Recycling Scheme for Twin BWRs Reactors

J. Ramón Ramírez-Sánchez, R.T. Perry, Gustavo Alonso V., Javier Palacios H.*
Instituto Nacional de Investigaciones Nucleares
Carretera Mexico-Toluca Km. 36.5, La Marquesa s/n, Ocoyoacac 52750, Mexico

Abstract

To asses the advantages of reprocess and recycle the spent fuel from nuclear power reactors, against a once through policy, a MOX fuel design is proposed to match a generic scenario for twin BWRs and establish a fuel management scheme. Calculations for the amount of fuel that the plants will use during 40 years of operation were done, and an evaluation of costs using constant money method for each option applying current prices for uranium and services were made. Finally a comparison between the options was made, resulting that even the current high prices of uranium, still the recycling option is more expensive that the once through alternative. But reprocessing could be an alternative to reduce the amount of spent fuel stored in the reactor pools.

KEYWORDS: Plutonium, MOX Fuel, Fuel Management, Spent Fuel.

1. Introduction

Reprocessing of spent fuel is a step in a closed fuel cycle where recycling can be done partially, this option can be used to reduce high level waste and improve the efficient utilization of uranium resources. The plutonium recovered during reprocessing is used as fuel in light water reactors in the form of MOX fuel, where the fissile material ^{235}U is changed for fissile plutonium using depleted uranium as matrix. Currently the plutonium recycling has been successfully implanted in a number of light water reactors in Europe and Japan, and will be implemented in the near future in the USA. While the spent fuel is being stored in the reactor pools, waiting for an alternative in the fuel cycle policy.

2. MOX Fuel Assembly Design

From the total amount of heavy metal (^{238}U + ^{235}U), existing in the fresh fuel for a nuclear reactor, after burn it several cycles, still remains into the spent nuclear fuel almost the total amount of 238U, small amounts of 235U, and roughly 1% of plutonium**[1]**

This plutonium content and composition (plutonium vector) depends on the total burnup of the fuel, type of reactor in which the fuel was burned and initial enrichment of the fuel. The Table 1 shows the different isotopes for LWR as reported by the IAEA **[2]**.

Table 1 Plutonium Isotopes concentration from LWR Spent Fuel

Isotope	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
% w	1.5	60.1	24.5	8.8	5

---

* Corresponding author, Tel. +52 (55) 53297200, Fax. +52 (55) 53297301, E-mail: jrrs@nuclear.inin.mx

After reprocess the spent fuel, there is a remaining 96% of heavy metal, mainly uranium and plutonium, the rest are fission products and fission gases.

In this part it is proposed a high moderation ratio MOX fuel assembly that can meet all the design requirements. The moderation ratio of fuel assemblies has been investigated before [3], and it has been found that changing the moderator to fuel ratio to a higher value, leads to a better thermalization of the neutron spectrum and enhances the net plutonium consumption. Other additional advantages as control rod worth enhance, higher fraction of MOX in core and smaller plutonium concentrations can be numbered into other studies.**[4]**

Keeping in mind these targets, a fuel assembly was designed for a BWR reactor, using the same mechanical design as for the uranium fuel. A layout of the high moderation fuel assembly is given in Figure 1, this corresponds to a 10x10 array with two water traps and 8 fuel rods replaced with water pins.

Figure 1 MOX fuel design proposed 7% $Pu_{tot.}$

3.9	5.4	6.4	7.1	7.9	7.9	7.9	6.1	5.4	4.6
5.4	6.4	6.4	W	G	7.1	W	G	6.4	5.4
6.4	6.4	7.9	7.9	7.9	7.9	7.9	7.1	G	6.1
7.1	W	7.9	G	7.9	W	W	G	W	7.9
7.9	G	7.9	7.9	6.4	W	W	7.9	7.1	7.9
7.9	7.1	7.9	W	W	6.4	7.9	7.9	G	7.9
7.9	W	7.9	W	W	7.9	7.9	7.9	W	7.9
6.1	G	7.1	G	7.9	7.9	7.9	7.9	G	7.1
5.4	6.4	G	W	7.1	G	W	G	6.4	5.4
4.6	5.4	6.1	7.9	7.9	7.9	7.9	7.1	5.4	4.6

This fuel lattice was used to simulate the complete fuel assembly in the core simulator, replacing the uranium fuel by MOX in several fractions and obtain the same cycle length. The Table 2 shows a breakdown of the plutonium fuel. This fuel assembly contains an average of 7% total plutonium with a quality specified in Table 1.

Table 2 Plutonium concentrations used in the MOX fuel Proposed

Pu_{tot} %w	3.9	4.6	5.4	6.10	6.40	7.10	7.90	W	Gd
Number of rods	1	3	8	4	10	10	35	16	13
$Pu_{fissile}$	2.69	3.17	3.72	4.20	4.40	4.90	5.44	-	-

3. Calculations

To perform the calculations, the FMS system from the company SCANDPOWER was used.**[5][6][7]** For the nuclear parameters the code HELIOS was used and the code CORE MASTER PRESTO for reactor simulation, a reference calculation based on a real fuel cycle for a BWR was made and compared to the results for several fractions of MOX fuel in the reload.

4. Scheme proposed

The BWR reactors of Laguna Verde Nuclear Power Plant have an electrical output of 654 MWe each, and the core contains 444 fuel assemblies, then to reach the 18 months of cycle currently established for operation, is necessary to reload around of 112 fresh fuel assemblies (approximately 1/4 of the core) after each operation cycle, 112 spent fuel assemblies will be discharged.

The BWR fuel assembly contains approximately 180 Kg of heavy metal (uranium), after discharge and reprocessing, the amount recovered will be 95% uranium and 1% plutonium, which means 171 kg of uranium and 1.8 Kg of plutonium with the expected composition for LWR given in the Table 1.

The amount of plutonium that can be recovered from each fuel discharge will be around of 200 Kg. with 68.9% quality, if the total discharge is reprocessed. This amount of plutonium could be used for MOX fuel manufacturing.

Assuming 1% of heavy metal in the spent fuel is plutonium, and from previous studies performed at ININ as discussed in section 2, about the plutonium content in MOX fuel**[8][9],**.where was determined that the necessary amount of plutonium to manufacture one MOX fuel assembly is in the order of 12.6Kg to reach an average concentration of 7% of total plutonium in the assembly, with these numbers we can calculate that 200 Kg of plutonium will serve to produce (15 – 16) MOX fuel assemblies, this amount can be double if we have two reactors. For each discharge of the two reactors we will have enough plutonium for at least feed one reactor partially reloaded with MOX fuel, having 32 MOX fuel assemblies in each reload, eventually at the fourth cycle we will have around of 128 MOX fuels into the core, so we start to discharge MOX in the same amount it is loaded, keeping an amount of MOX fuel assemblies in the core.

If the two units start working at the same time, each cycle we will have 224 spent fuel assemblies discharged from both reactors, the amount of plutonium contained in those assemblies will be of the order of 403 Kg which will be enough for the manufacturing of 32 MOX fuel assemblies using 12.6 Kg / MOX FA. However the MOX manufacturing will start 5 years later because the decay and cooling time of the spent fuel, so the MOX load can start after the fourth cycle of operation.

Once the MOX fuel is loaded into one of the reactors (in fact the MOX can be loaded into the two reactors dividing the amount of MOX available), the amount of UOX fuel assemblies will be reduced, and less spent fuel will be available for reprocessing, in consequence the plutonium production decreases and the amount obtained from the reprocessing will be enough for 27 MOX assemblies. Here the load of MOX assemblies is reduced and the amount of uranium assemblies loaded will be higher, increasing the uranium spent fuel discharged. Now the plutonium will be enough for the manufacturing of 28 MOX reaching the equilibrium point. All this scheme is shown in the Table 3.

Table 3 Recycling scheme for twin BWRs proposed

Number Of Cycle	Fuel load No. F.A.	Fuel load No. F.A.	Fuel discharged No. F.A.	Pu Inventory /MOX F.A.	MOX in core During Burnup
	Unit-1	Unit-2	From 2 Units	Kg Pu / F.A.	Core-1
1	444U	444U	224U	403/32	
2	112U	112U	224U	403/32	
3	112U	112U	224U	403/32	
4	112U	112U	224U	403/32	
5	80U+32M	112U	224U	403/32	32
6	80U+32M	112U	224U	403/32	64
7	80U+32M	112U	224U	403/32	96
8	80U+32M	112U	192U+32M	345/27	128
9	80U+32M	112U	192U+32M	345/27	128
10	80U+32M	112U	192U+32M	345/27	128
11	80U+32M	112U	192U+32M	345/27	128
12	85U+27M	112U	192U+32M	345/27	123
13	85U+27M	112U	192U+32M	345/27	118
14	85U+27M	112U	192U+32M	345/27	113
15	85U+27M	112U	197U+27M	355/28	108
16	85U+27M	112U	197U+27M	355/28	108
17	85U+27M	112U	197U+27M	355/28	108
18	85U+27M	112U	197U+27M	355/28	108
19	84U+28M	112U	197U+27M	355/28	109
20	84U+28M	112U	197U+27M	355/28	110
21	84U+28M	112U	197U+27M	355/28	111
22	84U+28M	112U	196U+28M	355/28	112
23	84U+28M	112U	196U+28M		112
24	84U+28M	112U	196U+28M		112
25	84U+28M	112U	196U+28M		112
26	84U+28M	112U	776U+112M		112

If a once trough cycle is considered for both reactors, the amount of fuel assemblies trough their entire life of operation will be 112 fuel assemblies/cycle multiplied by (number cycles -1) plus the initial load of the reactor. This produce 3244 assemblies for each reactor, then we will have a total of 6488 fuel assemblies or 1622 ton of high radioactive waste.

Recycling the spent fuel of both reactors practically all the uranium fuel discharged will be reprocessed except for the last four cycles (if the plant is planning to close and there is no license extension), so finally will exist 1392 UOX assemblies plus 637 MOX fuel assemblies as spent fuel from both reactors, or the equivalent to 500 ton of high radioactive waste. That means that using recycling the amount of waste is reduced to around 32% of the original amount produced if recycling is not done.

5. Economics

To asses the economics for each option, the parameters shown in the Table 4 were used. The costs for uranium and services corresponds to the spot prices reported for UxC Consulting Company during the last week of September 2005 **[10]**, and the enrichment and Burnup corresponds to technical data of LVNPP **[11]**. The table 5, shows the estimate costs for the back end of the cycle in the case that the spent fuel were going to be buried into a repository.

Table 4 Economic Parameters for Fuel

Enrichment	3.7%
Uranium cost	81. \$/KgU
Conversion cost	11.5 \$/KgU
Separative Work	114 /SWU
Kg HM/Fuel A.	180 Kg
Burnup	40 GWd/TU

Tabla 5 Costos for Once through Cycle

Interim storage	40 USD\$/Kg HM
Transport	50 USD\$/Kg HM
Conditioning	230 USD\$/Kg HM
Final Disposition	610 USD\$/Kg HM

To calculate the reprocessing, disposition, and MOX manufacturing costs, an OECD study published in 1994 was used [12], For the cycle with recycling the costs are shown in the Table 6.

Table 6 Costs for recycling

Storage	40 USD\$/Kg HM
Transport	50 USD\$/Kg HM
Reprocessing	1000 USD\$/Kg HM
High Level Waste	300 USD\$/Kg HM
MOX Manufacturing	1500 USD\$/Kg HM

6. Results

Applying the parameters shown above to the fuel management scheme for twin BWRs showed in Table 2, the results obtained after several calculations using electronic sheets developed for the fuel cycle costs, including the front and back end of the cycle, for once through and partial recycling options are shown in the Table 7.

Table 7 Economic Evaluation of Fuel Cycle Policy

	Unit Costs	Once Through		Recycling	
	USD$/Kg HM	No. F.A.	Cost USD$	NO. F.A.	Cost USD$
UOX F. A.	1548	6488	1808×10^6	5851	1633×10^6
MOX F. A	1500			637	169.6×10^6
Reprocessing	1140			4459	905.3×10^6
Final disposition	840	6488	981×10^6	2029	313.9×10^6
Total Cost $			**2789×10^6**		**3022×10^6**

The methodology applied corresponds to constant money calculations, to make a direct comparison between schemes, however the costs for final conditioning and disposition have uncertainties attached and the use of costs reported in the OECD study should be considered generic, taken into account this, the costs for the recycling option can be higher.**[13]**

7. Conclusions

The main result from this study, under the scenarios proposed, is the fact that even the current higher costs of uranium, The recycling option is more expensive than the once through option, the results shows that the recycling option is around 8.3% more expensive, and the reduction in the amount of high level waste (spent fuel) will be of 68% which is significative. Another possible advantage will be that the spent fuel storage pools will be almost empty except at the end of life for the plant.

References

[1] Ciclos de Combustible Nuclear, Organismo Internacional de Energía Atómica, Vol 35, No 3, 1993.

[2] International Atomic Energy Agency, Status and Advances in MOX Fuel Technology, Technical Report Series no.415, 2003, pp53.

[3] D. Porsch, A. Charlier, G. Meir, J.C. Mmougniot, K. Tsuda, “Overview of Neutronic Fuel Assembly Design and in Core Fuel Management”, IAEA C&S Papers Series 3/p, May 1999, pp 348.

[4] Patrick Barbrault, “A Plutonium–Fueled High–Moderated Pressurized Water Reactor for the Next Century”, Nuclear Science and Engineering 122, 240-246, 1996.

[5] AURORA, User Manual, SCANDPOWER, December 1995.

[6] HELIOS, User Manual, SCANDPOWER, December 1995.

[7] ZENITH, User Manual, SCANDPOWER, July 1996.

[8] J. Ramón Ramirez, Gustavo Alonso, R.T. Perry, J. Ortiz Villafuerte, “Comparative Assessment of MOX Fuel Assembly Design for a BWR Mixed Reload”, to be published in Nuclear Technology. July 2006.

[9] Ramirez Sanchez J. Ramon, R. T. Perry, ‘Mixed Reload Using MOX and UOX Fuel

Assemblies', 10th International Conference on Nuclear Engineering, ICONE10 Arlington, Virginia, USA, April 2002, pp 36
[10] UxC The Ux Consulting Company, LLC. Ux Weekly, September 26, 2005.
[11] Reload licensing report for LV-1 cycle 8, GE Nuclear Energy, july 1999.
[12] Economics of the Nuclear Fuel Cycle, OECD (1994)