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The MOX Myth

Risks and dangers of the use of Mixed Oxide Fuel

WISE News Communique 469/470

April 11, 1997

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Printed by Primavera, Amsterdam

Thanks to: Robert Jan van den Berg, Hermine Linnebank, Peer de Rijk, Yurika Ayukawa and Physicians for Social Responsibility.

Photos by: Greenpeace NL (p. 12, 35) and Jan Gevers-Leuven (p. 15, 20, 27).

Special thanks to **Stichting Vredesprojecten Nederland** and **The Margaret Laurence Fund for the Promotion of Peace and the Environment - Canada** for providing funds for the production of this issue.

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WISE Newscommunique #471 will be mailed out on 25 April 1997

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Chapter 1

Introduction

After US President Eisenhower's famous "Atoms for Peace" speech to the United Nations in December 1953, nuclear power and knowledge were no longer a military playground solely. Nuclear energy became available for civil purposes. The expectations were enormous: nuclear electricity would be so cheap and abundant, it's use wouldn't be worth metering. The ultimate goal would not be a nuclear chain with remaining wastes but a closed fuel cycle with everlasting energy.

During the first decade of commercial utilization of nuclear energy, in the 60s, it was thought that uranium would soon become scarce. The belief was that in about 20-30 years plutonium had to be used instead of uranium. Reprocessing and Fast Breeder Reactors were seen as the basis for the future of nuclear energy. This future should be reached in three stadia:

1- The first generation of nuclear power plants, mainly Light Water Reactors (LWRs) would produce plutonium.
2- The first Fast Breeder Reactors (FBRs) would be fueled with reprocessed plutonium from the spent fuel of these LWRs.
3- After a transition period, during which both LWRs and FBRs would operate together, FBRs would be the only nuclear reactors. They would "breed" more plutonium than they consumed. The newly bred plutonium inside the FBR spent fuel would be separated in special reprocessing plants, fabricated into plutonium fuel and fed into new FBRs. This would mean an infinite energy source.

The functioning of FBRs "kept the company waiting" and plutonium stocks issued from reprocessing were piling up. Reprocessing contracts that were already existing would only increase the plutonium pile in the future.

The aim of that infinite energy source has not been reached; the hope for a successful FBR program collapsed. It is even planned to rebuild some of the FBRs from breeders to burners of plutonium. Commercial utilization of FBRs is being pushed to the far future, between 2030 and 2050, if ever. But without the prospect of fast breeders and therefore of an infinite energy source, nuclear energy lost another of its promises.

As a result of the lack of perspective for fast breeder reactors (together with the amount of plutonium from dismantling of nuclear weapons), the need for reprocessing becomes more and more futile. The plutonium economy infrastructure must be kept alive until FBRs can be built again. By lack of the original justification for reprocessing, another destination for the tens of thousands kilograms of plutonium had to be found: the use of MOX in light water reactors.

MOX is an abbreviation of Mixed OXide; it is a mixture of depleted uranium and reprocessed plutonium. All nuclear fuel containing plutonium is in fact MOX-fuel, only the percentage of plutonium in the fuel varies: in FBRs it is up to 35% and in LWRs it reaches 4-8%. MOX is not a new process. The MOX fuel fabrication began in the 60s. Several countries (for example Belgium and France) opened their own fuel fabrication plants.

The nuclear industry uses several arguments in favour of MOX:

1. It supports non-proliferation, by reducing the quantity of separated plutonium and by making the diversion of plutonium more difficult.
2. It saves uranium by re-using plutonium and depleted uranium.
3. It avoids the cost of storage of large stocks of plutonium and saves up to 10% on front-end fuel cycle costs.

However, these arguments are easy to counter. We can argue that the use of MOX fuel

- has many proliferation risks
- is no solution for the problem of the storage of high-level radioactive waste
- it does not result in a substantial saving of uranium
- bears many extra safety risks, and
- is more expensive than the use of uranium fuel.

We hope that this special issue will help to increase the knowledge and improve the ability to counter the "pro" arguments used for the use of MOX. We hope that people learn that: first and most important, that MOX is an alibi for the continuation of reprocessing; that MOX reflects the hope of the nuclear industry for better times. It is important to stop MOX; it is important to stop reprocessing. It is of the utmost importance to stop nuclear power!

WISE-Amsterdam
April 1997

Chapter 2

History of plutonium policy and production

2.1 Introduction

A microscopic sample of plutonium was first isolated by Glenn Seaborg in August 1942 as part of the Manhattan Project. The first-milligram quantities were not created in a reactor, but by the irradiation of uranyl nitrate solution by the cyclotron at the University of California at Berkeley, US.[1] In December 1944 the construction of the chemical separation plants at Hanford were finished, and on February 2, 1945, Los Alamos received its first plutonium.[2] Plutonium is a highly carcinogenic, radioactive substance which does not exist in the natural environment and is only produced artificially in nuclear reactors. It is made by the irradiation with neutrons of uranium-238 in military as well as civilian nuclear reactors. Plutonium has 15 isotopes with mass numbers ranging from 232 to 246. Only two plutonium isotopes have military and commercial applications:

- plutonium-238 is used to make compact thermo-electric generators (for example satellites);
- plutonium-239 is used for nuclear weapons and for nuclear electricity.

PEACEFUL USES OF PLUTONIUM.
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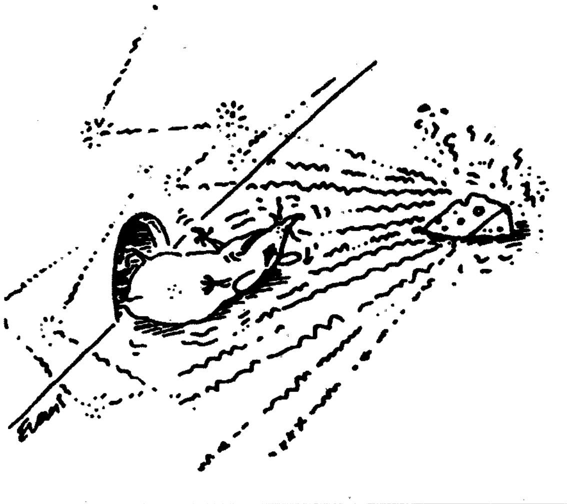

The plutonium isotopes 240, 241 and 242 have no commercial application and are merely contaminants.[3]

The formed plutonium is contained inside the spent fuel rods. The longer the fuel is inside the reactor, the more contaminant plutonium isotopes are formed. In military reactors the fuel is replaced after some weeks in order to obtain as much plutonium-239 as possible. In commercial reactors this is done after three to four years.

2.2 Plutonium grades: All plutonium is weapon-grade

The minimal amount of nuclear material necessary to sustain a chain reaction is called the critical mass. The smallest theoretical critical mass of Pu-239 is a few hundred grams.[4] The amount of plutonium used in fission weapons is in the 3-5 kg range.

Plutonium has been classified into grades by the US Department of Energy (DOE)[5]

Table 2.2 Plutonium grades

Grades of plutonium	Content of Pu-240
Supergrade	2-3% (>97% fissile Pu)
Weapon grade	<7%
Fuel grade	7-19%
Reactor grade	19% or more

This classification is, however, somewhat misleading. Fuel grade and reactor grade may be less suitable but still can be made into a nuclear weapon. There have been at least two known nuclear weapon tests with civil plutonium. In 1953, Britain exploded a 12-kiloton bomb, named Totem I, at one of their test sites in Australia.[6] In

1962, the US conducted an underground test with reactor grade plutonium at the Nevada test site.[7]

2.3 Plutonium production

During reprocessing, plutonium is separated from spent nuclear fuel. Reprocessing has pure military origins. Development of this technology dates back to the US of 1944, to the Manhattan Project whose only goal was the developing and production of the nuclear bomb. The plutonium was produced in dedicated military reactors with low-burn-up fuel. Fuel in power reactors is irradiated for longer periods to reach a higher burn-up, because the fuel irradiation generates the heat for the electricity production. The military purpose is the production of plutonium and therefore the burn-up is kept low to produce a plutonium-239 as pure as possible. It is important to keep the presence of higher isotopes, particularly plutonium-240, to a minimum.[8]

Reprocessing plants handle spent fuel mechanically and chemically in order to separate plutonium from mainly uranium and other fission products. Reprocessing is an extremely polluting technique mainly due to massive radioactive releases in air and water.

2.3.1 Civil Pu production

Civil reprocessing was applied on an experimental scale from 1966-1974 by the Eurochemic reprocessing plant in Dessel, Belgium, and from 1972-1990 by the WAK in Karlsruhe, Germany. From the late 1960s on, largescale reprocessing of spent fuel from commercial nuclear power plants started: in France the Marcoule plant UP1 (1958-1997) and La Hague UP2 (1966-1976); in the UK Windscale B-204 from 1969-1973; and in the US, West Valley (1966-1972).[9]

The two largest reprocessors and plutonium companies in the world are British Nuclear Fuel Ltd. (BNFL) and the French Compagnie Générale des Matières Nucléaires (Cogéma). Based on the nominal production capacity of 1600 MT/year for La Hague[10] and 900 MT/y for Sellafield[11] the maximum Pu production in the next 20 years will be about 500,000 kg Pu on the assumption of an average of 1% Pu in the spent fuel.

Table 2.3 Estimated civil world plutonium production[12]

Country	Plant	Prod. Cap. spent fuel (ton/yr)	Max. Pu prod. (kg/yr)	Start-up
India	Tarapur	100	1,000	1982
	Kalpakkam	100	1,000	1996
Japan	Tokai-mura	90	900	1977
France	UP-2 800	850	8,500	1994
	UP-3	800	8,000	1990
Russia	RT-1, Mayak [13]	400	2,500	1977
UK	THORP	700	7,000	1994
	B-205 MAGNOX	1,500	4,500	1964
Maximum total annual Pu production			33,400	

At present, about half of the annual plutonium production in civil nuclear fuel is separated in reprocessing plants. Each year about 60,000 kg of plutonium is produced in nuclear reactors, from which about half (some 33,400 kg) of plutonium is separated.

The estimated cumulative civil plutonium production in civil nuclear reactors until the end of 1995 is about a million kg of plutonium, from which about 800,000 kg is inside the spent fuel. About 190,000 kg of plutonium has been reprocessed. Of this plutonium 141,000 kg is stockpiled and 49,000 kg is recycled as MOX fuel in LWRs and FBRs.[14]

The amount of civil separated plutonium will increase enormously. The next 20 years the cumulative production of civil reprocessing plants will be about 600,000 kg of plutonium. This is twice the total military plutonium production from World War II till now.

2.3.2 Military Pu production

The five official nuclear weapon countries -- the US, Russia, Great Britain, China and France -- have produced an estimated 300,000-kg plutonium in the past 50 years.

In the US all 14 military reactors were closed by 1988. By then the reactors had produced about 100,000 kg weapon-grade plutonium and 11,000-kg fuel- and reactor-grade plutonium.[15]

In the USSR an estimated 177,000 kg of military plutonium were produced by 13 military reactors and separated by the end of 1993. Only three military reactors are still in operation.[16] Since about 1985, some 10 thousands of nuclear weapons have been dismantled. As a result, the stocks of weapon-grade plutonium are increasing. Both the US and Russia declared about 50,000-kg plutonium each as surplus stocks.

The UK, France and China together produced and separated about 12,000-kg weapon-grade plutonium.[17]

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Chapter 3

MOX policy and plans

3.1 Fast Breeder Reactors

The first reactor ever to generate (a modest amount of) electricity was a Fast Breeder Reactor (FBR) in Idaho, US. It went into operation in December 1951.[1] In spite of more than four decades of experience with FBRs, the option has proved to be a complete failure. Only in the very long term are FBRs seen by an optimistic nuclear industry as a commercially viable option. Japan plans to build FBRs again around 2030.[2] By now 13 FBRs have been closed worldwide. Only 10 FBRs remain, five of which are more or less regularly functioning. The other five are being repaired (Monju, Phenix) or rebuilt (Superphenix) or in hot standby, such as the FFTF. Three FBRs are little pilot plants: the FBTR in India, the Japanese Joyo and the EBR-2 in the US.

The FBRs were the first to use MOX fuel, except the Russian FBRs which use High Enriched Uranium. The share of plutonium in FBR MOX however is much higher: about 35% against 4-8% plutonium in LWR MOX fuel and the whole core is MOX fuel as in LWR only one-third of the core contains MOX fuel.

***Table 3.1** Present Fast Breeder Reactors*[3]

Country	Name	Capacity (MW)	Start up
France	Phenix	250	1974
	Super-Phenix	1242	1988
India	FBTR/ Kalpakkam	14	1985
Japan	Joyo	100 th	1976
	Monju *	300	1995
Kazakhstan	BN-350	150	1973
Russia	BOR-60	15	1969
	Bjelojarsk 3	600	1981
USA	EBR-2	62.5 th	1963
	FFTF**	400 th	1982

* *still closed after sodium-fire on 8 December 1995*

** *Put in hot standby in 1992* [4]

3.2 MOX fuel production

By the end of 1997 there will be four commercial fuel fabrication plants in the world for the production of MOX for Light Water Reactors. These four are:

- The Sellafield plant (SMP), England, with a production capacity of 120 ton MOX fuel/year, will start operation at the end 1997;[5]
- the Complexe de Fabrication des Combustibles Cadarache (CFCa) in France with an annual capacity of 15 tons.[6] The CFCa plant, owned by Cogema, was first meant to produce fuel for the fast breeders Rhapsodie, Phenix and Superphenix but has been rebuild for the fabrication of LWR MOX.[7]
- Etablissement Melox at Marcoule (France) with an annual capacity of 120 tons; increase is planned to a capacity of 160-200 tons after the year 2001.[8]
- the Belgonucléaire Usine de Fabrication d'Eléments Plutonium (P0) at Dessel, Belgium, with 35 tons/year started in 1973.[9]

So including the British MDF, the total capacity worldwide by 1998 to produce MOX fuel for Light Water Reactors would be roughly 313 tons per year. Expansion of the plants at Cadarache, Melox and Dessel are foreseen. The estimated world MOX fuel production in the year 2000 will be about 350 tons/year.

Assuming a plutonium content of 6% in the MOX fuel, the quantity re-used plutonium in the year 2000 will be 21,000 kg. This capacity is far too short considering the annual amount of 33,400-kg of plutonium being separated at reprocessing plants. Let alone the US and Russian weapons plutonium if they ever decide to use it as MOX fuel.

3.3 MOX use

LWRs are designed to use enriched uranium as fuel. In order to use MOX fuel, the reactors have to be adapted and relicensed.

An average of 30% of the uranium fuel in the core is replaced with MOX. It is important to maintain as much as possible the behavior in the reactor as with a non-MOXed fuel.

Worldwide there are about 23 LWRs using MOX fuel: in Belgium, France, Germany, India and Switzerland. Most of those are Pressurized Water Reactors (PWRs). Currently only four BWRs (Gundremmingen and Tarapur) are using MOX. There are only limited expectations and plans for MOX use in Boiling Water Reactors.[12]

***Table 3.2** Current and planned largescale LWR MOX fuel production plants*

Country	Plant	Prod. Cap. (ton/yr)	Prod. 1996	Start up
Belgium	Dessel	35	35	1973
UK	MDF	8	8	1993
	SMP [10]	120	-	1998
France	CfCa	30	24	1989
	Melox [11]	120	58	1995
Total		**313**	**125**	

***Table 3.3** Reactors with MOX-fuel (as of 31-12-96)**

Country	Reactor name	% Pu in MOX	MOX use since
Belgium	Tihange-2	7.5	3/1995
	Doel-3	7.5	5/1995
France	St. Laurent B1	5.3	1987
	St. Laurent B2	5.3	1988
	Gravelines-3	5.3	1989
	Gravelines-4	5.3	1989
	Dampierre-1	5.3	1990
	Dampierre-2	5.3	1993
	Blayais-2	5.3	1994
	Tricastin-4	5.3	1996
	Tricastin-?		1996
Germany	Grafenrheinfeld		1986
	Brokdorf		1992
	Grohnde		1986
	Neckar 1		1985
	Phillipsburg 2		1984
	Unterweser		1985
	Gundremmingen B		1995
	Gundremmingen C		1995
India	Tarapur 1	5	1994
	Tarapur 2		1995
Switzerland	Beznau-1		1978
	Beznau-2		1984

** Sources: see the Country Reports in Chapter 4.*

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Chapter 4

Country overview

4.1 Belgium

In 1994, Belgium decided to stop reprocessing its own spent fuel and make no more further reprocessing contracts. It wanted to use up the 4.6 tons of separated plutonium issued from older contracts as MOX fuel in its own reactors.[1]

All seven Belgian commercial reactors have reprocessing contracts with Cogéma at La Hague, France. The reprocessing contracts total 600 tons of spent fuel (with about 6,000 kg Pu) for the period up to 2000.[2] In 1963, the research reactor BR-3 started to use MOX on an experimental scale: a world premier.[3] In 1995, MOX has been inserted for the first time in two of the seven LWRs: Tihange-2 and Doel-3.

MOX fabrication

The Belgonucléaire plant in Dessel called P0, with a capacity of 35 ton/year, has been in operation since 1973, fabricating MOX fuel for FBRs. MOX for LWRs has been commercially produced by the Dessel plant since 1985, for LWRs of Belgium, France, Germany, and Switzerland. As of October 1996, over 300 tons of MOX fuel was fabricated. Belgonucléaire hopes to expand the production of the P0 to 40 tons of MOX a year.[4]

Belgonucléaire wanted to extend the facility by adding two new production lines called P1 with an annual capacity of 60 tons. Due to irregular licensing procedures, it has been brought to court, and the plant has never been constructed.

In July 1996, Belgonucléaire proposed to help the US to dispose of excess weapon Pu as MOX fuel. The company believes it would be possible to build a MOX fuel production plant in the US, to be used solely for producing MOX fuel from weapon Pu. Its design of the MOX P1 plant would be adaptable for use in the US. BN and its competitors Cogéma and BNFL are willing to produce test assemblies of MOX fuel for the US Department of Energy (DOE) at their European MOX plants. DOE does not intend however to ship its 50,000 kg of surplus weapons Pu to Europe for MOX production.[5]

4.2 Canada

The official nuclear policy has always been not to reprocess the spent fuel from the CANDU nuclear power plants. MOX fabrication costs for the CANDU reactors are not very favorable. The costs for fuel fabrication using plutonium would be "between five and ten times" the costs they face for natural uranium fuel. The US's DOE, which ordered the study, decided to keep the economic data classified.[6] Nonetheless the utility Ontario Hydro plans to burn MOX from US-Russian weapon-plutonium in its nuclear reactors. The Canadian government *"has agreed in principle"* to support MOX use in CANDUs, *"the challenge is going to be how it would be funded. The government won't subsidize Ontario Hydro"*. Canada will expand its cooperation on MOX with Russia in trying to construct a CANDU MOX plant in Russia.[7]

The US in cooperation with Ontario Hydro wants to test MOX fuel from US weapons plutonium in the Canadian Chalk River Laboratory NRU reactor, to see how the fuel will behave *(see Chapter 4.12: United States).*

4.3 European Union

The Directorate General for Energy of the European Union (EU) is funding a number of studies related to the disposition of fissile materials. The EU is currently funding 133 of the 202 projects of the International Science and Technology Center (ISTC), about 10% of which relate to nuclear fuels and storage of nuclear waste. The ISTC was set up in March 1994 by the EU, Japan, Russia and the US, to provide new work for unemployed Russian nuclear scientists. A US$580,000 study, Project N.369, carried out in the framework of the ISTC, is done on the "technical and economic feasibility of the use of ex-weapons plutonium and civil plutonium as fuel for both Fast Reactors and Light Water Reactors". The Project N.369 study involves all European companies with a plutonium-recycling technology:

Belgonucleaire, BNFL, Cogéma and Siemens. The project considers three options for the use of dismantled weapons:

- burning MOX in FBR on a single site (called the "Russian option");
- burning MOX in a combination of existing or future Russian LWR's (the VVERs) as well as in Fast Reactors (the "European option"); and
- burning MOX in VVERs, modified to handle 100% MOX cores (the "American option").

Another ISTC project, N.290, a three-year project funded by Japan and the EU, studies the transformation of Pu from dismantled nuclear weapons into Pu oxide and into MOX. Involved are: Siemens, BNFL, the EU Institute of Transuranium Elements in Karlsruhe, Germany, and Japan's Power Reactor & Nuclear Fuel Development Co. (PNC).[8]

4.4 France

Use of MOX fuel

EdF (Electricité de France) operates 58 Pressurized-Water Reactors: 20 1,300MW reactors, 34 900MW reactors, and four 1,450-MW reactors. EdF first loaded MOX in the PWR Chooz-A on an experimental scale in 1974. The Belgian-French reactor was closed in 1991.[9] Since 1987 nine of the 900 MW reactors have partially been loaded with MOX fuel: St. Laurent des Eaux B1 (1987), St. Laurent B2 (1988), Gravelines 3 and 4 (1989), Dampierre 1 (1990) and Dampierre 2 (1993), Blayais 2 (1994) and Tricastin 4 (June 1996)[10] and another one in Tricastin in November 1996.[11] Since January 1997 one more reactor has been loaded with MOX fuel.[12]

Only those reactors can be loaded with MOX fuel that meet certain requirements:

- the authorization decree for the creation of a nuclear plant must specifically mention the use of MOX fuel
- the reception, storing and reloading of a MOX assembly as well as the operation of the reactor need authorization by the Ministers of Environment and Industry after advice by the Minister of Health Affairs.[13]

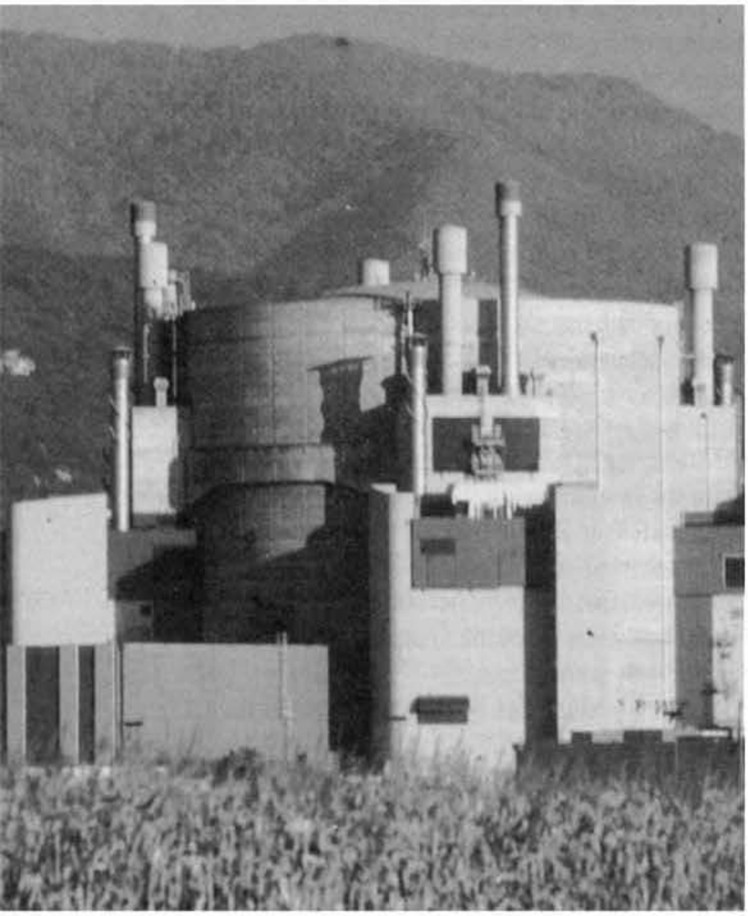
Sixteen reactors have such a decree: Blayais 1 and 2, Dampierre 1 to 4, Gravelines 1 to 4, St. Laurent des Eaux B1 and B2, and Tricastin 1 to 4.

Nearly all spent fuel from French reactors is being reprocessed. The annual amount of separated plutonium at the moment is about 8,000 kg. About 28 900MW LWRs are needed to burn this quantity of plutonium as MOX. Now only ten LWRs are burning MOX. EdF contracted to reprocess 1,000 ton of spent fuel past 2000.[14] Therefore EdF desperately wants more reactors to be licensed for the burning of MOX.

By 1998, all 16 reactors allowed are planned to burn MOX fuel. They will use about 100 tons of MOX a year. With a plutonium content of 5.3%, that is about 5,300 kg Pu/yr. In this way EdF will never succeed in loading all French-separated plutonium as MOX fuel into the licensed LWRs, since about 8,500 kg of plutonium will be separated annually in the future. Each year 3,200 kg of separated plutonium will have to be stored. To use all the annual separated plutonium, EdF has to load 162 tons of MOX into 28 PWRs from the 900 MW series.[15] This is exactly the number of reactors EdF wants to get licensed to use MOX at the end of the century. This, however, needs larger MOX fuel production capacity. Cogema and Framatome have launched a three-year investment program in the Melox fuel plant at Cadarache.[16]

A shortage of MOX fuel production capacity is not the only problem EdF faces. Another serious limitation to the use of MOX fuel in all 28 nuclear power plants of the 900 MW series, or even in the 20 PWRs of the 1300-MW series, is the fact that load following is not yet allowed for reactors with MOX fuel.[17] Load following means that reactors are allowed to operate under their maximum output. Because EdF has a large overcapacity in electricity generation, many nuclear reactors have to be operated under their maximum output, when electricity demand is low (at night, in the weekends and in summer). The reactors have the ability to operate between 20% and 100% of full power. While load following is not allowed with MOX fuel and if most or all PWRs are loaded with MOX fuel, the plants have to be shut down completely, instead of operating at low-power levels. This will have serious economic disadvantages, as it makes it very difficult if not impossible to follow the changing demand hour by hour.

The burn-up of MOX fuel is now limited to 36 MWD/kg. EdF wants to increase it to 52 MWD/kg.[18] There is little chance this will be permitted this century, especially after a test with MOX fuel at the Cabri Research Reactor ended in the rupture of the fuel.[19]



Superphenix

Fast Breeders

France has two Fast Breeders: Phenix and Superphenix. The country is the best example of the failure of the FBR technology. Most of the time these reactors are shut down, under repair or functioning less than half of their power. Superphenix will not (try to) breed anymore but will be rebuild into a research reactor for the burning of plutonium and transmutation of other actinides.[20] However, the French supreme administrative court, the Conseil d'Etat, annulled the 1994 operating license in late February 1997. The licensing decree assigned a "new purpose" of research and demonstration to the reactor's operation that was out of step with owner Nersa's 1992 application for restart and the dossier it submitted to public inquiry.[21] Phenix, in its turn, is also used for Pu-burning research and into the incineration of actinites. For these two research programs CEA is willing to continue operation for the next 10 years.[22]

MOX fabrication

The MOX fuel fabrication plant in Cadarache has been in operation since 1963 mainly for producing fuel for fast-breeder reactors, but has been engaged in fabricating MOX fuel for LWRs since 1990.[23] The Melox plant in Marcoule started operations towards the end 1994 and has a production capacity of 120 tHM/yr. The MOX production at the Melox plant stays behind expectations. The production in 1996 was 58 tons instead of the expected 85 tons.[24] Melox is owned by Cogéma and Framatome.

Reprocessing

The French electricity utility EdF has the policy to reprocess (nearly) all spent fuel from their LWRs. Some 350 tons of spent fuel, for which no reprocessing contracts are signed, will be stored each year in cooling pools at the reactor sites. In the past, the spent fuel from the GGRs has also been reprocessed. As the last GGR, Bugey 1 closed in 1994, the reprocessing plant in Marcoule, dedicated to reprocess GGR spent fuel will close in 1997.[25]

In 1995 about 750 tons of spent fuel from EdF was reprocessed by Cogéma in the UP2-800 plant at La Hague. EdF has asked Cogéma to reprocess 850 tons/yr (the full capacity of the UP2-800 plant) in the future. Then, the quantity of separated plutonium will be about 8,500 kg Pu/yr. It is very doubtful if the full production capacity will be realized each year.[26]

Zero value for plutonium

EdF uses some special tricks in calculating the costs of MOX fuel and enriched uranium fuel. Until 1995 EdF assigned a value to the plutonium content in the MOX fuel, equivalent to enriched uranium in uranium oxide fuel. In 1995 EdF shifted to a zero value for plutonium in MOX. In this way, the price difference between MOX and uranium fuel seems much smaller than it really is. Beginning in 1995 EdF has been loading the entire reprocessing cost to the uranium oxide (UO_2) fuel.[27] In this way, the UO_2 fuel is made artificially more expensive, while at the same time the MOX fuel seems much cheaper than it really is. The French nuclear community is putting a lot of effort in trying to solve the present problems with MOX fuel and to develop better and cheaper MOX fuels. A quarter of the FF400 million (about US$80 million) spent annually on nuclear fuel R&D, is devoted to MOX development.[28]

4.5 Germany

Till 1994, the official governmental policy obliged the utilities to reprocess all their spent fuel. This obligation has been changed. Direct storage of spent fuel is permitted under a renewed atomic law of May 1994. Since this policy change, some reprocessing contracts have been cancelled. The cancellation of these contracts of the German utilities HEW and RWE totalling 545 tons of spent fuel will decrease the quantity of separated plutonium and, therefore, the quantity of MOX made with the plutonium.[29]

The public resistance to direct temporary and final storage of spent fuel in Germany, however, is so strong that several utilities started negotiations to sign contracts with the UK and France for temporary storage of German spent fuel at their reprocessing plants, with an option to reprocess the spent fuel at a later moment.[30] Later, the existence of these contracts were denied by Cogema.[31]

Fierce opposition to the Castor transport of High Level Waste returning to Gorleben, Germany, from La Hague in France will probably have consequences on the decisions of German utilities about spent fuel management. In March 1997, these actions cost the state government of Lower Saxony between US$70 million and US$100 million, solely for the 30,000 police force, during that week.[32] Estimates about property damage costs due to sabotage and bomb attacks are not given yet, but could be of the same attitude.

If future transports of German spent fuel to Gorleben or to the other facility for interim storage of high level waste, Ahaus, are not possible, "we must either have more storage capacity built at the nuclear reactor sites or we must sign additional reprocessing and storage contracts with BNFL or Cogema", one utility official said after last years shipment to Gorleben. Seven reactors are possibly facing shutdowns due to lack of storage unless the spent fuel is shipped to foreign reprocessors.[33]

MOX use

The Obrigheim plant started to use MOX fuel on an experimental scale in 1972. The experiment stopped in 1976.[34] Unterweser and Neckarwestheim 1 reactors received the first MOX licenses in the late 80s. Grafenrheinfeld, Grohnde, and Philippsburg 2 reactors came next. Brokdorf, which started operation in 1986, was the first reactor that possessed a MOX license from the beginning.

Emsland, Isar 2, and Neckarwestheim 2, all of which started operation in 1988-89, have been constructed with MOX license. The first permit for boiling water reactors, Gundremmingen B and C had been granted in 1994.[35] Not all have been loaded with MOX yet. Gundremmingen B+C are loaded in July 1995.[36]

By the beginning of 1997 eight reactors have actually used MOX: Brokdorf, Grafenrheinfeld, Grohnde, Neckar 1, Philippsburg 2, Unterweser and Gundremmingen B+C.[37]

MOX fabrication

Siemens had two MOX fabrication plants in Hanau; one small demonstration facility in operation and a new one which was almost complete for fullscale operation with an annual capacity of 120 tons. But the demonstration facility was closed down in 1991 when there was a contamination accident. This old facility had safety concerns that could not meet the safety standards prescribed in the new German Atomic Energy Law.

The commercial scale facility in Hanau received partial license in 1987 and construction was started, but in 1993, the Higher Administrative Court declared three of the partial licenses to be unlawful.[38]

In April 1994, it became apparent that it was impossible to gain approval of the state government of Hesse for operation because of safety and economic reasons. The utilities decided not to finance completion of the new plant nor to keep paying the maintenance costs. Siemens finally gave up the plan in 1995 and declared itself "forced to abandon MOX fuel production in Germany."[39] As a result of that, the German utilities were forced to seek new MOX fabrication contracts in France and Belgium. In anticipation of these contracts with German utilities, Cadarache has invested over $100 million to upgrade the plant.[40] For a period of 10 years 25 tons of MOX fuel per year (containing 5%-6% Pu), will be fabricated for the Germans.[41] The Pu for this MOX comes from German spent fuel, reprocessed in France at La Hague under the so-called UP3 baseload contracts. The Germans also contracted for MOX fuel production with Belgonucleaire at its plant in Dessel in Belgium.[42]

An August 1996 court decision in Berlin may put an end, however, to expansion of MOX use in Germany. The court decided to forbid the use of foreign nuclear fuel in German nuclear reactors.[43] As all German MOX fuel fabrication plants are closed, all MOX fuel has to be imported. According to the court, new research must be done about the possible link between the use of a new type of nuclear fuel and the incidence of leukemia around the Kruemmel nuclear power plant near Hamburg, before the use of the new fuel is allowed.

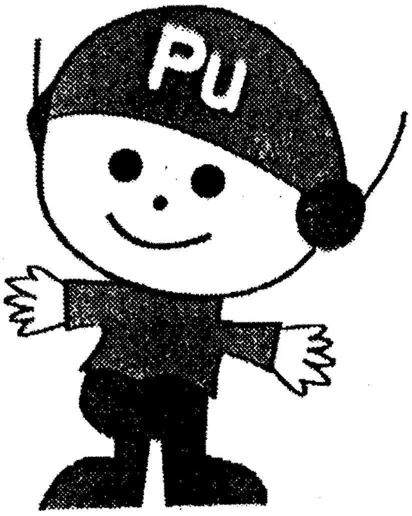
4.6 India

Against the wishes of the US State Department, in October 1995 India loaded home-made MOX fuel into its Tarapur-2 BWR, which was supplied by the US. Tarapur-2 will be reloaded with a core containing more MOX fuel assemblies than in Tarapur-1. In 1994, India loaded two MOX fuel assemblies in Tarapur-1, also supplied by the US. In coming years the Tarapur BWRs will be loaded with far less than 30% MOX fuel. India has notified the IAEA, which safeguards the Tarapur reactors under a trilateral agreement with India and the US. No decision is made about the handling of the spent MOX fuel. It is expected that India will dispose of the spent MOX as waste. The spent MOX fuel will be under IAEA safeguards. Reprocessing of the spent MOX fuel in a reprocessing plant dedicated to separation of plutonium from spent FBR fuel or other Pu fuel, would "contaminate" that facility with IAEA safeguards. That is something India would like to prevent. A reprocessing plant under construction at Kalpakkam, will be used to separate plutonium from unsafeguarded spent fuel from India's Pressurized Heavy Water Reactor. It will take several years to separate enough plutonium for the initial core of the 500-MW prototype FBR, which India still hopes to build. As FBRs are able to produce weapon-grade plutonium and India will not allow IAEA safeguards at its FBR, it seems as if India plans to use this FBR for military use. It is a clear example of the proliferation possibilities of the fabrication and use of MOX fuel.[44]

4.7 Japan

Japan wants to keep the possibility open to build Fast Breeder Reactors at around 2030. That is the justification to continue reprocessing and the use of plutonium. And, on the other hand, the amount of existing plutonium is another argument to use it in FBRs or in LWRs. The sodium fire on December 8, 1995, in the recently completed Monju FBR and the scandals surrounding the accident seemed to have created a new situation. The accident at Tokaimura on March 11, 1997, and the contamination of 35 workers[45] will most likely strengthen the public concern and opposition about the Japanese nuclear policy. On January 20, 1997, an interim report of the Nuclear Energy Sub-Committee of the Advisory Committee for Energy to the Minister of International Trade and Industry (MITI) stressed the necessity of implementing MOX use in light water reactors to cope with the stalled FBR program and the accumulating plutonium surplus which amounts to nearly 15,000 kg (end 1995).

This report can be regarded as the official response to the public concern and is a follow-up of the old pro-plutonium government policy.[46]
In February, Japanese nuclear utilities agreed to burn MOX fuel into 18 LWRs. Four of the 18, two BWRs and two PWRs, will load MOX by the year 2000. By 2010 all 18 LWRs will use MOX fuel. This is a clear policy shift from the earlier emphasis to burn plutonium in FBRs.[47] Until now, MOX fuel is only used in the FBRs Joyo and Monju and in the ATR Fugen and, so far not in LWRs. From 1966-1993 more than 123 tons of MOX fuel have been used.[48]



In 1993, a public relations campaign launched by the Japanese Power Reactor and Nuclear Fuel Development Corp. (PNC) produced a new cartoon character: Pluto Boy. Among the outrageous claims this animated character made were that plutonium is safe enough to drink and is extremely difficult to use to make nuclear weapons. In a television ad, a friend of Pluto Boy was shown drinking a glass of liquid containing plutonium, followed by the claim that "almost all of it excreted." Following the sound of a flushing toilet, the caption reads, "Refreshed, and feeling fine."
Source: MYTHBusters 10
Credits: PNC

MOX fabrication
Japan has four small-scale MOX fuel production plants[49]:

- Tokai-mura (PFPF), in operation since 1991, production capacity 35 tons/year of MOX for LWRs and ATRs (Advanced Test Reactors). Due to the fact that there is not yet any MOX fuel in Japanese LWRs the production of such fuel will be zero or very little.
- Tokai (PFPF-FBR), in operation since 1988, production capacity: four tons/year for FBR's
- Tokai (PFFF), in operation since 1972, production capacity: nines tons/year for ATRs
- Tokai (PFFF-FBR), in operation since 1972, production capacity: one ton/year for FBRs

At the PFPF MOX plant a 70 kg discrepancy of plutonium in book values and physical inventory was discovered two years ago. After long discussions with the IAEA, Japan agreed to a US$100 million upgrade of the plant. By now, the discrepancy is lowered to below 10 kg. The plutonium was said to have accumulated inside the equipment.[50] The policy of all nuclear utilities is to reprocess all their spent fuel, in the UK, France and in Japanese reprocessing plants. Since 1977 a reprocessing plant at Tokaimura is in operation, with a design capacity of 210 ton/year and an average effective capacity of 75 ton/yr.[51] A commercial scale reprocessing plant is under construction in Rokkasho-Mura, with a capacity of 800 tons spent fuel/year. This plant has been delayed several times and the estimated costs have doubled to US$16 billion. It is now expected not to go into operation until 2003.[52]
Over the next 15 years about 2,000 kg of fissile Pu/year will return from European reprocessing plants in the form of MOX fuel, totalling 30,000 kg fissile Pu separated in Europe.[53] After years of negotiations it was made public that the MOX will be manufactured by Belgonucleaire's MOX plant at Dessel in Belgium.[54] On February 10, 1997, the document which resolved the problem of allowing Belgonucleaire to fabricate the MOX was signed between Belgium, Japan and the European Commission. They detail the conditions under which an initial amount of Japanese-origin Pu can be moved from La Hague to Dessel. The exchange was necessary because Japan has no

agreement for nuclear cooperation with Belgium. The conditions are in conformity with the international non-proliferation framework, and subjects the material to Euratom and IAEA safeguards. An initial 221 kg of plutonium will be transferred from La Hague to Dessel by September 1997, followed by 262 kg by July 1998. A total of 3,088 kg of uranium will be shipped from Japan to Dessel for incorporation into the MOX elements.[55]

4.8 Netherlands

One commercial nuclear reactor is in operation: a 480-MW PWR at Borssele since 1973 and which will be closed in 2004. There was also a 59-MW BWR at Dodewaard, which went into operation on March 26, 1968, and was closed on March 26, 1997. The long established policy of the utilities is to reprocess the spent fuel. Several reprocessing contracts have been signed with La Hague and Sellafield. In total, Dodewaard and Borssele will produce 3,850 kg of plutonium. Some 200 kg of plutonium that was sold to the FBR Kalkar will fall back again to the original owners, since Kalkar never went into operation, and is now sold as a luna-park. Plutonium is also sold to the French Superphenix FBR. The Netherlands are partners in both projects.[56]

In the past, some MOX fuel has been burned on an experimental scale in Dodewaard. Nowadays no MOX is used anymore, nor are there any official plans to do so in the future.

Kokx, a spokesperson of the owner of Borssele, EPZ, expects the separated Pu would be sold to foreign customers for MOX in the French Melox facility. He expects no construction of a plutonium storage facility in the Netherlands.[57]

4.9 Russia

The former USSR had the ambition to build three new FBRs but Russia, it's "successor", does not have the funds. The Russian FBRs did not use MOX fuel, but High Enriched Uranium. Russia has no experience with fabrication or use of MOX in LWRs. Still, Minatom (Ministry of Atomic Energy) is interested in building MOX fuel fabrication plants in Russia, with financial and technical assistance from other countries. For the fiscal year 1995 Minatom requested US$85 million for producing MOX fuel from ex-weapons plutonium, but received much less. Russia would still have a weapons plutonium inventory of 125,000 kg. The civil plutonium stocks total 72,000 kg.[58] The intention was to export this Russian MOX to Western countries. Too much problems had to be solved, however, to realize these plans. The G-7 approved in October 1996 the burning of Russian weapons-Pu in the BRD. The German administration decided, however, not to import and burn this plutonium on security grounds. They fear sabotage and terrorist attacks of the plutonium transports (about 60 shipments of weapon-grade plutonium/year). An official said: *"There was no way we were going to take that risk"*.[59] For the German utilities the use of Russian military plutonium as MOX fuel in German reactors would have been a first step to discuss the sending and storage of German spent fuel to Russia.

The justification for all plans to fabricate Russian military plutonium into MOX fuel is prevention of proliferation risks. Because Russia is a Nuclear Weapon State (NWS), the IAEA does not safeguard any plutonium stored in Russia. It is reported that Russian safeguarding of military plutonium stocks is quite inadequate. In the past months, BNFL, Siemens, Cogéma and Belgonucléaire proposed plans to build pilot MOX plants in Russia. Russia has already pilot MOX fabrication plants in Mayak and Dimitrovgrad.[60] Almost 5,000 kg of military Pu will be generated annually from dismantling Russian nuclear weapons.[61]

4.10 Switzerland

There are five PWR reactors in operation and two reactors are using MOX fuel assemblies. The first reactor to install MOX was Beznau 1 (1978), Beznau 2 followed in 1984. Belgonucléaire started to fabricate MOX fuel for Goesgen in 1996.[62] But Goesgen will not be loaded with MOX fuel before August 1997.[63]

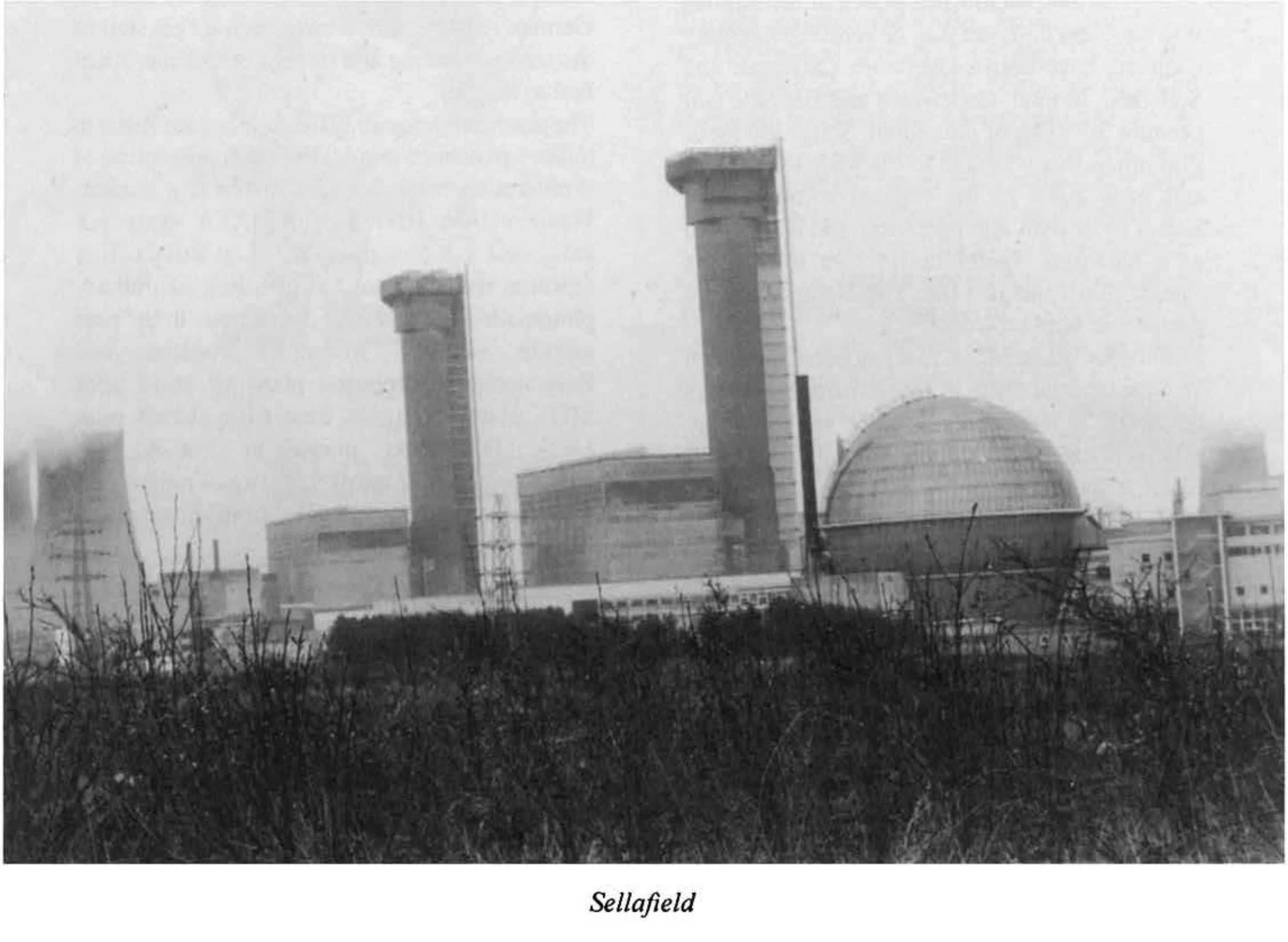
It is expected that MOX burning will continue in the two Beznau reactors till the end of their lifetimes, around 2005. The MOX spent fuel will be stored and not reprocessed. The Beznau plant has specially sealed dry-storage areas for MOX fuel awaiting loading.[64]

Switzerland plans to receive 2.2 tons of plutonium from its reprocessing contracts by the year 2003. And all the five reactors are licensed to receive MOX fuel.[65]

4.11 United Kingdom

In the UK, both FBRs have been closed. The Dounreay Fast Reactor, 15 MW, was closed in 1977, the 270-MW PFR, also at Dounreay, was closed in 1994 because the government stopped funding it. Expenditure for research and development of FBRs totalled 4 billion pounds from 1960-1995.[66] This is some US$6 billion in January 1993 exhange rates.

In Sellafield are two MOX fabrication plants for Light Water Reactors: MDF, in operation since October 1993, with a capacity of eight ton/year and a largescale commercial MOX fuel fabrication plant, the SMP, with a production of 120 ton/year for LWRs, which is still under construction.[67] Start of operation is postponed and now expected in 1998.[68] However, the SMP is constructed solely to meet the needs of BNFLs foreign reprocessing customers, notably Japan and Germany. It is very remarkable that no utility in the UK plans to use MOX in its reactors.



Sellafield

4.12 United States

In the US, development and construction of FBRs was abandoned earlier than in other countries. The last experimental FBR in operation, Fermi, was closed in 1972. The Clinch River FBR, under construction since 1976, was cancelled in 1983, as a (late) consequence of President Carter's Nuclear Non-Proliferation Act from 1978.[69] By then, breeder reactors and reprocessing were seen by the US government as too proliferation prone for civil use. The US put a lot of pressure on countries like Pakistan, Taiwan, South Korea and North Korea, to stop their reprocessing program. However, they didn't try as hard and didn't succeed to convince European countries to do the same. MOX production in the US has been conducted in the past by Westinghouse, Exxon Nuclear, Gulf United Nuclear Fuels and General Electric. These were all laboratory-scale facilities.[70]

On January 14, 1997, a record of decision has been signed by the outgoing Energy Secretary Hazel O'Leary, setting the Department of Energy on a dual-path approach to disposing of the 50 tons of excess weapon-grade plutonium taken from the dismantled nuclear warheads. The Department Of Energy (DOE) will pursue two options: -- the MOX track, burning the excess plutonium as MOX fuel in existing civil reactors. - vitrifying the Pu, that is, mixing it with molten glass and other materials.[71]

The US continues research and testing of the MOX option in Canadian nuclear reactors, the CANDUs. The Los Alamos National Laboratory (LANL) wants to export 1.04 kg of plutonium for MOX fuel to Atomic Energy of Canada Ltd.'s (AECL) Chalk River's NRU reactor for testing. But the DOE pulled back its application for a license authorizing the plutonium export when non-proliferation groups complained that the department was jumping the gun by moving ahead with the export and testing while still reviewing the plutonium disposition options.[72] But after the DOE's dual-path decision they renewed the bid and AECL announced the tests would take place in during the summer of 1997.[73] Opponents claim that the test program "is undoubtedly being watched carefully by other countries interested in plutonium options" -- including South Korea, India, Romania and Argentina, all of which have CANDU reactors and are thought to have had "an active program to develop nuclear weapons".[74] Because MOX has been produced in the US only a small scale, new MOX plants would have to be built or the partially built Fuel Materials Examination Facility at Hanford, Washington, be completed. The FMEF was built in the 1970s to produce FBR fuel.[75]

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Chapter 5

The MOX myths: only lies

The main arguments used by the nuclear industry[1] to justify the use of plutonium as MOX fuel in LWRs are:

1. It supports non-proliferation, by reducing the quantity of separated plutonium and by making the diversion of plutonium more difficult.
2. It saves uranium by re-using plutonium and depleted uranium.
3. It avoids the cost of storage of large stocks of plutonium and saves up to 10% on front-end fuel cycle costs.

These arguments will be dealt with below. It becomes clear that none of these arguments holds much truth. We will also look at the costs of MOX fuel compared to low-enriched uranium fuel.

5.1 Reduction of plutonium stocks?

Worldwide, discussion is growing about what to do with the surplus stockpiles of reactor-grade and weapon-grade plutonium. Each year about 70,000 kg of plutonium is generated in nuclear fuel in commercial nuclear reactors.[2] About 30,000 kg so-called "civil" plutonium is annually separated from this spent fuel in reprocessing plants, adding to the already large amounts of separated plutonium. The military plutonium stocks are estimated at 300,000 kg, the quantity of separated civil plutonium is about 190,000 kg. From this plutonium, 49,000 kg has been re-used into MOX fuel for LWRs and FBRs.[3] Russia and the US each have about 50 tons of weapon-grade plutonium surplus and are thinking of re-using this in MOX fuel in LWRs or CANDUs.

There are several options what to do with all the plutonium. One of the options is to burn the weapon-plutonium as MOX in LWRs and FBRs. The other option is to store the plutonium for the long-term, above ground or underground. To make the plutonium less accessible for potential diverters intending to use it for nuclear weapons, it can be mixed with nuclear waste and/or vitrified before storage.

One of the main arguments used in favor of MOX is that the plutonium stockpiles will be eliminated. However, this is not even true theoretically: to be able to eliminate the plutonium, the MOX fuel must be reprocessed and re-used many times, and so, slowly, the quantity of separated plutonium should be reduced. Apart from being quite expensive, each time the MOX fuel is used and reprocessed, the quality of the plutonium is degraded further and it will be more difficult to use it as fuel. That's why in practice, spent MOX fuel is not reprocessed and Pu is re-used only once. Technically it is possible to reprocess MOX fuel once (although it is not being done yet), but it raises technical problems and will be excessive expensive.[4] The term "recycling" is misleading. Degradation of plutonium means that the share of the fissile plutonium isotopes, Pu-239 and Pu-241, in the total plutonium decreases. Reactor-grade plutonium contains about 65% fissile plutonium, degraded plutonium less than 65%. The standard MOX fuel contains about 5% fissile plutonium and in total 8% plutonium. Because about 92% of the MOX fuel contains depleted uranium, new plutonium is formed at the same time as the old plutonium is burned. As a consequence, after three years in the reactor the amount of plutonium in the MOX fuel has decreased by a mere 18%.[5] Another limitation of the capacity of MOX to burn plutonium is the fact that the share of MOX in a reactor core is 20-30%. The other 70-80% of the core contains of enriched uranium fuel, in which so much new plutonium is formed, that the burning of 18% of plutonium in the MOX is more than compensated. The result is a net increase of plutonium. *(see Table 5.1)* The use of MOX only slows down the production of plutonium, but still helps the stockpiles of plutonium to grow.

Table 5.1* [6] *Pu balance in PWR with 30% MOX fuel in core

In contrast with the claim of the nuclear industry that the use of MOX fuel results in burning of plutonium, the opposite is true: even in nuclear reactors using MOX fuel, more plutonium is produced than burned. An example: A 1000-MW PWR, with 60 tons of nuclear fuel. Annually, one-third of the fuel, 20 tons, will be replaced. The new reloads contain 14 tons of LEU fuel with 4.2% enriched uranium and six tons of MOX fuel with 7% plutonium. After three years of MOX loading, the core contains 30% (18 tons) MOX fuel and 42 tons of LEU fuel and after four years an equilibrium situation is reached: each year as much MOX fuel is discharged as loaded.
The spent LEU fuel will contain 1.4% Pu and the spent MOX fuel will contain 82% of the original Pu.

Year	Reload	Full core	Spent fuel discharged	Pu in (kg)	Pu out (kg)
0	20 ton LEU	60 ton LEU	20 ton LEU with 200 kg Pu	0	200
1	14 ton LEU 6 ton MOX (420 kg Pu)	54 ton LEU 6 ton MOX	20 ton LEU with 200 kg Pu	420	200
2	14 ton LEU 6 ton MOX (420 kg Pu)	48 ton LEU 12 ton MOX	20 ton LEU with 200 kg Pu	420	200
3	14 ton LEU 6 ton MOX (420 kg Pu)	42 ton LEU 18 ton MOX	20 ton LEU with 200 kg Pu	420	200
4	14 ton LEU 6 ton MOX (420 kg Pu)	42 ton LEU 18 ton MOX	14 ton LEU with 196 kg PU 6 ton MOX with 344 kg Pu	420	540

The net plutonium balance after three years of MOX loading is an increase of 120 kg Pu annually (in core: 420 kg of Pu; out of core: 540 kg of Pu), against an increase of 200 kg Pu/year without MOX fuel. PWRs with 30% MOX fuel annually produce 80 kg of Pu less than reactors without MOX, but still produce more Pu than they burn.
It appears that using 20% or 30% MOX fuel in LWRs and the percentage of Pu in the MOX don't make any difference in burning or producing Pu: after use always 82% of the Pu in MOX will still be present.

The claim that the use of MOX prevents proliferation is apparently false. First, the production of separated plutonium is not reduced. On the contrary, the use of MOX is the main justification to continue reprocessing spent fuel and the production of separated plutonium. Without the use of MOX an important argument for the nuclear industry to reprocess disappears. The conclusion can be that reprocessing and production of separated plutonium is stimulated by the use of MOX. If the nuclear industry is really aware of the dangers of plutonium and are willing to do something about it, they would stop producing it!

Secondly, proliferation dangers increase through the use of MOX: many thousands of kg of plutonium are transported by air, by ship and road and are stored and fabricated at many places. The danger of diversion thus increases. MOX plutonium can be separated easier from uranium in fresh MOX fuel than in spent fuel, and relatively easily be diverted for construction of crude nuclear bombs.[7]

5.2 It saves uranium?

Some 30 years ago, it was believed that uranium would soon become scarce and expensive. Nowadays there is an oversupply of uranium and prices are low. It is expected that the supply of uranium will be abundant in the coming years and prices will decrease more.[8]

The need for the nuclear industry to use uranium as efficient as possible does not exist any more. It is claimed that the use of MOX can save about 15% of uranium by recycling of plutonium and depleted uranium. At the moment, the amount of enriched uranium fuel used annually by all nuclear reactors is about 7,000 ton. The amount of MOX fuel used in 1996 was about 125 tons or 1.8% of all fuel loaded in LWRs.

In 2000, when an estimated 350 tons of MOX will be used, the share of MOX fuel of all fuel loaded in LWRs will be about 5%. This is not a very impressive saving of uranium.

If the industry was really willing to make better use of uranium (of course they would stop using it, but besides that), they would pay more attention to

- Lowering of the Tails Assay during enrichment of uranium; and
- Higher burn-up of fuel.

5.2.1 Lower Tails Assay

Natural uranium contains 0.7% fissionable uranium-235. LWRs use uranium enriched up to 4.5% U-235. The past 10 years the percentage of U-235 left in depleted uranium after enrichment, the so-called Tails Assay, has increased from 0.25% to 0.35% U-235. This means that 25% more natural uranium is needed to produce the same amount of enriched uranium.[9] The choice for a higher Tails Assay is driven by economic motives: low uranium prices and high enrichment prices make it cheaper to use more uranium and less enrichment work.

If the nuclear industry was really concerned about a shortage of uranium, instead of making money, it could save 25% uranium by lowering the Tails Assay from the present 0.35% to 0.25% U-235. This 25% saving is five times the amount of uranium saved by the expected use of MOX in the year 2000. If in the future uranium prices increase and uranium shortages are feared, a further reduction of the Tails Assay to 0.2% U-235 would save another 10% natural uranium.

5.2.2 Higher burn-up

Burn-up is defined as the amount of energy the discharged fuel has produced. It is expressed in MegaWattDays (MWD), instead of the more usual unit MWhour (MWh). One MWD is 24 MWh. To reach a higher burn-up, the enrichment level is increased from about 3.1% to 4% or more U-235.

About 10 years ago, the majority of LWR nuclear power plants reached a burn-up of about 25-30 MegaWattDay per kilo fuel (MWD/kg).[10] Nowadays many reach a burn-up of 40-50 MWD/kg fuel. It is expected that most of them will reach 50-60 MWD/kg in the next 10 years.[11] A burn-up of 60 MWd/kg fuel is seen as the limit for the present LWR fuel. In the US the Department Of Energy even hopes to develop advanced fuel, reaching a burn-up of 100 MWD/kg, with enrichment levels of at least 5%.[12]

The fact that almost all nuclear utilities make use of this possibility is caused by its economic benefits and by the fact that nuclear electricity is more expensive than other electricity producers. For example in the Netherlands the owner of the Borssele PWR applied for a higher burn-up, from 33 MWD/kg to 52 MWD/kg fuel and a higher enrichment, from 3.3% to 4% U-235. This was justified by the "significant savings on nuclear fuel costs".[13] The increased burn-up results in 50% uranium savings, but the higher enrichment results in 30% more uranium use. The net result is a 20% saving in uranium use.

Problems with higher burn-up

The use of higher burn-up fuel has led to problems in many reactors. The main problems are:

- More corrosion of the fuel rods because of higher radiation;
- Deformation (bowing and swelling) of the fuel rods. This results in the sticking of control rods when they are lowered into the core to regulate the chain reaction;
- Higher releases of radioactive gases such as tritium;
- Longer cooling and storage time of spent fuel;
- Difficulties with reprocessing; and
- Difficulties with re-use of plutonium, separated from spent high burn-up fuel, in MOX fuel.[14]

5.3 MOX saves storage costs?

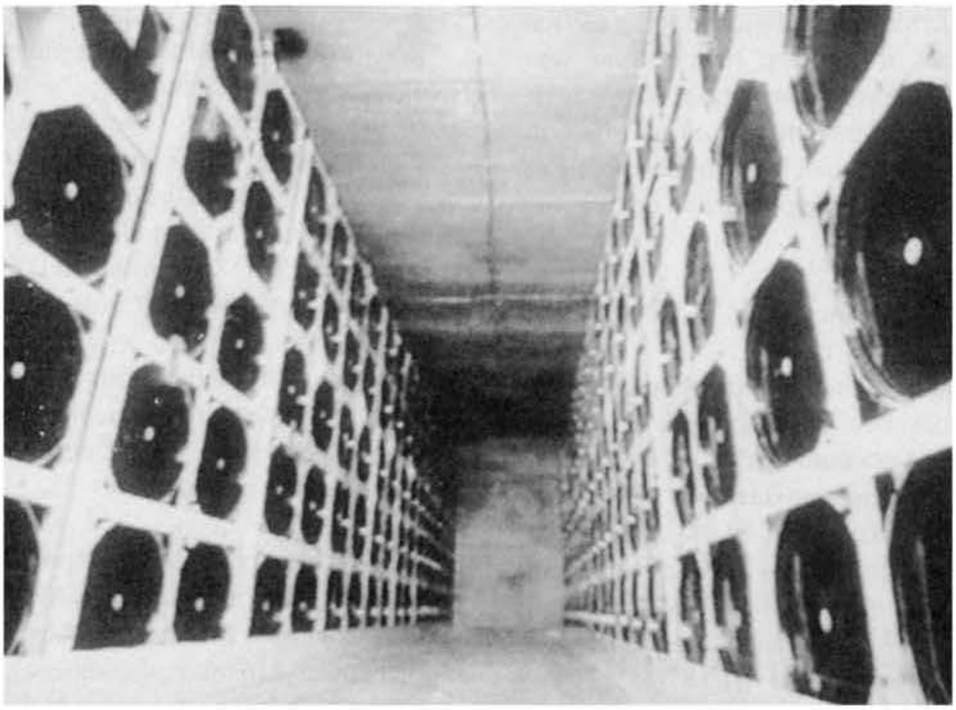
The nuclear industry maintains the claim that

- the quantities of nuclear waste are less when plutonium is re-used;
- Depleted uranium is also re-used in MOX and saves even more natural uranium;
- the more energy is extracted from each kg of uranium, the less uranium ore has to be mined, the less the environmental effects will be; and
- plutonium is responsible for the need of long-term storage of spent fuel. If the plutonium is separated from the spent fuel, the remaining waste doesn't need to be stored so long.

More instead of less problems

As we have seen in Chapter 5.1 MOX spent fuel will not be reprocessed. The result of the use of MOX fuel instead of uranium fuel is that when time passes by, reprocessed spent uranium fuel is gradually replaced by spent MOX fuel in the few countries where MOX is used. This will have consequences for the storage facilities.

Spent MOX fuel is much more radioactive than spent uranium oxide fuel. It contains 4%-6.5% plutonium, depending on the initial Pu percentage. This is on average five times more plutonium than spent uranium fuel. Spent MOX fuel contains also much higher amounts of transuranium isotopes: four times as much Neptunium-237 (half-life: 2.2 million years); nine times as much Americium-241 (half-life 430 years), which decays into Neptunium-237; 15-28 times more Curium-242 (highly radioactive) and 22 times more Curium-244 (half-life 18 years), changing into plutonium-240 (half-life 6,450 years).[15]



Plutonium "pits" - stored at the Pantex nuclear weapons plant, Texas, U.S.

After 10 years, the heat generation from spent MOX fuel is twice as high as that of spent uranium fuel. After 100 years, it is even three times higher.[16]

Given the very long half-life of Pu-242 (380,000 years), and Neptunium-237 (2.14 million years) the storage of spent MOX is much more complicated than of normal spent fuel. Instead of a partial solution of the high level waste problem, MOX creates even bigger waste problems:

- it needs more and longer cooling;
- it has to be stored much longer;
- it is more dangerous; and
- the costs are therefore higher.

5.4 MOX fuel costs

Besides the disadvantages cited above, there is an additional cost disadvantage, for both civil as military plutonium. In most cost calculations of MOX fuel, plutonium is viewed as a free energy source. This, however, is economically not correct. The costs of reprocessing have to be accounted to the produced plutonium. The first aim of reprocessing has always been the separation of plutonium. In the case of civil reprocessing, the plutonium was primary meant for use as MOX in FBRs. When the FBR option failed, the plutonium policy shifted to the re-use of plutonium in LWRs. The sole aim of military reprocessing was production of plutonium for nuclear weapons. If surplus military plutonium is used as MOX in PWRs, it is no more than logic to incorporate at least a part of the historic production costs in the cost of MOX fuel.

We will consider the costs excluding and including reprocessing costs.

In the first case (excluding reprocessing costs), most calculations show higher costs for MOX fuel than for enriched uranium oxide fuel. MOX fuel, according to the German Institute for Energy Economics (EWI), costs US$2,614/kg. That's four to five times more expensive than standard uranium oxide fuel, which costs about US$523/kg.[17] "World prices" for MOX fuel from civil plutonium are $2,587-$3,571/kg, according to EWI.[18] This is five to eleven times the cost of uranium oxide. Another study mentions the cost of MOX fuel as $1,500/kg, compared with US$275/kg for enriched uranium oxide fuel.[19]

Reasons for this: the smaller scale of the MOX fuel fabrication plants; the extra measures necessary because of the much more radioactive plutonium, such as heavier shielding to protect the workers in the plant and preventing criticallity. Utilities in the US want to consider using military MOX only, if the more costs of MOX fuel are paid by the government.[20] German utilities too want the excess costs of using MOX, if they ever use MOX made from Russian surplus weapon plutonium, to be compensated by US and European governments.[21]

Even without including the production cost of plutonium, the conversion of 50,000 kg of weapon plutonium into MOX fuel will cost US$1 billion-$5 billion, that is, US$20,000-$100,000/kg MOX fuel.[22] When reprocessing costs are included, the resulting MOX fuel prices are clearly much higher. This is no wonder as reprocessing is very expensive. Present prices of reprocessing spent LWR fuel range from US$1,569/kg[23] to about US$1,000/kg of spent fuel.[24] At the moment the standard MOX fuel contains 8% plutonium. To get 1 kg MOX fuel with 8% plutonium, 8 kg of spent LWR fuel (containing 1% plutonium) have to be reprocessed. The production cost of plutonium for MOX fuel are therefore about US$8,000/kg. When the extra costs of fabricating the MOX fuel, at least US$1,500/kg, are added, the price of MOX fuel is about US$9,500/kg.

Conclusions: "Civil" MOX fuel costs from twice to 11 times as much as uranium oxide fuel. "Military" MOX fuel costs 8.7 to 30 times as much as standard uranium oxide fuel. If reprocessing costs are included, MOX is more than 30 times as expensive.

The conclusion must be that reprocessing of spent fuel and re-use of plutonium as MOX doesn't have the advantages the nuclear lobby tells us. MOX fuel knows a number of additional problems and risks, which will be presented in the next chapter.

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Chapter 6

Proliferation and safety problems of MOX use

The increasing quantities of plutonium which are fabricated, transported, burned in reactors and stored give rise to several dangers and risks. In this chapter we will look at them.

6.1 Proliferation

6.1.1 No inspection in Nuclear Weapon States

It is not commonly known that the reprocessing plants and MOX fuel plants in France and England are not safeguarded by the IAEA, because they are Nuclear Weapon States (NWS). According to the discriminating Non Proliferation Treaty NWS are exempted from IAEA safeguards. In 1995 only one French nuclear facility (a storage facility at La Hague) was under IAEA safeguards and in England four nuclear facilities (two storage facilities at Sellafield; two enrichment plants of Urenco at Capenhurst).[1] These facilities were offered voluntarily for safeguards by the countries.

Only the spent fuel rods from Non-Nuclear Weapon States at the storage sites in La Hague and Sellafield are being safeguarded by IAEA inspectors: they count the number of rods when these arrive and when they leave to be reprocessed, and that's it. In the European Union (EU), the IAEA only monitors whether the bookkeeping of Euratom inspectors has been correct. This lack of safeguarding at reprocessing plants and MOX fuel plants could have as consequence that plutonium from Non-Nuclear Weapon States ends up in French or British nuclear weapons; for example Japanese plutonium in French nuclear weapons.[2]

It may be clear that it is rather difficult to divert plutonium, which is inside the highly radioactive spent fuel, because reprocessing is needed before it can be used for nuclear weapons. This is drastically changed when the plutonium has been separated from the spent fuel in reprocessing plants. The proliferation risks of separated plutonium, as plutoniumoxide or as MOX, are thus much greater than of plutonium inside the spent fuel. The nuclear industry assures us there is no proliferation risk, which they mainly base on two arguments.

- 'reactor-grade plutonium cannot be used for nuclear weapons'.

As we have seen, this is not true: two nuclear bombs made from reactor-grade plutonium have been tested, by the UK and the US. (see Chapter 2.2.)

- 'international control by IAEA and Euratom will prevent any diversion of nuclear materials'.

But what if no control takes place? Most of the nuclear facilities are inside the Nuclear Weapons States, where the IAEA does not have the right to safeguard any facility, if it is not offered voluntarily. In the five NWS, in 1995 11 nuclear facilities were offered voluntarily for IAEA inspection. Not one reprocessing or MOX plant belongs to these 11 facilities: one power reactor and one research reactor in China; two enrichment plants in the UK; seven storage facilities (two in the UK; one in France; one in Russia; three in the US).[3] So this attempt of assurance by the nuclear industry is not very convincing.

In the meantime the first case of smuggling of MOX has been reported. On August 10, 1994, at the Munich airport in Germany, 560 grams of MOX powder was seized. Analysis showed that 350 grams (or 62%) of it was plutonium and 87% of this was Pu-239.[4]

6.1.2 Material Unaccounted For

MUF stands for the difference between the quantity of nuclear materials in (part of) a facility or container as calculated and as measured. The difference can be negative or positive. The IAEA sees the quantity of MUF only as important if it is equal to or more than one Significant Quantity (SQ). This is a short-sighted approach, because it is possible that over a long period, several amounts of sensitive nuclear materials smaller than one SQ are booked as MUF. But more important: if there is uncertainty of the exact measurements the IAEA can accept a much larger MUF than one SQ.[5] In the largescale reprocessing plants and MOX fuel plants in England and France, it is even possible that some 3.3% of the plutonium can go missing, without any alarm being raised.[6]

On a throughput of 1,600 tons of spent fuel and 16,000 kg of plutonium per year, as is the case in the reprocessing plants UP-2 and UP-3 in La Hague, this means that each year 528 kg of plutonium can be missing without anybody noticing. As the number of reactors using MOX fuel increases, so does the number of storage sites of fresh and spent MOX fuel.

An example of how large amounts of plutonium can get lost is the PFPF MOX plant in Japan, where 70 kg of plutonium were booked as MUF in 1994. Compared to the throughput of the plant, five tons of MOX/year, equivalent to 300 kg Pu/yr, this was seen as a very large amount of MUF: more than 23%. It was only after the Washington-based Nuclear Control Institute raised public awareness that the IAEA announced that it was taken seriously. After two years, the quantity of MUF was reduced to about 10 kg Pu.[7]

6.1.3 More nuclear material; less safeguards

The IAEA safeguards budget has known a zero growth for more than 10 years. In 1995 the regular safeguards budget expenditures were a meager $87.56 million, far too short to effectively safeguard all nuclear facilities. Already in 1985 only at 514 from the 887 nuclear facilities under safeguards inspections were carried out. At 168 from the facilities with a significant amount of nuclear material the inspection goal was attained. It was possible to carry out only 72.9% of the planned routine inspections (which are announced beforehand).[8] The zero budget growth since 1985 has led to a further reduction in the attainment of inspection goals. As Bruno Pellaud, Deputy Director General of IAEA Safeguard Division, says: *"it must be emphasized that with a continuing zero-growth budget the Agency will not be able to cope with the extended programs and demands placed on it"*.[9] At the same time the quantities of nuclear materials under safeguards by IAEA increased enormously. Expressed in Significant Quantities, the increase was threefold: from 31,116 SQ in 1985[10] to 90,291 SQ in 1995.[11] The annual expenditure of safeguarding one SQ decreased from $3000 in 1980 to $1000 per SQ in 1995.[12] Director General of the IAEA, Hans Blix, said in September 1991 that the safeguards system would have to undergo a threefold strengthening to cope effectively with suspect cases, such as in South Africa, Iraq and North Korea.[13]

Driven by the lack of funds, the trend is to reduce the number of inspections by the IAEA at nuclear facilities.[14] In the countries of the European Union (EU), inspection efforts have been largely reduced after the introduction of the so-called "New Partnership Approach" (NPA) in 1992 between the IAEA and Euratom. In a MOX fuel fabrication plant the continuous presence of inspectors will be replaced by a presence of four to five days a month.[15] In the EU, the IAEA becomes more and more dependent on information from Euratom inspectors. To achieve as much cost savings as possible, duplication of inspection is stopped: formerly both Euratom and IAEA inspected nuclear facilities, at present there is only one of them, mostly Euratom.

***Table 6.1** Significant quantities and timelines goals*[16]

Category	Type	Significant quantities	Timelines goals
Direct-use material	Plutonium*	8 kg	1 month
	High-enriched Uranium	25 kg U-235	1 month (fresh) 3 months (spent)
	Pu in spent fuel	8 kg	3 months
	Uranium-233	8 kg	1 month
Indirect-use material	Low-enriched Uranium	75 kg U-235	12 months
	Thorium	20 ton	12 months

**for Pu containing less than 80% Pu-238*
*** less than 20% U-235, includes natural and depleted uranium*

The result of the threefold reduction of expenditures per SQ is that the objective of safeguards is in serious danger. The main objective of safeguards by the IAEA is the "timely detection of diversion of significant quantities of nuclear materials from peaceful activities to the manufacture of nuclear weapons".[17] Both the timely detection goals and the diversion of SQ in largescale reprocessing and MOX fuel plants can no longer be attained.[18]
Another reason for the shortcoming of the present safeguard system is the fact that both civil and military nuclear materials and facilities in the Nuclear Weapon States are not covered by the IAEA safeguards. For example, in 1992 only 28% of the world's plutonium inventory and less than 1% of the world stock of High Enriched Uranium is under IAEA safeguards.[19] The IAEA safeguards less than 25% of all plutonium. The same situation applies to High Enriched Uranium. Proliferation dangers will increase when the stockpiles of weapon-plutonium in the US and Russia will be used as MOX fuel for commercial reactors, as is being planned: the IAEA has no right to inspect the facilities and sites where the weapon-plutonium is handled or stored. Given the bad state of security and control in Russia, such a future must arouse apprehension. During the storage, handling and transport of especially the separated plutonium, the risks of hijacking and stealing are real. The plutonium present in MOX fuel can be quite easily separated and used for producing nuclear bombs.
Never before have such large quantities of plutonium been stored, handled and transported. The largescale reprocessing and recycling of plutonium will have the effect of normalizing the use of plutonium. Each country can start a plutonium program now and simply justify this by pointing to the others. This effect is seen clearly already by the neighbors of Japan: The two Koreas, China, Taiwan. They fear that the massive Japanese plutonium program has a latent proliferation background. They feel they are being forced to start and own a plutonium program. Especially if the US decides to realize their present plans for the use of plutonium in commercial reactors, the White House may find it is impossible to convince other countries not to use plutonium in their reactors. The real plutonium society has arrived.

6.2 Safety

Light Water Reactors are designed to use low-enriched uranium fuel. Reactors need to be adapted to use MOX. There are specific problems concerning the safe operation of MOX facilities and reactors using MOX. Accidents will have more impact due to more actinides.

6.2.1 Pu degradation and Americium-241

MOX fuel contains, next to depleted uranium, 4-8% of plutonium. This is called first generation plutonium because it has been reprocessed only once. The plutonium inside spent MOX fuel is called second generation.[20] The concentration of plutonium in MOX fuel must increase to 8-10% plutonium in the future, to be equivalent to 3.5% enriched uranium. This is because the present high burn-up spent fuel (which reprocessed plutonium will be used for MOX) contains degraded plutonium. This means the plutonium contains less fissile Pu-239 and Pu-241 and more non-fissile isotopes: Pu-240 and Pu-242. The higher the share of non-fissile Pu-isotopes, the less it is suitable for the production of electricity.

Another problem will be the presence of Americium-241 (Am-241), which is a decay product of plutonium-241. Because of the relatively short half-life of Pu-241 (13.2 years), the amount of Am-241 quickly increases. The presence of Am-241 in plutonium makes it even more dangerous and less efficacious. Am-241 is a hard alpha and gamma emitter. Therefore, in the fabrication of MOX fuel, the amount of Am-241 must be as low as possible. The plutonium which is used for MOX fabrication must not be older than three years, because of this americium increase. Separated plutonium older than three years must first be "recleaned", that is, reprocessed to separate the Am from the plutonium before it can be used. This is a very expansive operation.[21] The Belgian PO MOX fuel plant can work with plutonium containing up to 1.7% of americium-241 on average, the French Cadarache MOX fuel plant is limited to 1%.[22] The newer Melox plant is licensed to use up to 3% Am-241.[23] MOX fuel must be used quickly. After five months, the fuel has lost 3% of its durability.[24]

6.2.2 Gallium

Recently, a new problem was discovered in connection with the presence of gallium in Russian and US weapon-grade plutonium. The gallium has to be removed from the plutonium before MOX fuel is fabricated.[25] Gallium causes problems during the production of MOX fuel, the use in reactors and the disposal of spent MOX fuel. The gallium attacks the zirconium, present in the fuel rods, and so deteriorates the fuel rods. This leads to migration of fission products in the spent fuel and to serious waste disposal problems.[26]

6.2.3 Worker hazards

Workers in a MOX fuel fabrication plant must be protected against the much higher radiation levels of MOX. A $40-million investment program is planned for the Dessel PO MOX plant. This is necessary to allow the plant to respect the new, more severe, worker- exposure limits of ICRP-60, to be passed into Belgian law by 2000, despite the anticipated degradation in the quality of the separated plutonium. This means among others further automation and the massive introduction of neutron shielding in the workshops.[27]

The International Commission on Radiological Protection (ICRP), which cannot be said to be very critical on nuclear energy, sets a standard for occupational exposure to radiation at 100 mSv over five years, with a maximum of 50 mSv in any one year. If you interpret this by comparing workers in a uranium fuel fabrication plant with workers om a MOX fuel fabrication plant, the standards for protection against inhalation are roughly two million times stricter in plutonium processing than in uranium processing.[28]

6.2.4 Accidents at MOX fabrication plants

Accidents at MOX fuel fabrication plants have occurred. In June 1991, the storage bunker of the MOX fuel fabrication plant in Hanau, Germany, was contaminated with MOX. It occurred after the rupture of a foil for container packaging in the course of an in-plant transportation process. Four workers were exposed to plutonium.[29] This accident was the main reason the fabrication plant at Hanau was shut down.

In November 1992, a fuel rod was broken through a handling error, and MOX dust was released during the mounting of MOX fuel rods to fuel assemblies in the fuel fabrication facility adjoining the MOX facility in Dessel, Belgium. In the event of such accidents, if the ICRP recommendations for general public exposure were adhered to, only about one mg of plutonium may be released from a MOX facility to the environment. As a comparison, in uranium fabrication facility, 2kg (2,000,000mg) of uranium could be released in the same radiation exposure. A one mg release of plutonium can easily happen during various smaller incidents.[30]

6.2.5 Behavior of MOX fuel in the reactor

All Light Water Reactors are designed to use uranium fuel. Therefore MOX fuel assemblies should be comparable to the operation of uranium assemblies with the same kind of performance. In order to use another fuel such as MOX, the reactor must be adapted. This is done by increasing the number and the reactivity of the control rods and of the quantity of boron dissolved in the cooling water.[31] These changes lead to smaller safety margins when the reactor is switched off and the fuel rods and damaged sooner.[32] The rate of fission of Pu tends to increase with temperature. This can endanger reactor control. The higher the share of Pu-239, the greater this problem. With the general introduction of higher burn-up fuels, the drive is also to use more plutonium in the MOX fuel.

Utilities want to increase the burn-up of MOX fuel to the same level as the uranium fuel. In a PWR, MOX assemblies with three different concentrations of plutonium are inserted. The Nuclear Energy Agency (NEA) gives as example a core with three sorts of MOX fuel rods: with 8.7%, with 7% and with 4.3% plutonium, all in the center of the core.[33]

The use of MOX fuel has several problems. A few are:

- Different enrichment levels of plutonium and uranium lead to peak burn-ups, which cause weakening of the fuel rods.
- A principal limiting factor for the share of MOX in the core and the percentage of plutonium in MOX fuel is the substantially higher release of fission gas within MOX fuel rods than in uranium fuel, which increases sharply with burn-up.
- MOX fuel is "hotter" than uranium fuel at equivalent power.
- High local burn-up, sometimes more than three times average burn-up, due to the heterogeneous microstructure of MOX fuel, which yields clumps with high plutonium concentration.[34]
- The higher energy of the neutron spectrum of MOX increases the rate of radiation damage to the core structures. This could cause the reactor vessel to become brittle in the end, which is another factor for safety concerns.[35]

For these reasons French nuclear safety authorities for instance continue to deny EdF a license for higher burn-up of MOX fuel. The burn-up of MOX in France is now limited to 36 MWD/kg. EdF wants a license to increase the MOX fuel burn-up to 52 MWD/kg.[36] As we have seen in Chapter 5.2.2. higher burn-up also has negative safety aspects; an important one is fuel rods' deformation which results in sticking of the control rods. During an experiment with MOX fuel on January 24, 1997, in the Cabri research reactor at Cadarache, an unexpectedly violent rupture of the MOX fuel clad occurred, leading to dispersal of fuel fragments in the test channel. If this rupture were caused by the MOX fuel, it would be bad news for utilities wanting to use MOX fuel and for MOX fuel fabricators. One more MOX fuel test with a two-cycle MOX fuel pin is scheduled this year. However, only when and if the Cabri reactor is refitted with a water loop (it now has a sodium coolant loop) it will be able to represent LWR conditions. A decision is expected in June 1997. Utilities and regulators will be left with at least two years of uncertainty over the significance of the Cabri MOX fuel failure. The deputy director Rousseau of the French regulatory organization DSIN said that the latest test result "isn't going to encourage us to go faster" in licensing high burn-up MOX fuel. EdF has to wait several years before it is allowed to increase the burn-up of its MOX fuel.[37]

6.2.6 Accident scenario when burning MOX

Accidents involving overheating and meltdown are possible in any nuclear reactor. In such accidents, not only would readily volatile noble gases like iodine and caesium be released to the environment, but a small portion of the actinides, including plutonium and neptunium, would be released. As the activity of the actinides is substantially higher in the case of MOX, the consequences of such severe accidents become more serious.

When MOX fuels are used, the probability of having such serious accidents or trouble would increase due to the high content of plutonium in the fuel. Even if an accident is not a serious one, it could become serious since even a small portion of the inventory of actinides released to the environment could cause significant radiological consequences. According to a comparative analysis of possible consequences of a core meltdown accident in the German Kruemmel nuclear power plant with and without the use of MOX fuel.[38]

- The radiation exposure from inhalation of radioactive materials during the passage of the radioactive cloud is higher by several dozen percentages than if U fuel elements were exclusively used.
- Radiation exposure through the route of inhalation of remobilized long-lived actinide isotopes is more than doubled.
- The land areas to become out of use by long-term contamination increases as the re-suspension pathway is a limiting factor and the greater part of the dose resulting from the pathway comes from the actinides.

6.2.7 Plutonium transport problems

The consequence of more and more reactors using MOX is an increasing number of dangerous transports with highly radioactive plutonium by road, rail, air or sea.

Compared to the once-through option, where the spent fuel is stored at the reactor or at a central storage, with MOX there is a fourfold increase of plutonium transports. The increase in distances covered is far more: since there are only a few reprocessing plants worldwide and clients the whole world over. For instance: Spent fuel sent by sea from Japan to French and English reprocessing plants; from there to MOX plants in Dessel, Melox or CfCa in Cadarache, or to MDF in Sellafield; finally the shipment of thousands of kg of plutonium the whole way back.

Transport of radioactive waste

In 1984 190 kg of plutonium was transported by sea from France to Japan; in November 1992 a second transport of 1,700 kg of plutonium took place, which was heavily criticized, escorted by an armed vessel and watched from a satellite. Many countries along the route refused to allow these to pass by in their coastal waters.[39] From 1994 till 2010, about 30,000 kg of plutonium will be transported from Europe to Japan.[40]

Around the year 2000, the number of MOX transports in France will be more than 400, with more than 40,000 kg of plutonium.[41]

Most nuclear countries have transport regulations, based upon several publications of the IAEA; basic "Safety standards" in the *"Regulations for the Safe Transport of Radioactive Material"*, (Safety Series No. 6); *"Safety Guides; Schedules of Requirements for Transport of Specified Types of Radioactive Material Consignment"*, (Safety Series No. 80).

The shipments of radioactive materials, whether they are private or government-owned, must be packaged and carried according to these regulations. Containers have to fulfill requirements and to withstand accidents and radiation and proliferation risks. Packages are divided into four categories:

- Industrial packages for nuclear materials with lower specific activity, such as uranium, thorium and slightly enriched uranium hexafluoride;
- Type A containers, for medium radioactive materials: fresh fuel, uranium oxide;
- Type B packages for higher radioactive materials: spent fuel, separated plutonium, high level reprocessing wastes.
- A new container, Type C, which has to withstand air crash accidents, still has to be developed.

The test conditions for the four categories differ strongly.

Type A containers must meet special tests to ensure they would withstand normal transport conditions, for example to withstand an impact of only 13 meters/sec.[42] Any radioactive material shipment that exceeds the limit of Type A package specifications must be shipped in a Type B package. Only the conditions for Type B containers claim to guarantee their integrity after an accident. They must withstand both normal shipping conditions and hypothetical accidents without a breach in the containment. Type B containers are subjected to four tests: Impact Test, Crush Test, Thermal Test and Water Immersion Test.[43]

On September 10, 1996, the IAEA adopted revised standards for the transport of radioactive material at the Board Meeting held in Vienna. They will go into effect by the year 2000. The revision allows the continuous use of existing Type B casks for plutonium and MOX shipments, provided transporters can demonstrate that radionuclides will not be dispersed (so-called Low-Dispersable Materials, LDM) following a severe accident that ruptures the container. Type B containers are designed to survive a crash speed of 48 km/h and a 30-minute fire of 800 degrees Celsius, but B-containers have not been tested in a plane crash. In 1992 an El Al plane crashed in Amsterdam at 520 km/h and burned intensely for hours. The standards also create a new container category, Type C, which is stronger and could be used for shipping materials which are not LDM. An exemption, however, is made for shipping MOX fuel, which is LDM, in Type C containers. Strong oppposition came from Greenpeace International and the Nuclear Control Institute (NCI). They will campaign to prevent the new IAEA standards from being accepted by the International Maritime Organization (IMO) and the influential International Civil Aviation Organization (ICAO). Opponents assert that the plutonium industry pressed for the LDM exemption for MOX, because shipment in Type C containers would increase the cost of MOX transport. The US will not allow plutonium flights in US airspace because neither Type B nor Type C containers meet US standards. The new Type C container is not yet ready; testing involves a mere 90 mile/hour impact. A crashing airplane could have a higher speed.

The US plutonium air transport standards require a cask to survive a “maximum credible accident”, with impact speeds of 180 meter/second, twice the IAEA Type C standard. Cogema's Ricaud said that a cask meeting the US standards would be "much more costly" than a Type C container, but Cogema does not need plutonium air transport standards. Ricaud did not mention air shipment of MOX to Japan.[44]

The Greens in the European Parliament charged that the new recommendations on stricter safety standards for the transport of nuclear materials do not go far enough. They asked the European Commission to suspend the transports of MOX fuel until the new guidelines are reviewed. The US Nuclear Control Institute also asked the EU states to ban the transport of nuclear material.[45]

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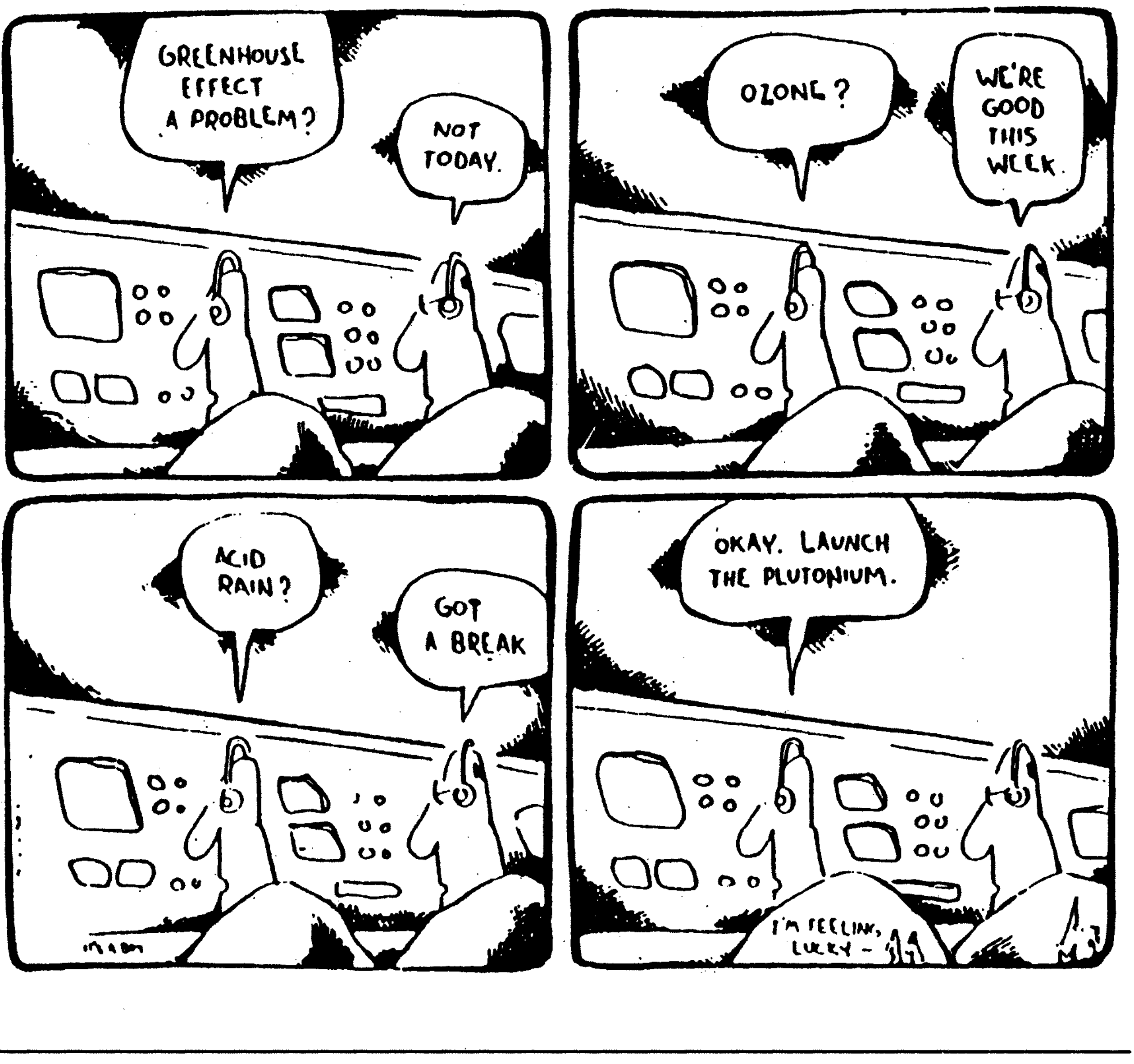

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Summary

As we have argued, MOX is not and can not be the solution the nuclear industry would have us believe.

MOX
- is seen by the nuclear industry as an interim solution until such time as the hoped-for commercial use of Fast Breeder Reactors has become standard
- provides a justification for continuing reprocessing
- does not reduce plutonium stocks; the increase is merely smaller than that generated by the use of uranium fuel
- does not save large amounts of uranium: by the year 2000 the saving will have been about 5%
- does not save storage costs; on the contrary, due to the large quantity of actinites, it produces more radiation and heat than uranium fuel and is therefore more difficult to handle
- is expensive: when reprocessing costs are added, it is up to eleven times more expensive than uranium fuel.

In practice the plutonium can only be re-used once because of degradation: it becomes less fissionable and more non-fissionable Pu-istopes appear.
Due to the presence of plutonium, MOX production is more dangerous than uranium fuel production. Small accidents, which occur all the time, are likely to have far more serious consequences than than they do at present, because of the wide-spread use of plutonium.

The use of MOX will not decrease the danger of nuclear proliferation, as is often claimed, but on the contrary, will increase it, due to:
- continued reprocessing,
- the inevitable increase in the transportation of separated plutonium,
- the use of plutonium will become more wide-spread,
- countries building plutonium stocks will provide a bad example,
- safeguarding nuclear materials will become more and more difficult due to the quantities of material involved and the inevitable financial limitations.

Light Water Reactors are designed and constructed for the purpose of burning uranium fuel. They have to be adapted and relicensed for the use of MOX.
The use of MOX has three specific consequences for the behaviour of the reactor:
- leak burn-ups cause the fuel rods to weaken.
- far more fission gas is released during the process,
- the reactor vessel may become brittle as a result of increased radiation damage, due to the higher energy of the neutron spectrum.

It is clear that the objective underlying the arguments in favour of MOX is the continuation of the production of nuclear power. It should be obvious that this is undesirable.

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