PHYSOR 2004 – The Physics of Fuel Cycles and Advanced Nuclear Systems: Global Developments
Chicago Illinois, April 25-29, 2004, on CD-ROM, American Nuclear Society, Lagrange Park, IL. (2004)

Over-moderated MOX Fuel Assembly in a BWR Mixed Reload

J. Ramón Ramírez S., Gustavo Alonso V, Javier Palacios H.
Instituto Nacional de Investigaciones Nucleares
Carretera México-Toluca km. 36.5,Estado de México, México

KEYWORDS: Plutonium fuel,MOX, Fuel Management,Reactor Physic

1. Introduction

In prior years, the use of MOX fuel in thermal reactors was considered only as an alternative back-end policy option. However, the plutonium recycling and MOX fuel technology has evolved to industrial level and currently several countries have established recycling as integral part of their fuel cycle policy. Countries such as Belgium, France, Germany, Japan and Switzerland are using MOX in a considerable number of power reactors (PWRs and BWRs) Of their 40 licensed reactors, 33 have MOX fuel loaded or have applied for a license to use MOX fuel at levels up to 30% of the reactor core**[1].**

Currently, the amount of MOX fuel in the core is limited to 30 to 50% by licensing requirements**[2]**, as they are constrains in the reactivity worth of control rods, fast neutron fluence on the reactor vessel and a harder fission spectrum of ^{239}Pu compared with ^{235}U. So by increasing the moderator to fuel ratio could be possible to overcome theses limitations. This study is focused in determine how this technology can be implemented. This paper presents the results of some of those studies that have been conducted at ININ (Instituto Nacional de Investigaciones Nucleares).

2. Fuel Design Features

The MOX fuel assemblies that currently exist in the international market are geometrically similar to the conventional uranium fuel assemblies. The mechanical design of the MOX fuel assembly is exactly the same as the mechanical design as the enriched uranium fuel assembly, the fissile material, of course, does change.

The main neutronic design criteria for the MOX fuel assembly, is that the burn-up at discharge should be the same burn-up as the enriched uranium fuel assembly at discharge. This design criteria is complicated by other more general requirements, for example, the MOX fuel assemblies should be compatible to the enriched uranium fuel assemblies with regard to reload strategies, 2) the assembly cycle in the core should not add constrains for the reactor operation, 3) the cycle length for a mixed core should be the same as for enriched uranium fuel, and 4) the thermal limits should not exceed the limits currently established for uranium fuel. These requirements must be met without modifying the shutdown and reactor control systems.**[3]**

The MOX fuel assembly design and the core design are not independent process. The assembly design procedure starts by defining some average plutonium content for the MOX fuel assemblies. Next, core design calculations are used to determine if this average plutonium concentration for the MOX fuel assemblies meet the design goals.

Plutonium is obtained from UOX fuel irradiated in power reactors, so the plutonium isotopic

Jose Ramon Ramirez Sanchez, E-mail jrrs@nuclear.inin.mx, ININ – Mexico.

composition depends on the initial enrichment of the UOX, reactor type, discharge burn-up, and storage time of the spent fuel. The isotopic composition is called the plutonium vector and is shown in the Table 1. For the calculations here, the plutonium isotopic concentration from LWR reactor fuel was used.**[4]** This plutonium is called reactor-grade plutonium and has a typical quality of 69%.

Table 1 Plutonium Isotopes employed for LWR MOX

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

3. MOX Fuel Assembly Design

In this paper we propose an over-moderated MOX fuel assembly that can meet all the design requirements. The over moderation of fuel assemblies has been investigated before[4], and it has been found that changing the moderator to fuel relation 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.**[5]**

Keeping this in mind those targets, a fuel assembly was designed for a BWR reactor, using the same mechanical design as for the uranium fuel. A layout of the over moderated 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.

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

Figure 1 Over moderated MOX fuel assembly

Jose Ramon Ramirez Sanchez, E-mail jrrs@nuclear.inin.mx, ININ – Mexico.

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
Pins Number	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	-	-

4. Calculations

To perform the calculations, the FMS system from the company SCANDPOWER was used.**[6,7,8]** 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.

5. Results

Several calculations were done before.**[9]** to find the optimum FMR (Fissile Material Ratio) that match the length of cycle, where a normal moderated MOX fuel assembly was used, the gadolinium concentration was changed for a complete reload of fuel in a BWR reactor, on this way it was found that at lower gadolinium concentration the larger the fuel cycle length, as shown in the Table 3.

Table 3 MOX fuel cycle length at several Gd concentrations

Folder	**FMR**	**Gd 2%**	**Gd 3%**	**Gd 5%**
		Cycle (days)	**Cycle (days)**	**Cycle (days)**
01	**1**		**270.41**	**198.21**
02	**1.362**		**328.11**	**266.85**
03	**1.489**	**426.01**	**375.74**	**321.71**
04	**1.8**	**469.33**	**427.31**	**379.51**
05	**1.9**		**443.81**	**397.41**
06	**2.02**		**459.98**	**415.22**
07	**2.1**		**472.78**	**431.99**

The target in those studies were to find the optimum concentration of fissile plutonium that could match a cycle length of **469 efpd** corresponding to the normal fuel cycle length for uranium fuel with an average enrichment of 3.66%. So with the ratios of fissile material, a simulation of complete core was made for several fractions of reload and even a complete reload was modeled, the results shows that the best gadolinium concentration for our scenario was 2%, and 1.8 as fissile material ratio.

Modeling an over moderated fuel assembly, the fuel cycle length was matched with only a fissile ratio of 1.33 given a total fuel cycle of **467.46 efpd,** which corresponds to an average concentration of fissile plutonium of 4.85% and 2% of gadolinium concentration.

Conclusions

For the conditions given, the over moderated MOX fuel assembly showed better performance than the normal MOX fuel assemblies calculated previously, which means that some plutonium can be saved if the over moderation is used. Some additional advantages as improvement in the shutdown margin and a major number of fuel assemblies into the core can be achieved.

References

1. K. Fukuda, J.S. Choi, R. Shani, L. Van der Durpel, E Bertel, E. Sartori, "Mox Fuel Use as a Back end Option: Trends Main Issues and Impacts on Fuel Cycle Management", MOX Fuel Cycle Technologies for Médium and Long Term Deployment, IAEA-SM-358-I, Vienna, Austria, 1999.

2. Jan Leen Kloosterman, Evert E. Bende, "Plutonium Recycling in Pressurized Water Reactors: Influence of the Moderator to Fuel Ratio", Nuclear Technology VOL. 130, June 2000, pp 227-241.

3. Laura Zanotti, Jacques Porta, Gilbert Rouviere, "Influence of Neutron Spectrum Modifications on Recycled MOX Fuel in Boiling Water Reactors", 7th International Conference on Nuclear Engineering, Tokio, Japan 1999.

4 "Status and Advances in MOX Fuel Technology", International Atomic Energy Agency, Technical Reports Series 415, 2003, pp 48-53

5 Patrick Barbrault, "A Plutonium–Fueled High–Moderated Pressurized Water Reactor for the Next Century", Nuclear Science and Engineering 122, 240-246, 1996.

6 AURORA, User Manual, SCANDPOWER, December 1995.

7 HELIOS, User Manual, SCANDPOWER, December 1995.

8 ZENITH, User Manual, SCANDPOWER, July 1996.

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