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Commercial Viability of Mixed Oxide Fuel Transport in the United States

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ABSTRACT

The commercial viability of a Mixed Oxide (MOX) fuel feedstock for United States (US) nuclear power stations is predicated on the US regulatory framework and the physical infrastructure of these plants. MOX fuel is a blend of uranium oxide and plutonium oxide. The commercial reactors in the United States currently rely on traditional fresh uranium feedstock. However, the international community has been utilizing reactor grade MOX fuel since 1972. A basic review of these fuel types in conjunction with the safety and security issues associated with the transport of this material is presented. An overview of various MOX fuel shipping casks is also provided.

Recommendations to optimize the use of MOX fuel in the US are developed based on a comparison of the US transport regulatory culture and the international model. These security recommendations include privatization of certain aspects of the transport of MOX fuel and the harmonization of NRC/DOE classifications. Development of MOX transport systems amenable to the applicable MOX fuel fabrication plant and the respective utilities' fresh fuel assembly receipt infrastructure is necessary.

INTRODUCTION

The nuclear industry is currently implementing or preparing to implement MOX fuel re-loads in a number of countries (France, Germany, Switzerland, Belgium, Great Britain, Japan and Holland). As of today, 35 reactors are currently loading MOX in Europe. Comprehensive transport systems fully compliant with current Safeguards and Physical Protection requirements in these countries have been developed. The industry is operating MOX transportation on a routine basis and has succeeded in streamlining transportation costs while maintaining the required high level of safety and security.

In the US, the industry proposes to conduct MOX fuel commercial operations in conjunction with existing fresh fuel operations. The mission is to conduct commercial MOX transport operations with high capacity MOX transport casks and high security vehicles fully compliant with the US regulatory framework.

Nuclear Reactor Fuel Streams

Currently there are two fuel streams for light water reactors: fresh uranium dioxide fuel and MOX fuel. Fresh uranium is mined, enriched, and manufactured into fuel assemblies. The enrichment level is typically 3-5%. Based on the current regulations governing fresh uranium fuel, the shipment of this fuel stream is allowed by commercial carrier in the United States and internationally.

Reprocessed uranium is derived from the treatment process which chemically separates the used nuclear fuel's various constituents into uranium, plutonium, and nuclear waste [1]. The reprocessed uranium is eventually converted into a solid form, re-enriched and recycled [2].

This reprocessed enriched uranium is shipped similar to fresh enriched uranium. The plutonium, from the treatment cycle, is converted into oxide powder and is shipped in sealed canisters that are subject to the applicable transport regulations of the specific country involved [1].

Mixed oxide, or MOX fuel, is a blend of uranium and plutonium which behaves similarly to the enriched fresh uranium fuel. The plutonium in MOX fuel can be derived from either spent fuel discharged from reactors or nuclear weapons material.

Reactor grade MOX, derived from commercial reactor spent fuel, contains quantities of fissile (U-235, Pu-239, and Pu-241) and fertile (U-238) material. Uranium and recovered plutonium constitute the basis for reactor grade MOX fuel.

Weapons grade MOX is derived from surplus nuclear weapons. The main difference between weapons grade plutonium and reactor grade plutonium is the percentage of the plutonium isotopes present in each fuel type. Table I [3] delineates the difference between these two fuel streams.

Table I. Plutonium Isotopic Compositions of Weapons Grade and Reactor Grade MOX [3]

Isotope	Plutonium Grade	
	Weapons Grade (wt%)	Reactor Grade (wt%)
^{238}Pu	0	1 – 4
^{239}Pu	92 – 95	50 – 60
^{240}Pu	5 – 7	24 – 27
^{241}Pu	0 – 0.5	6 – 11
^{242}Pu	0 – 0.05	5 – 10

Transport of Reactor Fuel Streams

The transport of reactor fuel is governed by the domestic regulations of each country. International institutions, such as the IAEA, issue recommendations and standards but are not a regulatory body. Both safety and security issues must be addressed to properly transport any type of nuclear fuel.

The “packaging” of a radiological transport system typically consists of the cask assembly including impact limiter, cask body, etc. The conveyance consists of a vehicle (e.g. trailer and truck) utilized to transport the packaging.

Safety Aspect of Transport

The obvious purpose of safety regulations is the well being of the public, workers, and environment. The major concerns of any radiological shipment are: containment, shielding, and criticality. To optimize the transport of MOX fuel, it is necessary to evaluate each MOX fuel

type against these concerns. The isotopic differences between reactor grade and weapons grade MOX drives the design aspects for shipment of these fuel types.

Description of Safety

One of the main discriminators in ascertaining the complexity of a normal form radiological shipment is the "A2" value associated with the radio-nuclides in the payload. The "A2" factor, generally speaking, aids in determining the allowed external and internal exposure of normal radioactive transport material for a first responder. In gross terms, the lower the A2 limit, the more stringent the design requirements.

If a particular payload has an activity which is less than the published A2 limit, the cask to transport this material may be designed to meet Type "A" requirements. A Type "B" cask must be used for transporting payloads for which the activity exceeds the A2 limits. Type "B" casks have much more stringent design requirements than Type "A" casks. A Type AF cask transports a payload with an activity of A2 or less, but which is fissile.

In fresh uranium fuel, the isotope of interest is U-235 and the A2 value for this radionuclide is *unlimited* [4] which allows fresh fuel to be shipped in a Type AF container. Conversely, Pu-239 has an "A2" value of $1.0X10^{-3}$ terabecquerel [4]. This low A2 limit forces MOX fuel assemblies to be transported in a Type B container.

Furthermore, as shown in Table I, reactor grade MOX has higher concentrations of Pu-238, Pu-240, Pu-241, and Pu-242. In addition, Pu-241 decays to Am-241. The concentrations of these radioactive isotopes necessitate additional shielding measures for reactor grade MOX fuel.

MOX TRANSPORTS

Introduction

Internationally, reactor grade MOX has been transported since the early 1970s. Casks such as the FS69, MX6, and MX8 have been extensively utilized for this work. The design of a transport for fresh or reactor grade MOX fuel is essentially the same in the United States or internationally. However, production scale shipment of weapons grade MOX has not been commercially undertaken.

MX6 and MX8 [5]

The Transnuclear International FS 69 cask was used in France beginning in 1987 to deliver MOX fuel to Électricité de France (EDF) power plants. MX8 cask development was launched in 1997 for the French market. MX6 cask development was launched in early 2000 for the European market. The MX6 and MX8 casks have been developed by TN International to transport fresh MOX fuel assemblies for both BWRs and PWRs. These casks replace the previous Siemens type III, Siemens BWR, and FS 69 casks.

The TNI MX6 and MX8 casks are designed to transport both reactor grade and weapons grade MOX fuel. This design approach could be useful for the US industry. The MX6 design enables transportation up to six (6) PWR fresh MOX fuel assemblies and up to sixteen (16) BWR fresh MOX fuel assemblies (Figure 1). It has a total gross weight of less than 20 metric tons (MT)

with a total length of 5,980 mm, a body diameter of 1,340 mm and a shock absorber diameter of 2,130 mm.

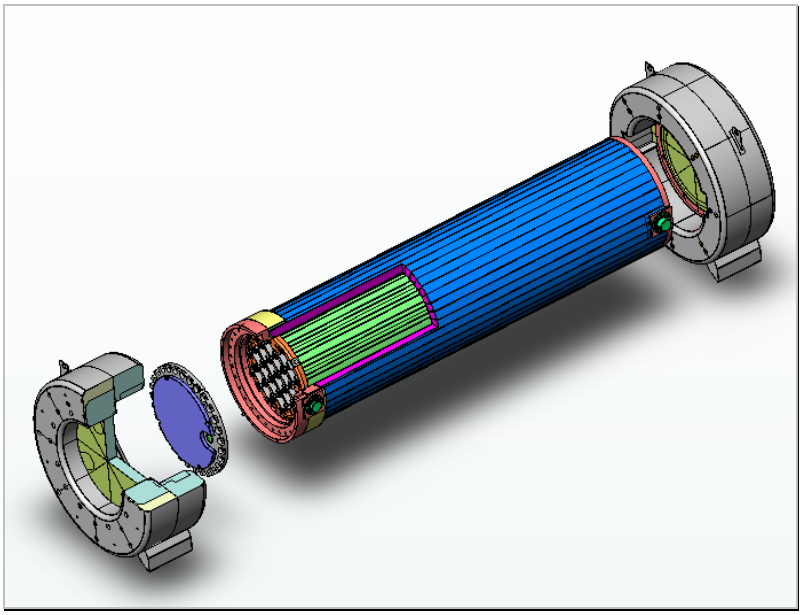

Fig. 1. MX6 cask with BWR basket.

The MX8 cask (Figure 2) can be loaded with 8 PWR MOX fuel assemblies. It has a total gross weight of around 22 MT, a total length of 5,183 mm, a body diameter of 1,379 mm and a shock absorber diameter of 2,282 mm.

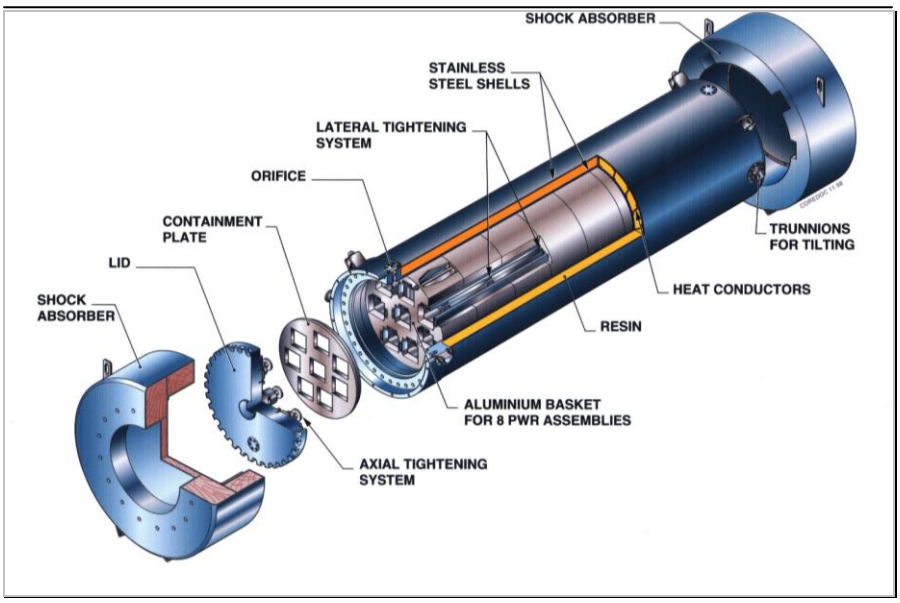

Fig. 2. MX8 cask with PWR basket.

The MX8 cask design was approved by the French authorities in France in November 2001, and fully extended since December 2006. The MX6 cask design was approved by the French authorities in France in December 2002 and in Germany by the German authorities since October 2003. It has also been validated in Switzerland.

SECURITY ASPECTS OF FRESH NUCLEAR FUEL

United States Approach

"Special Nuclear Material" (SNM) is defined in the Atomic Energy Act of 1954 as plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235. MOX Fuel, given the presence of plutonium and uranium, is considered SNM. SNM categories have been developed by NRC and DOE to determine the appropriate safeguard measures for a given SNM.

DOE utilizes a graded approach that evaluates the "attractiveness level" of the material. This process determines the appropriate safeguard category by evaluating the ease of detecting theft or diversion and the additional processing steps that would be necessary to convert the SNM into a form for illicit use. NRC, as with the IAEA, considers only mass amounts to classify material. With respect to MOX fuel, Table II provides the current definition for safeguards categories for plutonium, as established by DOE and by NRC.

Table II. Current Safeguards Categories for Low-grade Plutonium [6]

DOE		NRC and IAEA	
Category	Quantity (kg)	Category	Quantity (kg)
ID	N/A	I	>2.0
IID	>16	II	0.5-2.0
IIID	≥3, <16	III	15 g-0.5
IVD	<3		

In the United States, the Nuclear Regulatory Commission has codified the SNM transit requirements. The transport requirements for Category I SNM are delineated in 10CFR 73.25. This section defines the performance capabilities for physical protection of ***strategic*** SNM in transit. 10CFR 73.67 delineates in-transit requirements for the physical protection of special nuclear material of ***moderate and low strategic*** significance which are equivalent to Category II and Category III SNM, respectively.

Given that typical reactor grade PWR MOX fuel assembly contains approximately 10% of plutonium per weight of heavy metal, shipments are considered Category I by the NRC based on mass of the SNM only. Due to the challenges of illicit removal of large heavy fuel assemblies from "in route" transport casks in conjunction with the complexities of extracting plutonium from manufactured MOX fuel assemblies, it is assumed this material would be reclassified if a DOE type graded approach was utilized. Through **"**Rulemaking Plan: Part 74 – Material Control and Accounting of Special Nuclear Material," NRC has recommended that a Commission paper that describes DOE's risk based categorization program be authored [7]. The outcome of this

NRC paper could positively affect the commercial viability of MOX shipments in the United States.

Currently, only the National Nuclear Security Administration (NNSA) Office of Secure Transportation (OST) has developed transport systems that meet the NRC requirements for transporting Category I quantities of SNM. Assuming the introduction of MOX fuel as feedstock to US reactors, private entities may be interested in developing this transport capability.

It is worthwhile to point out that some of the shipments shown in Table III [3] of MOX fuel were transported in the United States by private shippers prior to the DOE taking charge of this type of transport. The precedent has been set for private shippers to conduct US MOX transports adhering to NRC/DOE regulations.

Table III. United States MOX Transports [3]

Reactor	PWR/ BWR	MOX LTA Start	Total Number of Assemblies	Total Number of Fuel Rods
Vallecitos	BWR	1960s	--	≥ 16
Big Rock Point	BWR	1969	16	1248
Dresden-1	BWR	1969	11	103
San Onofre-1	PWR	1970	4	720
Quad Cities-1	BWR	1974	10	48
Ginna	PWR	1980	4	716
Catawba-1	**PWR**	**2005**	**4**	**full 17 x 17 assemblies**

International Approach

As shown in Table II, the category classifications for SNM (including Pu) utilized by the international community and NRC are identical. The key difference is in the implementation of this security. The steps in Table IV delineate the international security approach based on the IAEA standard "***The Physical Protection of Nuclear Material and Nuclear Facilities" (INFCIRC/225/Rev.4)*** **[8].**

Table IV. Overview of INFCIRC/225/Rev.4 [8]

1. IAEA recommends to Member States…. To provide a set of recommendations on requirements for the physical protection of nuclear material… during transport... The recommendations are provided for consideration by the competent authorities in the States. Such recommendations provide guidance but are **not mandatory upon a State** and do not infringe the sovereign rights of States….

↓

2. Member States develop regulations/laws governing safety/security… To establish conditions which would minimize the possibilities for unauthorized removal of nuclear material and/or for sabotage…..

↓

3. Industry adheres to domestic regulations through the development of transport plans, design of cask and trailers/trucks, and qualifications of transport drivers...

↓

4. Member States conduct inspections of industry to ensure both safety and security are being met….. the State's competent authority should ensure that evaluations are conducted …..for transport. Such evaluations, which should be reviewed by the State's competent authority, should include administrative and technical measures, such as testing of detection, assessment and communications systems and reviews of the implementation of physical protection procedures….

In France, under this approach, the Competent Authority defines the specification of secured conveyance, approves the design, and operates its communication center for real-time tracking of the shipment. The fleet of vehicles, drivers, design and manufacturing is the responsibility of the private sector with government oversight.

More extensive transports to Japan involving multiple countries and ocean transits have been successfully performed. In France, over 150 MTHM/yr of French MOX capacity is dedicated to twenty 900 PWRs with 30% of each core comprised of MOX fuel assemblies.

CONCLUSION

The harmonization of NRC/DOE safeguard categories in conjunction with the reclassification of MOX fuel assemblies based on “attractiveness levels” would be a positive first step in optimizing United States MOX shipments.

However, to successfully introduce this fuel into the United States nuclear fuel cycle, it will be necessary to align the transport process with the international community. This approach will

place the open and closed fuel cycle on a similar risk basis. The concept of privately owned and operated conveyances under governmental escorts has been shown to meet the commercial demands for MOX fuel while establishing an unblemished safety and security record for over thirty years. This approach has the additional benefit of "freeing up" US governmental resources to concentrate on higher transport priorities.

The efficiency of the international MOX transportation model is based on the assumption that the cask and conveyance designs can be developed by one engineering entity. For example, the incorporation of physical security measures into the cask design has found to aid in the optimization of the MOX fuel shipping campaigns while adhering to the appropriate safety regulations. Development of MOX transport systems amenable to the applicable MOX fuel fabrication plant and the utilities' fresh fuel assembly receipt infrastructure is also necessary. To ensure a successful outcome, the design of the US commercial MOX transport system should involve both domestic and international stakeholders.

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