577.88	514.82	594.20	665.42	615.98	615.98	664.52
Uranium weight	400.27	356.80	410.64	461.49	423.02	423.02	461.47
Zr-4 weight *2	91.04	99.70	98.57 4.98	110.48	116.71	116.71	110.45
Inconel 718 weight *3	3.287	1.763	4.98	4.328	0.578	0.578	5.146
SS-304 weight *4	3.276	1.71	0.615	2.95	0.19	0.19	4.23

*1: weight-Kg
*2: Includes Zircaloy control rod guide thimble.
*3: Includes top and bottom grid.
*4: Distributed throughout the PWR core in sleeves and so forth. But not includes top, bottom nozzles and plenum spring.

1. Introduction

Korea has been very prodigal with its uranium by employing the once-through uranium fuel cycle. As the nuclear power generation becomes the major source of energy supply, Korea starts looking into the optional utilization of uranium resources. Korea imports all of its uranium required. Furthermore, the present capacity of on-site spent fuel storage will be exhausted by the end of 1980's for the case of KNU 1 and after the middle of 1990's for the other units in Korea.[1] Hence, the optimization of nuclear fuel cycle should be closely scrutinized for efficient utilization of uranium as well as energy self-reliance.

PWR spent fuels contain 0.8-0.9 w/o U-235 and 0.6 w/o fissile Pu which may be efficiently used. The fissile content of PWR spent fuel is higher than that of the CANDU fresh fuel. Since Korea has both PWRs and CANDU reactor, the tandem fuel cycle becomes very attractive, in which PWR discharge fuels are utilized in tandem with CANDU charge fuels.[2] For the study of the tandem fuel cycle feasibility, it is necessary to calculate the amounts of uranium and plutonium nuclides in PWR spent fuels.

2. Caculational Method

In this study, as a part of tandem fuel cycle feasibility study, the contents of uranium and plutonium nuclides in PWR discharged fuels are computed batch by batch for each Korea Nuclear Unit using ORIGEN2 computer code[3,4,5] to investigate the potential of utilizing them as CANDU charge fuels. ORIGEN2 is a versatile point depletion and decay computer code for use in simulating nuclear fuel cycle and calculating the nuclide compositions of materials contained therein. The general function of ORIGEN2 is to determine the buildup and depletion of nuclides in materials during irradiation and decay. The nuclides contained in the ORIGEN2 data bases have been divided into three segments: 130 actinides, 850 fission products, and 720 activation products (a total of 1700 nuclides). Therefore, ORIGEN2 code is suitable for the study to calculate the PWR spent fuel composition. Korea will have nine operable nuclear power plants by 1989. Among them, KNU 3 is a CANDU reactor and the rests are PWRs. In this study, we considered only the PWR spent fuels

Table 2. The Assumptions and Parameters Used for Computation.

Item	Unit	Data
Fuel Assembly	KNU 1	Cycle 1-Cycle 7:SEA
		Cycle 8-EOL :OFA
	KNU 2	All Cycles: SFA
	KNU 5 & 6	Cycle 1:SFA
		Cycle 2-EOL :OFA
	KNU 7 & 8	All Cycle:OFA
	KNU 9 & 10	All Cycle:SFA

produced by KNU 1 through KNU 10. KNU 11 & 12 which are on order at present are excluded. The composition of spent fuels discharged from a reactor depends upon fuel design parameters such as burnup, burnup day, and enrichment. The fuel loading patterns in each Unit are provided by Korea Electric Power Corporation and other nuclear design data are obtained from Nuclear Design Reports and given in Table 1.[6] We assumed that the life time of nuclear power plants is 30 year and the capacity factor is 80 percent. All together, the assumptions and parameters used for this study are summarized in Table 2. Based upon the above assumptions, the annual and accumulated discharged amounts of uranium and plutonium nuclides are computed for the PWRs from KNU 1 through KNU 10.

3. Results and discussions

The results of this study are summarized in Table 3 through 5 as follows:

Table 3 The Annual and the Accumulated discharged Amounts of Uranium and Plutonium Nuclides in PWRs Spent Fuels in Korea,

Table 4 The Annual and the Accumulated Discharged Amounts of Uranium with Respect to U-235 Content,

Table 5 Discharge Burnups and Uranium Contents in Resh and Spent Fuels for KNUs in Equilibrium Cyle.

Based upon the above results of study, the following summary can be drawnup:

1. As shown in Table 3, radioactive decays of uranium nuclides are neglected due to their long half-lives. However, the radioactive decay of Pu-241, whose half-life is 13.2 years, is taken into account. The amount of Pu-238 slightly increases for a few years after discharge due to decay of 163-day Cm-242 and (n, γ) production of Np-237 which is decayed from U-237, but eventually decreases with a half-life of 86 years. Pu-239 can be also produced by decay of

Table 3. The Annual and the Accumulated Discharged Amounts of U and PU and PWRs Spent Fuels in KOREA

Year	Annual Production					Accumulated Amount				
	Uranium (MTU)	Pu239 (Kg)	Pu241 (Kg)	Fissile Pu (Kg)	Total Pu (Kg)	Uranium (MTU)	Pu239 (Kg)	Pu241 (Kg)	Fissile Pu (Kg)	Total Pu (Kg)
1980	19.74	97.33	21.99	119.32	167.95	27.56	132.29	27.51	159.80	221.05
1985	29.28	147.70	34.48	182.18	258.49	133.84	664.71	134.61	799.32	1154.84
1990	155.50	792.90	195.49	988.40	1433.61	696.35	3478.29	713.44	4191.73	6088.51
1995	155.62	822.01	218.92	1040.92	1553.31	1471.01	7562.05	1523.78	9085.83	13776.43
2000	155.64	821.63	217.62	1039.22	1548.80	2245.96	11652.67	2153.83	13806.50	21501.32
2005	155.64	821.63	217.62	1039.22	1548.80	3024.16	15760.82	2638.80	18399.62	29245.32
2010	142.74	752.47	198.93	951.38	1417.63	3805.04	19874.12	3003.32	22877.44	36971.27
2015	171.74	873.73	213.12	1086.81	1588.27	4565.95	23826.09	3224.41	27050.51	44311.38
2019	70.27	310.14	54.95	365.09	494.61	5037.34	26079.32	3019.39	29098.71	48165.11

Table 4. The Annual and the Accumulated Discharged Amounts of Uranium with Respect to U-235 Content

Year	Annual Production							
	*1	*2	*3	*4	*5	*6	*7	*8
1980	3.5	0.0	0.0	0.0	0.0	15.5	0.0	0.8
1985	1.6	0.0	0.0	0.0	0.0	27.7	0.0	0.0
1990	47.1	0.0	42.9	29.9	0.0	23.5	12.2	0.0
1995	69.0	0.0	0.0	10.6	63.9	0.0	12.2	0.0
2000	50.1	0.0	0.0	48.4	45.0	0.0	12.2	0.0
2005	50.1	0.0	0.0	48.4	45.0	0.0	12.2	0.0
2010	47.8	0.0	0.0	37.8	45.0	0.0	12.2	0.0
2015	47.9	0.0	0.0	37.8	45.0	0.0	0.0	41.1
2019	0.4	0.0	0.0	0.0	22.5	0.0	0.4	46.9
Year	**Accumulated Amount**							
	*1	*2	*3	*4	*5	*6	*7	*8
1980	3.5	0.0	0.0	0.0	0.0	15.5	6.6	2.0
1985	7.4	0.0	0.0	0.0	15.3	102.6	6.6	2.0
1990	183.6	45.4	63.1	29.9	108.3	194.5	67.0	4.6
1995	510.0	45.4	122.1	147.3	239.6	274.1	127.8	4.6
2000	833.0	45.4	122.1	294.7	483.3	274.1	188.7	4.6
2005	1083.5	45.4	122.1	536.6	708.2	274.1	249.5	4.6
2010	1333.6	45.4	122.1	757.5	933.0	274.1	310.4	30.7
2015	1572.5	45.4	122.1	946.7	1157.8	274.1	346.9	102.2
2019	1606.4	45.4	122.1	1007.5	1315.1	274.1	347.7	322.5

*1 -0.711 w/os
*2 0.711-0.73 w/os
*3 0.73-0.75 w/os
*4 0.75-0.78 w/os
*5 0.78-0.80 w/os
*6 0.80-0.90 w/os
*7 0.90-1.00 w/os
*8 1.00 w/o -s

Table 5. Discharge Burnups and U Content in Fresh and Spent Fuels for KNUs (Equilibrium Cycle)

Unit Number	Burnup (MWD/MTU)	Charge (w/o)	Discharge (w/o)
1	35121	3.30	0.7588
2	33343	3.45	0.9052
5 & 6	36809	3.32	0.7039
7 & 8	36922	3.45	0.7566
9 & 10	33820	3.25	0.7870

Cm-243. However, the amounts of Pu-238 and Cm-243 are too small to be neglected. Hence, it is observed that there are no change in the total amount of the plutonium except Pu-241 decay. The loss of Pu-241 due to radioactive decay could be reduced if it is early utilization in a reactor as a form of MOX fuel is implemented. Also, the content of fissile Pu is approximately 0.6 w/o, which is very significant. Furthermore, the annual discharged amounts of fissile Pu will reach 1.0 tons in 1990 and will increase thereafter.

2. Table 3 shows that the major portion of discharged fuels has the enrichment of 0.7-0.8 w/o U-235, which is slightly lower than the expected value of 0.8-0.9 w/o. It is because the discharge burnups are higher than the generally referred burnup of 33,000 MWD/MTU. The discharged

fuels which have lower than the enrichment of 0.711 w/o U-235 are produced in abundance, because the enrichment of the discharged fuel from equilibrium cycle of KNU 5 & 6 is 0.704 w/o U-235 and that of the discharged from initial core of KNU 7 & 8 is less than 0.711 w/o.

4. Conclusions

The annual discharged amounts of uranium and plutonium will reach 150 and 1.5 tons after 1990, respectively. therefore, the optimization of nuclear fuel cycle should be required. When the tandem fuel cycle is utilized, only the fissile uranium and plutonium in spent fuel produced from domestic PWRs will be enough for a MOX fuel. Especially since plutonium is high value, its better utilization should be also researched. In this study, KNU 11 and 12 are excluded. Since KNU 11 and 12 will start its commercial operation in 1995 and 1996, respectively, the amounts of fissile materials through spent fuels will increase after 1998.

Acknowledgements

The authors would like to thank Korea Science and engineering Fund for its financial aid. Thanks are also due to Mr. Ji Bok Lee of the Korea Advanced Energy Research Institute for Providing useful informations.

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