

DISPOSITION OF WEAPONS-GRADE PLUTONIUM IN PWRs: A TECHNICAL ASSESSMENT BASED ON MOX FUEL EXPERIENCE ACQUIRED IN FRANCE

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INTRODUCTION

As a consequence of the strategic treaties Start I and II the planned dismantling of nuclear weapons has raised the question of weapons-grade plutonium (W-Pu) disposition. The United States and Russia should dispose of an amount of 50 mt (metric tons) of W-Pu each. Because of proliferation risks, conversion to non-weapons-grade material is highly recommended.

Both the United States and Russia are considering the mixed Uranium and Plutonium Oxide (MOX) option as a sound way to solve the problem. The immobilization of the plutonium surplus for disposal in a repository constitutes the second track considered by the US Department of energy (DOE).

MOX fuel presents advantages over immobilization.

“Moxified” plutonium undergoes isotopic degradation during its use in reactor. When the MOX fuel is unloaded the proportion of fissile plutonium (Pu239 and 241) compared to non fissile material (Pu240 and 242) is such that the recovered material is far from having the requisite qualities for military devices. The spent MOX fuel unloaded matches the “Spent Fuel Standard” as defined by the US National Academy of Science. This standard is defined as “Aa concept to make the plutonium as unattractive and inaccessible for retrieval and weapons use as the residual plutonium in spent fuel from commercial reactors.”

Moreover, W-Pu in MOX fuel burnt in reactor uses the high energy potential of plutonium to generate electricity. The fission of 50 tons of W-Pu in pressurized water reactors (PWRs) could produce about 350 billion kWh of electricity that is close to the French annual consumption from nuclear power plants.

Unlike the immobilization, using W-Pu in MOX fuel is a way to benefit from the experience of the commercial MOX industry. This use of W-Pu could soon be implemented in existing Light Water Reactors (LWRs) on the basis of the cumulated experience in the MOX fabrication and MOX fuel utilization in reactors.

As a matter of fact, plutonium recycling in MOX fuel is a fundamental component of nuclear fuel cycle in France. For more than 20 years the French nuclear industry has devoted important means to develop specific process and facilities for MOX. Today this specific industry is mature and can be easily adapted for W-Pu.

The aim of this paper is to describe the French experience in MOX industry and to analyze the impact of the W-Pu implementation in MOX fuel.

MOX fuel in reactor

French experience has been developed for more than 20 years (from fabrication to the spent MOX fuel management). Based on the extensive UO_2 experience, the MOX fuel has required some evolutions or adaptations because of plutonium specificity. The AMoxification Aof 900 MW commercial PWR required only minor adaptations.

The fission and capture cross sections for MOX Fuel Assemblies (FAs) are larger than fission and capture cross sections for UO_2 FAs. It results from this a hardened neutron spectrum in MOX FAs. Therefore, nuclear reactions take place at higher average neutron energy and the efficiency of thermal absorbers such as soluble boron and control rods decreases. This is the most important difference between partial MOX cores and UO_2 cores.

In partial MOX cores, due to the large thermal absorption cross section for MOX fuel assemblies, neutrons are greatly absorbed by MOX fuel rods. As a result large thermal flux gradient occurs at the interface between MOX and UO_2 FAs and high peaking factors can occur at the periphery of MOX fuel assemblies.

Implementation of MOX FAs has an impact on reactor physics parameters. Then, it is necessary to perform safety analyses to prove that reactors with partial MOX cores can be safely operated. Safety analyses consist in checking core response under normal or accidental transients.

Moderator temperature coefficient is more negative for partial MOX cores than for UO_2 cores which is an advantage of MOX cores for the overall safety. However the steam line break accident is affected by this parameter and the consequence will depend on the available shutdown margin and boron efficiency.

Prompt neutron lifetime and delayed neutron fraction are reduced in partial MOX cores so that reactivity insertion accidents in safety analysis such as rod ejection have to be reassessed.

The hardened neutron spectrum has an impact on MOX fuel rod reactivity coefficients. The reactivity level decreases more slowly in MOX FAs than in UO_2 FAs. As a result fuel rod

temperature is higher in MOX fuel rod than in UO₂ rod and it has to be taken into account in LOCA analysis (Loss Of Coolant Accident).

Decay heat is higher so that for partial MOX cores the performance of existing systems used for residual heat removal must be checked, particularly for accidental conditions.

To overcome these differences between UO₂ cores and partial MOX cores, some technical modifications have been made by FRAMATOME. The use of zoned MOX (i.e. varying Pu content from inner rods to outer rods) FAs minimizes the power peaking factor at the interface of MOX and UO₂ FAs. The efficiency of the control rods has been improved on 900 MWe power plants by adding 4 "black" rods. Black rods are the heaviest rods in term of neutronic effects. The efficiency of soluble boron has been improved by increasing boron concentration in boron storage tanks.

Concerning MOX fuel handling, it was necessary to implement special plutonium related security rules on the French reactors using MOX fuel. Specific modifications were also required for physical protection. The fresh fuel container handling crane capacity has been increased due to the heavier container used for fuel and that crane was also modified to guaranty a better reliability.

A special checking cell for fresh fuel has been designed to insure the radiation protection of operators during visual check up of the MOX assemblies.

With these improvements, the 900 MWe power plants have the technical capability to burn MOX fuel. 28 are in operation in France and the administrative authorization to load MOX has been received by 20 of these units - demands for the 8 remaining are pending.

As previously stated, a MOX fuel is constituted of three different plutonium contents to prevent a resulting power rise at the interface between MOX and UO₂ FAs. The plutonium content is determined to obtain FAs equivalent to uranium fuels with a 3.25% ²³⁵U enrichment. The physical content of plutonium varies from 4.5 to 5.3% (presently authorized limit), depending on the isotopic composition of the plutonium batches.

The current core management mode is called "hybrid mode." In such mode, a quarter of the UO₂ FAs and a third of MOX FAs are replaced each year. Since about 30 % of the core is composed of MOX fuel, the reload has the following composition :

28 UO₂ assemblies enriched to 3.7% in ²³⁵U for the 4-batch core management,
16 MOX assemblies with a plutonium content equivalent to a 3.25% enrichment in ²³⁵U
for the 3-batch core management.

Since 1987 MOX FAs has been loaded in 17 reactors that have the same operation mode and behavior as those using only enriched uranium fuel. It is to be noted that the amount of waste generated by both type of reactors are the same. In terms of assemblies 1000 MOX FAs have been delivered to EDF as of December 31, 1998. The cumulated experience is now around 150 reactor-years, and proves the flexibility and the feasibility of MOX fuel in commercial reactor.

MOX fuel fabrication

Pooling the production resources of three independent plants, the COGEMA group has set-up an homogeneous and versatile MOX fuel fabrication tool referred to as "the COGEMA Group MOX Platform (CGMP)". With a current production reaching 180 tHM/y the prospective production capability of this "platform" is up to 330 tHM/y. Any type of MOX fuel can be manufactured and delivered to the Utilities. The CGMP involving the MELOX plant, the COGEMA Cadarache Plant and most of the production capacity of the BELGONUCLEAIRE PO plant (in Dessel), is the result of an harmonization policy in terms of process and quality control. The CGMP also includes the MOX fuel assembling chop of FBFC-International.

The MELOX plant operated by COGEMA was commissioned in 1995. In 1997, it delivered 100t of PWR fuel for the French utility EDF. As of July 31st 1998, more than 650 tHM fabricated by the plants of CGMP have been delivered to Belgian, French, German and Swiss Utilities. This cumulated production corresponds to about 1500 FAs of various types, from 14 x 14 to 18 x 18 PWR FAs, and from 9 x 9 to 10 x 10 BWR FAs. Benefiting from the CGMP's high flexibility, this product range can be extended to other designs such as 11 x 11 BWR FAs. It should be noted that the next significant event in the framework of MELOX plant evolution is scheduled to start up in 1999 and will add fuel production flexibility from its PWR and BWR multi-design assembling line. By early 2000's, the MELOX plant could produce up to 250 tHM/year, of which 80 tHM/year for BWR fuels.

The fabrication of MOX fuel is based on the same principles as the fabrication of enriched uranium fuel. However, handling plutonium requires specific operating modes and precautions especially in terms of criticality safety, radiological protection and heat release.

Fabrication includes several steps, the first one being similar to the fabrication of ceramics. It consists in metering, mixing, grinding and homogenizing the uranium oxide (UO₂) and plutonium oxide (PuO₂) powders.

At the MELOX plant, the process used for powder mixture is the A-MIMAS process (Advanced-MIcronized MASTer blend), which is based on well proven techniques, qualified in the BELGONUCLEAIRE-DESSEL and COGEMA-CADARACHE plants:

- PuO₂ powder is micronized in a ball mill with some of the UO₂ powder to form a primary blend of 30% Pu content.
- The primary blend is diluted with a free-flowing UO₂ to obtain a secondary blend at specified enrichment.
- Scraps (powder, green or sintered pellets) can be recycled at both stages in the process line after a specific treatment.
- The powders are fed into a large size blender (about 700 Kg) , where the secondary batches are blended with a small quantity of pore forming agent.

The powder obtained is pressed to form cylindrical pellets which are then sintered. The pellets are ground to obtain the required diameter to within a few microns and are finally controlled.

The inspected pellets are inserted into empty rods. The rods are purged with an inert gas and welding of plugs is then performed under pressure. The rods are cleaned and then checked by automatic control machines.

The rods are placed in a metallic structure to form a fuel assembly. The main process stages in fuel assembly are automated. The completed assemblies are cleaned and submitted to final fabrication controls.

Impact of W-Pu in MOX fuel

Although very similar to civil Pu, W-Pu is isotopically different from it. Fissile isotopes content is typically above 90 % while civil plutonium issued from typical commercial PWRs contains up to 65 % of fissile isotopes.

Preliminary analyses were performed by FRAMATOME to compare civilian plutonium partial MOX cores and W-Pu partial MOX cores. The result is that the neutronic characteristics of W-Pu partial MOX range between standard UO₂ cores and current MOX cores using civil plutonium, which was described here above.

For a fresh W-Pu MOX fuel, due to a lower enrichment in Pu (for energetic equivalence with civilian Pu) and to less contents of Pu 238 and 240, the neutronic spectrum is close to UO₂ fuel. As a result, the W-Pu MOX and the UO₂ fuel in-core behavior are similar.

During irradiation in reactor, Pu 238 and 240 contents increase in W-Pu MOX fuel. The neutronic spectrum is hardened and evolve towards the civil MOX fuel spectrum until it is unloaded. At the unloading stage, W-Pu MOX neutronic characteristics have not reached those of civil MOX fuel. With W-Pu MOX fuel in-core, the moderator temperature coefficient is less negative than for civil MOX fuel and then there is less impact on the parameters of steam line break accident analyses. The efficiency of the control rods is also higher.

Further studies are still necessary to check core response under normal or accidental transients, but it seems that improvements implemented on French 900 MWe PWR are perfectly adapted to Weapons-grade Plutonium partial MOX cores.

As previously stated, MOX FA is constituted of three different plutonium contents for interface power transition between MOX and UO₂ FAs. With current fuel management, the plutonium content is determined to obtain a FA equivalent to a 3.25 % enriched uranium one. W-Pu MOX FA should be similar to the civil MOX FA and should be managed like MOX fuel without further adaptation. After 3 cycles the W-PU MOX spent fuel would fully match the Spent Fuel Standard.

MOX experience feed-back demonstrates MELOX capacity to produce various designs of MOX FAs: all kinds of EDF PWR reactors, foreign LWR reactors (BWR and PWR). MELOX products have been designed to comply with different core managements. This production flexibility

illustrates the ability of COGEMA and FRAMATOME to cope with new MOX requirements such as W-Pu based MOX.

For a MOX FA the 3 Pu contents are defined by equivalence to a UO₂ 3.25 enrichment, meaning an equivalent energy potential and an equivalent reactivity level. The final blend is then dosed to produce similar reactivity from W-Pu as the one from reactor grade Pu. A W-Pu MOX FA would not generate supplementary constraints in the areas of MOX plants.

W-Pu is easier to handle than the reactor-grade plutonium already in use: specific thermal power is 7 to 10 times lower, radioactivity is also seriously reduced (α , γ , and neutrons).

A-MIMAS process offers a comprehensive recycling of scraps. This efficient recycling ability is particularly suitable for W-Pu MOX plant, since all of the process-charged plutonium is to be used or dry recycled.

However criticality considerations would lead to the need for some specific adaptations of the civilian MOX technology; for example, smaller size equipment in the first part of the facility. This is not perceived as a difficulty. In fact, the exact adaptation would depend on the form under which W-Pu is released to the commercial cycle.

It is to be underlined here the agreements between French nuclear actors and Russia MINATOM program to burn W-Pu in MOX fuel. The trilateral initiative between the Russian Federation Germany and France announced in October 1996 was confirmed by the intergovernmental agreement signed on June 2, 1998. These agreements are open to other partners, and cover the 4 following areas:

- Pu conversion, a project to design a plant for converting W-Pu into suitable plutonium oxide (CHEMOX).
- MOX fuel fabrication, a project to design a MOX fuel fabrication facility using W-Pu oxide (DEMOX)
- MOX utilization in VVER and BN reactors, a program (design studies, safety reports and licensing) for loading MOX fuel in a Russian VVER and BN reactors, and for MOX spent fuel management.
- " AMOX demonstration" VVER 1000 fuel assemblies containing MOX rods made with Russian W-Pu in one Russian VVER-100 reactor.

Several public organizations and industrial teams from the Russian Federation, Germany and France have begun to work together in 1997 toward operation of an efficient system for the peaceful use of W-Pu after the turn of century.

Moreover, the U.S. Department of Energy (DOE) has recently called for an integrated industrial solution for building government-owned MOX fabrication plant on a DOE site, producing MOX fuel and irradiating it into three to eight existing commercial U.S. reactors. Proposals were

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submitted in early September 98 and the choice of a sole contractor is expected in the coming months.

US/European consortium comprising DE&S, S&W, COGEMA, Duke PC, VEPCO, NFS, Belgonucléaire and EDF submitted an offer to DOE.

Conclusion

Disposition of W-Pu MOX fuel in existing PWRs is technically feasible with no major modification on overall systems and processes. The last analysis performed by FRAMATOME shows that the neutronic characteristics of W-Pu is ranged between those of UO₂ fuel and civil MOX fuel. The W-Pu MOX fuel should be implemented with the help of the large experienced and qualified fuel management already carried out at industrial scale. Within this framework W-Pu MOX fuel could be safely irradiated and then could match the Spent Fuel Standard with the additional advantage of using the considerable potential energy in W-Pu.

Thanks to the impressive MOX fuel fabrication experience of COGEMA group, a plant of MELOX type wouldn't need any major adaptation to implement W-Pu with the required safeguards, safety and cost effectiveness.

The unique extensive European MOX experience could easily be made available to help develop an efficient, cost effective disposition program for W-Pu.