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SAFETY IMPLICATIONS OF MOX FUEL USE IN THE BORSSELE NUCLEAR POWER PLANT – LESSONS FROM FUKUSHIMA

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INTRODUCTION

The Fukushima-daiichi nuclear accident has been underway for approaching five months. As high levels of radiation continue to be released into the environment and thousands of workers struggle to bring the site under control, a full understanding of the long-term consequences of the accident remain many months and years into the future. What is clear is that the safe operation of nuclear power plants in Japan and worldwide, and the effectiveness of international and national regulation is exposed as fundamentally flawed. It is in this context decisions made to embark on new nuclear operations must be understood.

One of the reactors at Fukushima-daiichi, unit 3, unlike the other reactors at the site, operated for six months with a reactor core containing plutonium MOX fuel. The implications of the accident and the additional safety issues arising from the MOX fuel in unit 3, as already stated are many years away from being understood. Yet, only a few days before the beginning of the Fukushima-daiichi accident, the Government of the Netherlands granted a licence to the utility EPZ to operate its Borssele nuclear reactor with plutonium MOX fuel. The safety case that formed the basis of this decision was compiled in the years and months prior to the accident. Issues of MOX fuel safety that had long been discussed in Japan, but which remain unresolved, have not been debated within Dutch society. This report is an attempt to explain the multiple issues concerning MOX fuel use and why a decision to proceed with MOX fuel use in the Netherlands is both ill conceived and a direct threat to public safety and security.

PLANS FOR MOX FUEL USE AT BORSSELE

The Netherlands for over thirty years has shipped spent fuel arising from its two power reactors, Borssele and Dodewaard to the reprocessing sites at la Hague in France and Sellafield in the UK. As a consequence controversy has persisted through this period as the Netherlands has played its role in the international plutonium economy.[1]

Official information on plutonium generated by reactors in the Netherlands is in comparison with nations such as the UK, Japan, and even the Russian Federation, not transparent. The Dutch government does not submit an annual report to the International Atomic Energy Agency, IAEA, on its plutonium stocks, the so-called INFCIRC-549 declarations.[2] However, from other sources it is possible to estimate the amount of plutonium that has both been generated in the Borssele reactor, how much of this is contracted under reprocessing contracts with French state company, AREVA, and how much separated plutonium is assigned to the Netherlands.

Up until 2006, 326 tons of spent fuel produced at Borssele had been reprocessed at la Hague.[3] This spent fuel would have yielded between 2.8 and 3.2 tons of plutonium.[4] According to plans

1 See, for example, Testimony of Paul Leventhal President, Nuclear Control Institute on Reprocessing, Waste and Non-Proliferation Presented to a Parliamentary Hearing of the *Tweede Kamer* The Hague, The Netherlands October 24, 1997.

2 See, http://www.iaea.org/Publications/Documents/Infcircs/1998/infcirc549a8.pdf

3 See, Appendix Table 6A.1. Foreign spent fuel reprocessing 1978 – 2014. Sources: Areva NC, Traitement des Combustibles Uses Provenant de l'Etranger Dans les Installations d'Areva NC de La Hague, Rapport 2009, 2010, as reported in the Fifth annual report of the International Panel on Fissile Materials Global Fissile Material Report 2010 Balancing the Books: Production and Stocks, www.fissilematerials.org.

4 The range is due to the percentage of plutonium within the spent fuel. The generally accepted figure is 1% of the total spent fuel is plutonium. However, this is a general figure and more precise figures have been made available. The lower figure is based upon the figures provided by the Tweede Kamer der Staten-Generaal, Brief Van de Minister Van Economische Zaken - vergaderjaar 1996–1997, 25 June 1997, which stated that the mean plutonium content of the Dutch spent fuel reprocessed at La Hague should be less than 1%, but rather 0.83%. As Coeytaux and Marignac noted this is surprisingly low considering the current spent fuel management by quarter and initial enrichment of 4%, see, Extension of Dutch Reprocessing: Upholding the Plutonium Industry at Dutch Society's

submitted by Borssele's owners they plan to load MOX fuel with a 5.4 enrichment of fissile plutonium.[5] Fissile refers to the plutonium isotopes 239 and 241. In addition to this are the non-fissile plutonium isotopes – 238, 240 and 242. In typical reactor-grade plutonium reprocessed from Light Water Reactor spent fuel, the ratio of fissile to non fissile is around 70/30 respectively. Therefore the total plutonium content of MOX fuel to be manufactured for Borssele will be around 7.8%.

If the plutonium arising from reprocessed Borssele spent fuel was fabricated into MOX fuel this would yield between 35.8 and 40.9 tons of MOX fuel.[6]

However, the Netherlands does not have tons of plutonium awaiting fabrication into MOX fuel.

While Dutch commitment to reprocessing has extended over three decades its plans for plutonium have been a complete failure. With the end of European fast breeder reactor programs the demand for plutonium, including Dutch, did not materialise. Despite this, reprocessing of spent fuel continued and plutonium produced in Borsselee accumulated at la Hague. In 2004 the then operator of Borssele, EPZ, announced the extension of its reprocessing contract with AREVA. While stating that it was committed to recycling, it was declared that,

"it won't recycle its plutonium in Borssele as mixed-oxide (MOX) fuel "because our plant is too small.""[7]

It was admitted by EPZ that it had made available its plutonium to other clients, however, spokeswoman Monique Linger declined to elaborate, citing the private nature of the contract.[8] It now appears that out of maximum of 3.2 tons of plutonium separated at the la Hague and of Dutch origin by the end of 2008, 2.9 tons of plutonium was provided to Electricite de France for use in its 900 series of reactors. Reports suggest that EPZ paid EDF for its plutonium - such are the economics of plutonium.[9]

As of 2009, the separated plutonium assigned to the Netherlands at la Hague amounted to 300kg.[10] This amount of plutonium if fabricated into MOX fuel would be sufficient for 3.8 tons. As of August 2011 this remains the amount of plutonium assigned to the Netherlands.

Since 2006, between 264-307 kg of plutonium will have been discharged from Borssele although not reprocessed.[11] If this was reprocessed, the plutonium stock available to Borssele for MOX

Expenses? Xavier COEYTAUX, Yves MARIGNAC June 2004, commissioned by Greenpeace Netherlands.

5 See, Approval for MOX use at Borssele 06 July 2011 http://www.world-nuclear-news.org/IT-Approval_for_MOX_use_at_Borssele-0607114.html EPZ submitted its application in May 2008 to use MOX (with 5.4% fissile plutonium content) as 40% of the fuel load.

6 Ibid, The plutonium content, or enrichment, is specified by the utility and can be both higher and lower depending on the technical assessment of the operator. In the period 2006 – 2011 a further 30.7 tons of spent fuel will have been discharged from Borssele. Thus in total until 2011 around 435.8 tons of spent fuel will have been generated at Borssele by the end of 2011, all of which has been covered by reprocessing contracts with la Hague running to 2015.

7 See, "Dutch utility announces renewal of reprocessing with Cogema", Ann MacLachlan Nuclear Fuel, March 15th, 2004.

8 Ibid.

9 See for example, R.J.M. Konings, et al., *Nader onderzoek naar de verwerking van gebruikte splijtsof uit Nederlandse kerncentrales*, NRG rapport 21483/99.24187/p, maart 1999, in which the reprocessing approach was reconsidered, concluded that the 'Dutch' plutonium may have a negative economic value for the European and Japanese market to at least 2015." Bruno Lescoeur, Senior Executive Vice President, International Industrial and Public Affairs of EDF for the first time confirmed publicly in Paris, 6 May 2008 that EDF gets paid by EPZ, to take title of the plutonium from the reprocessing of Dutch spent fuel, http://www.ecology.at/nni/index.php?p=site&s=29

10 See, Table 1.3. Plutonium inventory at La Hague reprocessing plant, as of 31 December 2008, 2009 Global Fissile Material Report: "Nuclear Weapon and Fissile Material Stockpiles and Production, www.fissilematerials.org

11 As of December 2007 the Dutch government reported that there were 186 elements in storage at Borssele. With 32

fabrication would be a maximum of 607kg, sufficient for 7.8 tons of MOX fuel. In reality, as of August 2011, only 300kg of plutonium belongs to Borssele as most of the spent fuel discharged since 2006 remains in the pools at the reactor site.

Insufficient plutonium ?

One question that arises out of this is does the Netherlands own sufficient plutonium to embark on a MOX program ?

The Borssele reactor currently operates with 112 uranium fuel assemblies amounting to 38.8 tons.[12] The current strategy at Borssele is for 32 fresh assemblies to be loaded during April each year, amounting to 11 tons of uranium fuel. EPZ have been licensed to operate with a 40% MOX core, or 15.5 tons. However, as of August 2011 EPZ only owns sufficient separated plutonium for 3.8 tons of MOX fuel, or around 11 fuel assemblies.

If EPZ is intending on moving to a 40% MOX core the likely loading schedule at Borssele would be in the first year the loading of 8 assemblies of MOX fuel, this would be followed in year two with 16 assemblies and in year three 32 assemblies. But EPZ has sufficient plutonium only to make the first years load and 3 more assemblies.

As of August 2011, EPZ does not own sufficient plutonium to manufacture the amount of MOX fuel it is says it plans to load into the Borssele reactor. EPZ will perhaps make the argument that it has spent fuel awaiting reprocessing but this is not convincing, as sufficient plutonium will not be available for several years.

On the basis there are a further 95 tons of spent fuel at Borssele and awaiting reprocessing at la Hague, a further 570-950 kg of plutonium will in the coming years become available to EPZ. The current contract between EPZ and AREVA runs until 2015. So an additional 160 assemblies weighing 54 tons, and containing between 320-540kg of plutonium will be available to EPZ.

So in total, taking its existing separated plutonium stock, together with all contracted plutonium to 2015, EPZ could own between 1190-1740kg of plutonium. This is sufficient for between 15.2 and 22 tons of MOX fuel.

Thus upon completion of all reprocessing EPZ will have sufficient plutonium to operate a 40% MOX core for three years. But reprocessing of all of Borssele spent fuel under contract until 2015 will not be completed before 2020 or later due to the need to store spent fuel in the reactor pool before transport to la Hague. If the reprocessing contract is extended, the spent fuel arising after 2015 will still require cooling in the pools at Borssele for some years, prior to transport to la Hague, followed by reprocessing. EPZ could arrange a swapping arrangement that would provide plutonium earlier for fabrication into MOX. But the argument remains, EPZ will have to acquire

assemblies discharged annually, there is likely to be 282 assemblies in storage as of December 2010. There appears to be a major inaccuracy in the figures cited by the Government on the amount of spent fuel arising at Borssele. In its submission to the IAEA Spent Fuel Convention, of which the Netherlands is a signatory, the inventory of spent fuel at Borssele is given as 186 assemblies with a weight of 561,585kg. The actual figure is 10% of this – 56 tons. See, JOINT CONVENTION ON THE SAFETY OF SPENT FUEL MANAGEMENT AND ON THE SAFETY OF RADIOACTIVE WASTE MANAGEMENT National Report of the Kingdom of the NetherlandsThird review conference (May 2009) Ministry of Housing, Spatial Planning and the Environment Ministry of Social Affairs and Employment Ministry of Economic Affairs Ministry of Foreign Affairs, The Hague, October 2008, http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2009/06/01/national-report-on-the-joint-convention-on-the-safety-of-spent-fuel-management-and-on-the-safety-of-radioactive-waste-management-national-report-of-the-kingdom-of-the-netherlands-third-review-conference-may-2009.html

12 See,http://ec.europa.eu/energy/nuclear/radiation_protection/doc/art35/tech_report_Borssele.pdfhttp://ec.europa.eu/energy/nuclear/radiation_protection/doc/art35/tech_report_Borssele.pdf

additional plutonium beyond that produced in the Borssele reactor.

The spent fuel discharges from Borssele over its remaining lifetime (whatever that period) would see a maximum of 100 kg of plutonium annually, sufficient for a further 1.2 tons of MOX fuel per annum – but annual MOX demand will be 3.8 tons (if the reactor is operated on a 40% MOX core)

However, what must be taken into account is that 3 years after commencing a MOX program, 40% of the Borssele core will be MOX fuel, of which 25% will be discharged annually. Thus an inventory of spent MOX fuel will accumulate at the site, whether or not any of this is transported to la Hague, it will not be reprocessed. While AREVA has conducted test batches of spent MOX fuel in the past it does not conduct commercial scale spent MOX fuel reprocessing and has no plans to do so in the existing reprocessing plants at la Hague. This is in large part due to the much higher radiation and heat levels within spent MOX fuel (and the lack of demand for plutonium)

While EPA and the Dutch authorities, KFD, state that "MOX can in principal be reprocessed again," the reality is that only limited amounts of spent MOX fuel have been reprocessed at la Hague, that it is not current practise, and with no plans or commercial demand for it in the foreseeable future. EPZ even cite AREVA as reporting that, "Existing reactors ...are not really suitable for the use of fuel made from reprocessed MOX elements."[13]

Therefore, the amount of spent fuel available for reprocessing arising from Borssele each year will be reduced by 40% or whatever percentage EPZ load with MOX fuel. In other words, its plutonium arising available for reprocessing will drop to 60kg per annum.

The conclusion of this assessment is that either EPZ will have to significantly delay its plans to load MOX fuel in Borssele, or it will have to obtain additional plutonium. The latter option would likely see EPZ entering into negotiations (if it already has not done so) with EDF and AREVA. Is it possible that after paying EDF (and AREVA ?) to take possession of its plutonium up to 2006, it is now about to reenter negotiations to obtain additional plutonium from EDF so as to be able to embark on a MOX program at Borssele that makes no economic sense Will EPZ have to pay EDF for plutonium ?

Reports that the real reason EPZ has applied for a MOX license is that it is a condition set by AREVA for the extension of the reprocessing contract beyond 2015[14] prompt these authors to suggest that it is one further reason to both scrap plans for MOX fuel and terminate further reprocessing with la Hague.

The justification made by the few nations that have embarked on a MOX program is that it was necessary to manage their plutonium. The Netherlands appears to be in the unique situation of inventing a solution for a problem that they almost don't have.

MOX FUEL USE AT FUKUSHIMA AND JAPAN – SAFETY ISSUES

The accident at the Tokyo Electric Fukushima-daiichi nuclear power plant began on March 11th and as of August 1st are still unfolding. In addition to three reactor core meltdowns, damage has occurred in four spent fuel pools. The accident has been rated as a Level 7 on the IAEA International Nuclear Event Scale, INES. Releases of radioactivity have continued for more than four months, with no expectation that they will end anytime soon, the resultant contamination has

13 The KFD is the Department of Nuclear Safety, Security & Safeguards (the KFD, KernFysische Dienst, see Verslag Bezoek opwerkingsfabriek en MOX splijtstoffabriek AREVA , 13th-15th May, 2008, door beleidsmedewerkers SVS, vertegenwoordiger KFD en vertegenwoordigers EPZ).

14 Verslag kwartaaloverleg EPZ-KFD, 18 december 2007

spread throughout Japan, in particular Fukushima Prefecture. Inhabited areas including Fukushima City, 60km from the reactor site, have levels of background radiation many times above government set safety limits. More than 140,000 people have been evacuated, with many more now exposed to elevated levels of radiation that warrant sheltering at minimum, and in many cases relocation. Food crops in many Prefectures as far south as Shizuoka have been contaminated above safety limits and have led to their withdrawal. The full extent of contamination is still unknown.

Among the many safety issues that have arisen as a consequence of the Fukushima-daiichi accident, is TEPCO's use of plutonium MOX fuel in unit 3. While the accident at unit 3 was clearly not caused by the use of MOX fuel, its presence in the molten fuel that now lies at the bottom and outside the reactor pressure vessel, raises additional important nuclear safety issues relevant to any utility operating or planning to operate a reactor with MOX fuel.[15] There is no evidence that EPZ or the Dutch authorities have considered any of these.

This section briefly describes the use of MOX fuel at Fukushima-daiichi 3 and the safety implications, with particular reference to plans by EPZ to load the same fuel into the Borssele reactor.

Tepco's Delayed MOX Program

Plans to load MOX fuel in unit 3 of Fukushima-daiichi were drafted during the mid-1990's, but it was not until September 2010 that the reactor began operation with MOX fuel. A decade and half in the planning, TEPCO's MOX program lasted six months until the events of March 11th 2011. Japan's MOX program delayed for many years is now in utter disarray. TEPCO as the largest utility and with more plutonium then any other is unlikely ever to receive approval to use MOX fuel.

TEPCO assigned plutonium reprocessed at the UP3 Cogema (now AREVA) reprocessing plant was fabricated in MOX fuel during the 1990s under contract to COMMOX (consisting of Cogema and Belgonucleaire). The plutonium MOX fuel rods were manufactured at the P0 MOX plant operated by Belgonucleaire at Dessel in Belgium, and assembled at the Framatome M5 fuel plant also at Dessel.[16] Thirty-two assemblies were produced for loading into Fukushima-daiichi 3. The MOX fuel was shipped to Japan between July and September 1999.[17]

The issue of MOX fuel was already a major public safety issue in Japan prior to the first delivery in 1999. The range of safety issues included: quality of MOX fuel, impact on reactor operational safety, radiological consequences in the event of an accident, and long term storage of spent MOX fuel. The 1999 shipment, including MOX fuel manufactured by British Nuclear Fuels Limited, BNFL, at the Sellafield site, created a global controversy. The shipment was opposed by more than 50 nations along the potential and actual transport routes. During transit, it was disclosed that BNFL had falsified vital safety data during fuel manufacture. BNFL denied that the falsification did not

15 See for example, United States Congressional Research Service, which noted that ***"Another danger comes from the potential release of plutonium from the MOX fuel used at reactor 3. Even very small amounts of plutonium, if inhaled, can potentially cause lung cancer. This explains the concern about that reactor, as it is the only one that uses MOX fuel, although irradiation of uranium fuel also creates plutonium"***, see, The Japanese Nuclear Incident: Technical Aspects Jonathan Medalia, CRS, March 31, 2011.

16 In 1993, Greenpeace and others challenged Belgonucleaire's plans for the construction of a new MOX plant, the so called P1. This facility was intended to increase MOX production to 70 tons each year. Citing that there had been inadequate public consultation before the construction license was granted, the organisations charged that the facility could not be built under the license granted by the government. After more than five years, the Belgium Supreme Court finally ruled in late 1998 that construction could not take place under the license. Belgonucleaire did not attempt to obtain a new license, and the P1 has not been built, see, http://www.klimaatkeuze.nl/wise/monitor/515/5062

17 See, http://www.greenpeace.org.uk/media/press-releases/japanese-commandos-surround-mv-greenpeace-while-witnessing-deadly-plutonium-shipment, and http://www.youtube.com/watch?v=aEDQIdX6qEI

concern the 8 PWR MOX assemblies then being shipped to Japan, but rather Japanese MOX fuel still at the Sellafield site. The MOX fuel arrived in Japan in the midst of major citizen and political opposition.

The authors of this paper spent months during 1999 investigating MOX fuel use in Japan and the manufacturing process of European suppliers. Together with Japanese citizens groups, Green Action and Mihama-no Kai, Greenpeace made the case that the BNFL MOX fuel contained falsified fuel data.[18] Following 2 months of denial by BNFL, the reactor operator, Kansai Electric, and the Japanese Government, and on the eve of a court case brought by Japanese groups seeking an injunction to prevent loading of the MOX fuel, it was finally admitted that the fuel data had been falsified. Plans for MOX fuel use both at Kansai Electric and TEPCO were set back years.[19]

The BNFL scandal triggered even greater debate in Fukushima Prefecture. In August 2000, 850 citizens filed a petition calling on TEPCO to abandon plans to load its AREVA MOX fuel. In December 2000, the Fukushima district court heard evidence from these authors on behalf of TEPCO shareholders. Evidence on the safety of MOX fuel including the quality control of its manufacture and the possibility that data had been falsified was presented against TEPCO.[20] The judgement was that although the case against TEPCO was not proven, it was agreed that quality control data be released publicly, as demanded by citizens. Fukushima Prefectural Governor, Sato Eisaku, suspended approval for MOX loading in unit 3 in 2001.[21]

During the intervening decade, the MOX program in Japan made little progress. Instead of 10-15 reactors loaded with MOX fuel by 2010, as government and utilities had stated through the 1990s, two reactors had been loaded prior to Fukushima-daiichi 3 in September 2010.[22] While ten reactors had been licensed to load MOX fuel, Prefectural approval was required and there was strong public opposition across Japan.

In August 2010, the Fukushima Prefectural Assembly endorsed the decision of the current governor Sato Yuhei, to accept the 'pluthermal' power-generation plan, and MOX fuel was loaded into the reactor on August 21st with commercial operation in mid September.

Effect of MOX fuel on reactor safety

The background to the MOX program in Japan is that many safety issues were debated throughout society, in particular during the late 1990's and to the present. The debate in Japan has been far in advance of any other nations embarking on a plutonium MOX program, including in France, the largest MOX producer and consumer. Below is a summary of some of the issues that have been addressed by civil society in advance of TEPCO's MOX loading in Fukushima-daiichi unit 3. Plutonium MOX reactor fuel has physical properties that are different from ordinary UO2 reactor fuel, affecting the thermal and mechanical performance of the fuel rods. The main effects are:

18 See, http://archive.greenpeace.org/pressreleases/nucreprocess/1999sep24.html
19 After compensation agreement between the Governments of Japan and the UK, the 8 MOX fuel assemblies containing approximately 230kg of plutonium were shipped back to the Sellafield site, opposed by over 60 nations. See, Plutonium ships sail through Irish Sea Protest Flotilla Rainbow Warrior, Irish Sea, September 16th 2002
20 See, MOX Production standards and quality control at Belgonucleaire and the implications for reactor safety in Fukushima-1-3 submission to the Fukushima District Court, Fukushima City, Japan, Dr Frank Barnaby, Oxford Research Group/Shaun Burnie, Greenpeace International December 26th, 2000, http://archive.greenpeace.org/nuclear/transport/mox00/moxqc.pdf
21 See, Former Fukushima Governor Sato Eisaku Blasts METI –TEPCO Alliance: "Government must accept responsibility for defrauding the people" Onuki Satoko,March 30th 2011, http://www.japanfocus.org/-Onuki-Satoko/3514
22 The first reactor, Genkai-3 PWR, operated by Kyushu Electric, was started with MOX fuel in its core in November 2009 and produced first electricity on 2 December 2009; Shikoku Electric utility began commercial operation with MOX fuel on March 2nd, 2010, at the Ikata-3 PWR.

• reduction of the control rod and neutron absorber worth's because of the higher thermal absorption cross-sections of Pu relative to those of U, reducing the margin for shutting down the reactor;[23] The effect of this is to make less effective the use of control rods, thereby reducing safety margins;

• MOX has greater fission cross-sections at higher neutron energies than UO2 fuel, resulting in the coolant void coefficient of reactivity being less negative for MOX than for UO2 fuel, leading to greater risk, particularly when trying to control the reactor in emergency situations;

• the harder neutron energy spectrum in MOX fuel, and the consequent higher neutron energies, may increase the damage done to the pressure vessel of the reactor by neutron irradiation,[24] because the thermal conductivity of MOX, compared with UO2, is reduced, the energy stored in the fuel rods in a loss-of-coolant-accident is increased, with a resultant increase risk of rapid fuel meltdown and through the pressure vessel;

• higher temperatures also increase the release of fission gases from MOX fuel and increase the pressure in the rods; plutonium hot spots may affect the behaviour of MOX fuel[25] and the cladding of MOX rods during reactivity accidents, a problem that has not been resolved[26];

MOX fuel relocation and pellet column collapse into the lower part of the fuel rod takes place earlier than with uranium fuel. In addition, the ballooning of AREVA supplied M5 cladding in MOX fuel has been detected; Both of these impact on the effectiveness of emergency core cooling systems in the event of an accident, increasing the risk of core melt;[27]

• the different concentrations of fission products and actinides in MOX fuel may increase the severity of a reactor accident; the larger amounts of actinides in MOX fuel determine that the decay heat of the fuel rods will be greater, leading to an additional challenge to effect cooling and consequent risks of fuel melt;

• the much larger amounts (by between 5 and 22 times) of actinides in MOX fuel may increase, by

23 See, Report of the International MOX Assessment, Comprehensive Social Impact Assessment of MOX Use in Light Water Reactors: J. Takagi, M. Schneider, F. Barnaby, I. Hokimoto, K. Hoskowa, C. Kamisawa, B. Nishio, A. Rossnagel, M. Sailer, Citizens' Nuclear Information Center, Tokyo, November 1997.

24 See, United States Nuclear Regulatory Commission, Mixed-Oxide Fuel Use in Commercial Light Water Reactors, Memorandum from Executive Director for Operations, United States Nuclear Regulatory Commission, Washington DC, April 14, 1999.

25 See, Willermoz, G., Bethoux, P., Bruna, G. B., Castelli, R. and Serant, D., Modelling of manufacturing fuel heterogeneities in a PWR via a stochastic - perturbative method, Prog. Nuc. Energy, Vol.33, pp. 265-278, 1998.

26 See, Grandjean C. and Lebuffe C., High Burnup Fuel Cladding Embrittlement under Loss-of-Coolant-Accident Conditions, Proceedings of the Topical Meeting on Safety of Operating Reactors, ANS Seattle, September 17-20, 1995. 67 see, Lyman, E. S., The Impact of the Use of Mixed-Oxide Fuel on the Potential for Severe Nuclear Plant Accidents in Japan, Nuclear Control Institute, Washington DC, October 1999; see also Estimation of the Grain Boundary Gas Inventory in MIMAS/AUC MOX Fuel and Consistency with REP-Na Test Results Francette LEMOINE Institut de Radioprotection et de Suˆreteˊ Nucleaire, DPAM/SEMCA/LEC, France, Journal of NUCLEAR SCIENCE and TECHNOLOGY, Vol. 43, No. 9, p. 1105–1113 (2006).

27 Lyman has raised the issues impact of fuel relocation effects during a loss of coolant accident which may be more severe for MOX fuel rods than for uranium fuel rods of the same burn-up, due to differences in characteristics such as fuel fragment sizes and fuel-clad interactions. This is a key safety issue highlighting that current assessments are inadequate because they do not address the uncertainties associated particularly with M5-clad MOX fuel. The French safety agency IRSN has reported that during a loss of coolant accident the MOX fuel pellet column collapses into the lower part of the fuel rod sooner than LEU fuel. In addition IRSN has highlighted that that modem, low-tin, high ductility cladding materials, such as the M5 cladding that is used in MOX fuel will form bigger "balloons" than conventional Zircaloy and are likely to have higher blockage ratios. See, A. Mailliat and J.C. Melis, IRSN, at "Phebus STOLC meeting" with NRC staff (October 23rd, 2003, as cited in United States of America Nuclear Regulatory Commission Docketed before the Atomic Safety and Licensing Board, USNRC in the matter of Duke Energy Corporation (Catawba Nuclear Station, units i and 2) December 5,2003 (11:25am) Docket no's. 50-413-ola, Office of Secretary 50-414-Rulemakings and Blue Ridge Environmental Defense League's second supplemental petition to intervene, 2003.

about one-third, the number of fatal cancers produced by a reactor accident.[28] Releases of up to 5 per cent of the actinide inventory of a PWR core may be released in severe accidents;

• Increased risks from longer storage of spent MOX fuel in the reactor cooling pools due to higher heat burden, and greater radiological inventory, as above in terms of off-site hazards.

Some of the above are more pertinent to the Fukushima-daiichi accident than others.

Fukushima MOX use and safety

The Fukushima-daiichi unit 3 was loaded in August 2010 with 32 assemblies of MOX fuel, this is a loading of 5.4% of the total core (548 assemblies). The amount of plutonium in the fresh MOX fuel was around 225kg. The reactor began operation in September 2010 so burn-up rates were relatively low at the time of the accident.

Issues of particular relevance to the Fukushima-daiichi unit 3 accident -

* the thermal conductivity of MOX, compared with UO2, is reduced, and the energy stored in the fuel assemblies in a loss-of-coolant-accident is increased. Fukushima-daiichi suffered a complete loss of cooling capacity, the consequence of which was that the MOX assemblies have melted in unit 3, along with the uranium fuel, with the 32 MOX fuel assemblies now located in the bottom of the reactor (with burn through of the reactor pressure vessel most likely) in a molten mass.[29] It is currently being cooled with twice as much water as reactors 1 and 2.[30] There is no official explanation for this currently, but according to the latest measurements published by NISA, there is little to differentiate between units 2 and 3 temperature at the bottom head of the reactor pressure vessel.[31] It may emerge over the coming years that the presence of MOX fuel was one explanation for this variance. TEPCO have stated that it will be ten years before recovery of the fuel will be possible – it will be many years before the condition of the fuel, including comparative analysis between units 1, 2 and 3, will be possible including what if any impact the presence of MOX fuel had on the condition of the fuel, including whether issues such as rapid MOX fuel relocation in comparison to uranium fuel was a factor. What can be said is that if TEPCO had succeeded in loading 180 assemblies of MOX fuel into unit 3 the heat burden of the molten fuel would have been greater than the present situation at the reactor, with consequences for cooling time the volume of contaminated water arising, and potential off-site impact;

* On the matter of hydrogen risks, which played such a decisive role in the damage severity and radiological outcome at Fukushima Dai-ichi, the IAEA mission team that visited Fukushima called for a detailed evaluation. The source of the hydrogen was the vigorous and exothermic reaction with

28 See, Lyman, E. S., The Impact of the Use of Mixed-Oxide Fuel on the Potential for Severe Nuclear Plant Accidents in Japan, Nuclear Control Institute, Washington DC, October 1999.

29 After two months TEPCO released date that confirmed analysis from Large&Associates in mid-March. TEPCO data showed that the fuel pellet temperatures initially dropped from the normal operating temperature of about 800 to 900oC to ~300oC as the earthquake invoked reactor SCRAM actioned but, thereafter, following the tsunami strike, a dwell whilst it is assumed the electrical power independent steam turbine driven pump (and, possibly, the isolation condenser) continued to engage cooling for about 1 to 2 hours. At this point in time, the fuel temperature soared to melt and then boiling levels (~2,800oC) within two hours with, physically, the fuel corium mass slumping and passing down through the fuel core support plate into the bottom of the RPV. During the early phases of 1 to 2 hours of melting, RPV steam temperatures would have been sufficiently high to provoke a Zircaloy-steam exothermic reaction, adding heat to the corium forming mix and liberating high volumes of hydrogen (that subsequently exploded at about +24 hours into the incident), and melting the boron alloy control cruciform plates triggering neutron activity within the corium – see - Update on the Nuclear and radiological situation at Fukushima-daiichi, Dr John Large, May 25th 2011, commissioned by Greenpeace Germany.

30 As of August 2nd, 9 cubic meters per hour of cooling water is being applied to unit 3, compared to 3.5 cubic metres per hour for 1 and 2.

31 See, http://www.nisa.meti.go.jp/english/press/2011/08/en20110802-1-2.pdf, for August 1st 2011 data.

the zirconium-alloy fuel cladding (and fuel assembly bracing, etc) with the steam that filled the depleted water spaces in the RPVs of Units 1, 2 and 39 - this zirconium clad fuel system is common to all light water moderated reactors (essentially BWR and PWR) worldwide. So, according to the IAEA preliminary findings, all light water NPPs worldwide sharing this Zircaloy fuel system should be subject to detailed evaluation (reactor fuel cores and spent fuel ponds).[32] The additional thermal load of MOX fuel may or may not have been a factor at Fukushima-daiichi unit 3 (the core was 5% MOX fuel), however an urgent assessment is required on the impact of MOX fuel loads on zirconium-alloy cladding, including the AREVA M5 fuel;

* increase in fission gas release – as the Fukushima accident has shown, a major release of cesium 137 has been underway since March 12th, with dispersal throughout Fukushima Prefecture.[33] Evidence of fission gas generation problems with MOX include results from the fuel test facility in France known as VERCORS, which observed that during the early stages of core degradation, ***"releases of volatile radionuclides from MOX are more extensive than from conventional fuels at similar levels of burn-up"*** which is ***"consistent with the peculiar nature of porosity that develops in MOX during burnup."***[34] In particular, in a test in which spent fuel was held at a temperature of 1780 K (Kelvin) for one hour, the cesium release fraction for a MOX fuel rod with a burnup of 41 GWD/t was 58%, compared to only 18% for an LEU rod with a burnup of 47 GWD/t.[35] The fuel temperature experienced at the Fukushima-daiichi reactors were recorded at 2800 C. It is too early to say what if any effect the presence of MOX fuel in unit 3 had on fission gas release – it may never be known. What is known is that in a fuel melt situation more fission gases are released from a MOX core than a uranium fuelled reactor;

* the much larger amounts (between 5 and 22 times) of actinides in MOX fuel may increase, by about one-third, the number of fatal cancers produced by a reactor accident.[36] Reports on actinide fallout from the Fukushima accident remain limited at this stage. Plutonium measurements so far published have been limited. There is no explanation for this. Of the five sample data published, two appear to be the correct ratio of pu-238/239+240 isotopes for it to be AREVA reprocessed reactor-grade plutonium, suggesting that the source is the MOX fuel in unit 3. However, given the meltdown of three reactor cores and unknown releases from spent fuel pools, it is not possible to state with absolute certainty the origin of the plutonium. Japanese authorities clearly believe that two of the samples originate from the reactor cores.[37] Publication of the americium content would provide further verification of the source of the plutonium. As Lyman has noted, ***"Throughout the operating cycle, MOX cores have larger inventories than LEU cores of most transuranic (TRU) radionuclides, including plutonium-239 (Pu- 239), americium-241 (Am-241) and curium-242 (Cm-242). Since many of these radionuclides are long-lived alpha-emitters, with relatively high radiotoxicities if inhaled or ingested, small releases during an accident can contribute significantly to public radiation exposure."***

* MOX fuel impact on emergency countermeasures, including evacuation/relocation. Related to the above, in the event of a serious accident and radioactive release, the area of land affected and population requiring evacuation is greater for a MOX fuelled than uranium fuelled reactor, for the

32 See, Review of the International Atomic Energy Agency (IAEA) preliminary summary of its fact finding expert mission to Japan of 24 May to 1 June 2011 Greenpeace France, Large&Associates, June 2011.

33 Contamination of food crops such as green tea in Shizuoka several hundred kilometres to the south of Fukushima-daiichi illustrate the extent of contamination.

34 See, U.S. NRC ACRS, "Use of Mixed-Oxide Fuel in Commercial Nuclear Power Plants" (letter report to NRC Chairman Shirley Jackson, May 17, 1999, as cited in Lyman, E. S., The Impact of the Use of Mixed-Oxide Fuel on the Potential for Severe Nuclear Plant Accidents in Japan, Nuclear Control Institute, Washington DC, October 1999.

35 U.S. NRC ACRS, Proceedings of the 461st Meeting of the Advisory Committee on Reactor Safeguards, April 9, 1999, as cited in Lyman, ibid.

36 Opcit, Lyman.

37 See, Result of Pu measurement in the soil in Fukushima Daiichi Nuclear Power Plant, March 28th 2011, http://www.tepco.co.jp/en/press/corp-com/release/betu11_e/images/110328e14.pdf

same level of severity. In the case of Fukushima-daiichi over 140,000 persons were evacuated, but the level of contamination across a wide area of Fukushima Prefecture and in terms of projected radiation dose to the population should necessitate a larger evacuation and relocation. The implications of this for emergency response in all nations operating nuclear reactors are significant. The lack of data on plutonium releases from Fukushima-daiichi means that it is unknown what impact if any the additional MOX fuel has had on overall actinide contamination. Numerous studies have shown that the numbers of public requiring countermeasure action following a MOX fuelled accident are considerably larger. In analysis for the Flamanville EPR, Large&Associates projects that for a 100% LEU fuelled EPR operating at current levels of fuel irradiation (burn-up) a (statistically mean) area of about 5,600km2 entailing about 230,000 individuals would require evacuation tailing off over the first week following a containment failure and radiological release. If the EPR is fuelled with a 30% MOX core the land area requiring evacuation expands to about 11,660km2 involving about 567,600 evacuees.[38]

Clearly, the Fukushima-daiichi accident is both severe and on-going. What is clear is that the impact of the accident would have been more severe if TEPCO had implemented its original plan which was to operate all Fukushima reactors with a 30% core of MOX fuel, which if had it been successful would have meant the loading of around 180 assemblies of MOX fuel containing approximately 1,170 kg of plutonium. If the original TEPCO schedule had been achieved this loading would have begun in 2000 with a scaling up of MOX fuel during past ten years. In addition to a core containing over 20 tons of MOX fuel, the spent fuel pool of Fukushima-daiichi would also have contained multiple tons of spent MOX fuel. The active opposition of hundreds of informed and concerned citizens in Fukushima and Japan over the last 15 years has undoubtedly lessened the severity of the catastrophic accident now unfolding at Fukushima-daiichi and across the nation. For any nation considering embarking on a MOX program the lessons of Fukushima demand to be taken seriously by citizens and policy makers alike.

SAFETY IMPLICATIONS OF MOX FUEL USE IN BORSSELE

The safety issues that were summarized in the previous chapter are all relevant to the plans of EPZ to operate Borssele with MOX fuel and should be addressed by Dutch authorities.

In assessing the risks of MOX fuel nearly 20 years ago, a nuclear engineer, now a member of the German government nuclear safety division observed that,

"In critical situations, the requirements of which transcend normal levels - in particular reactivity incidents and transients - even small reductions of safety margins in control can lead to serious problems and accidents. The danger that incidents for which the plant is designed develop into major accidents is thus increased by the use of MOX."[39]

The Fukushima-daiichi accident has already had major impacts on the future development of Japan's nuclear program. The prospects for plans to expand the use of plutonium MOX fuel, already much delayed, are perhaps one of the most directly impacted. TEPCO, the largest holder of plutonium of any Japanese utility is unlikely to load any MOX fuel in its remaining reactors in the years ahead. The nine other utilities MOX plans are already set back years by Fukushima, and perhaps indefinitely. The analysis of Dr Sailer and others on the risks of MOX fuel is very well understood within Japanese society. However the authors of this report have no evidence that the

38 Based upon the European COSYMA modelling, see, Assessments of the radiological consequences of releases from existing and proposed EPR/PRW nuclear power plants in France, Large&Associates commissioned by Greenpeace France, February 2007, http://www.largeassociates.com/3150%20Flamanville/r3150-final-summary.pdf See Appendix 1 for calculations.

39 See, Dr Michael Sailer, member of the German government's Commission for Nuclear Safety, including member of the working group on plutonium and spent fuel management, as cited in “The MOX Industry”, IPPNW, 1994.

scale of these issues are even acknowledged by the Dutch authorities. And yet a license has been granted to EPZ to load up to 40% of the core of Borssele with MOX fuel.[40]

In addition to the safety issues described earlier there are additional serious questions over EPZ MOX plans.

Borssele MOX safety analysis

The license approving MOX fuel use in the Borssele nuclear reactor is based upon a safety case prepared not by Dutch authorities but by Gesellschaft fur Anlagen und Reacktorsicherheit, or GRS. As the GRS states, "

"Since the Netherlands operate only one nuclear power plant, they do not have their own TSO. GRS fulfils the role of a Technical Safety Organisation in Germany. As it has the technical competence required, GRS is now also assuming to a growing extent the role of TSO for the Netherlands... One of the tasks involved in the scientific and technical support was e.g. the assessment of the use of so-called MOX fuel assemblies at Borssele."[41]

A more direct way of putting this is that the Netherlands does not have the technical competence to assess the safety implications of loading MOX fuel in its one operating commercial reactor. When it comes to the operation of the reactor with MOX fuel will GRS personnel be responsible for on-going safety assessments? This is unknown but nevertheless troubling. Given the safety implications of operating nuclear power plants, in particular with plutonium MOX fuel, this is an extraordinary situation. Made all the more unusual when one considers that since the start of the Fukushima-daiichi accident, Germany's seven oldest reactors have since March been closed and will now not operate again. A decision by the Germany government, based in part on a safety assessment report prepared by the RSK. All of these reactors have operated for fewer years than the Borssele reactor, which began operation in 1973.

One of the safety issues raised in Japan over the past 15 years was plans to load MOX fuel in an ageing reactor - the Fukushima-daiichi unit 3 began operation in 1976. Yet, in the Netherlands a reactor designed by KWU/Siemens in the 1960's and nearing its 40th year of operation, is planning to proceed with the use of MOX fuel. As the RSK stated,

"The events in Japan have shown that incidents can occur that exceed any of the scenarios hitherto taken into account. This gives rise to the need to analyse the situation unconditionally, taking the current events into account. It now needs to be examined to what extent scenarios that have not been taken into account so far call for a reassessment in the light of what happened in Japan, particularly in relation to the seven oldest nuclear power plants in Germany".[42]

There is no evidence that this is the policy of the Dutch authorities, and even if it were, they do not have the national technical competence to undertake such an analysis. The June 2011 decision to license Borssele for MOX is one clear example of a failure to acknowledge the consequences of the Fukushima-daiichi accident and therefore a disregard for public safety in the Netherlands and beyond.

40 The Ministry of Economic Affairs, Agriculture and Innovation informed EPZ of its decision to approve its fuel diversification plan in a letter dated 27 June 2011.

41 See, http://www.grs.de/en/content/kfd

42 See, German nuclear power plants to undergo safety review Seven nuclear power plants to be shut down for three months http://www.bmu.de/english/nuclear_safety/doc/47187.php

Emergency response

Five days after the start of the Fukushima-daiichi accident the United States government issued a warning to its citizens in Japan that recommended evacuation and no entry within a 50 mile/80km radius of the Fukushima plant.[43] It was based on U.S. regulations that requires protective actions when projected doses could exceed 1 rem (10 miliSieverts) to the body or 5 rem to the thyroid. This of course contrasts with the Japanese government decision to evacuate an area 20km radius from the Fukushima plant. The U.S. advice was extended in May when the U.S. State Department issued an advisory stating that U.S. citizens should still avoid entering the 50 mile/80km radius. They did state that it was possible to either travel on the Shinkansen or by car through the area. More than two months after the start of the accident, the U.S. government was still advising non-occupation by U.S. citizens within the 50 mile radius of the plant, and those still living in this area are advised to evacuate.[44] The U.S. government extended its advice on Fukushima on June 9th, with a review due on September 15th 2011.[45]

One impact of the Fukushima-daiichi accident is to expose the flaws in current emergency response measures worldwide in the event of a serious nuclear accident. The citizens of Fukushima City (around 220,000) are currently being exposed to radiation dose rates that are equivalent over one year to that of a nuclear industry worker or above, with demands from citizens for decontamination and where necessary evacuation and relocation, with a particular emphasis on children and infants.[46] The implications are clear for any population within close proximity to a nuclear power plant.

In the case of the Borssele reactor it is located 55km from the city of Antwerp Belgium, 80 km from Rotterdam, 120km from Utrecht, and 130 km from Amsterdam. As the noted by the European Commission, ***"The overall region within a perimeter of 200 km (of Borssele) is a highly populated region of high electricity consumption and an area of agricultural and high industrial activity***."[47] Antwerp's population is currently 455,000, with a density of 2226 per sq/km, this compares with the average in Japan of 800 per sq/km.

The emergency response plans for the Netherlands when seen in the light of Fukushima, with or without MOX fuel, are clearly inadequate. The Japanese government has been much criticized for its setting of permitted dose limits for children in Fukushima at 20 milisieverts within one year, since when it has stated that it aims to reduce this to 10mSv.[48] However, the Dutch authorities would permit dose levels between 50mSv-250mSv within a year before instituting evacuation. The population density of the Netherlands may be one explanation for this policy. However, given the additional risks of such dose it highlights that operating a nuclear reactor in the Netherlands, with or without MOX fuel, is not acceptable from a public health perspective.

As cited earlier, the consequences of a serious accident at a reactor operating with a MOX fuelled core are more serious in terms of area contaminated, population required to be evacuated and long term health impact, in particular latent cancer rates.[49] Unlike the extensive and prolonged public

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43 See, No. 11-050 NRC PROVIDES PROTECTIVE ACTION RECOMMENDATIONS BASED ON U.S. GUIDELINES, March 16, 2011.

44 "Out of an abundance of caution, we continue to recommend that U.S. citizens avoid travel within the 50-mile radius of the Fukushima Daiichi Nuclear Plant. U.S. citizens who are still within this radius should evacuate or shelter in place", Travel Alert U.S. DEPARTMENT OF STATE, Japan May 16th, 2011 Bureau of Consular Affairs http://travel.state.gov/travel/cis_pa_tw/pa/pa_5454.html

45 See, http://travel.state.gov/travel/cis_pa_tw/pa/pa_5454.html

46 See, http://fukushima.greenaction-japan.com/2011/07/01/petition-02-protect-the-children-of-fukushima/

47 See, Technical report Borssele nuclear power station the Netherlands reference: nl-08/01 verifications under the terms of article 35 of the Euratom Treaty, European Commission Directorate-General for Energy and Transport Directorate D – nuclear energy d.4 radiation protection, 03 march to 07 march 2008.

48 Opcit, see, National report of the Kingdom of the Netherlands Third review conference (May 2009)

49 Opcit, Large&Associated, Assessments of the radiological consequences of releases from existing and proposed

debate of these issues in Japan over the past decade or more, there is no evidence that these issues have been addressed at a public level in the Netherlands, including in population centres that would be severely impacted in the event of a serious accident. It is the responsibility of the Dutch authorities to openly and clearly explain to their citizens the additional risks with the planned use of plutonium MOX fuel.

AREVA MOX fuel manufacture and quality control

On the basis that EPZ utilizes its small, but significant,stock of plutonium at la Hague, and obtains additional amounts from other sources, most likely EDF, the MOX fuel will most likely be manufactured at the AREVA MELOX facility in Provence, north of Avignon. There are a multiple of safety and security issues that arise but which are not included in this report.[50]

One issue that has persisted over the past decade and half is the production standards and quality control of MOX fuel manufacture. While the original MOX scandal in Japan related to fuel produced by BNFL at Sellafield, the issue spread to encompass the two other European producers, Cogema/AREVA and Belgonucleaire. The latter is no longer operating its MOX plant having failed to secure new business. Whereas BNFL had for decades a reputation for secrecy and cover-ups in its operations, vital safety and quality control data was made publicly available in response to the 1999 MOX scandal. BNFL's lack of transparency however pales when compared to the French state nuclear company Cogema/AREVA. No such hard data has ever been released by Cogema/AREVA, despite requests over many years from Japanese citizens, utility customers and the courts.

In addition to the poor production standards and quality control already cited and documented in recent years, recent examples of poor practise by AREVA demonstrate that there are outstanding issues of safety of direct relevance to its customers, including EPZ, and therefore the wider Netherlands.

In August 2009 Japanese utility Kansai Electric Power Company (KEPCO) announced that MOX fuel pellets being fabricated at Areva's MELOX plant for its Takahama units 3 and 4 PWR's failed to meet its own internal standards.[51] It decided not to use the defective pellets and to reduce its order from 8 fuel assemblies each for the two reactors to 8 assemblies for Unit 3 and 4 assemblies for Unit 4. The problematic pellets represented 25% of the total order. KEPCO refused to disclose costs or the results of the inspection on the grounds that they were commercial in confidence under the terms of its contract with MELOX. It also stated that it does not have sufficient information from AREVA, which refused to provide data and resisted halting production claiming that the pellets were usable even though they did not meet KEPCO quality control standards.

These authors have confirmed in meetings with French nuclear safety regulators that there is no regulatory oversight of the nuclear fuel industry, including MOX fuel.[52] The regulators do not

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EPR/PRW nuclear power plants in France; and Lyman, E. S., The Impact of the Use of Mixed-Oxide Fuel on the Potential for Severe Nuclear Plant Accidents in Japan.

50 These include weak security arrangements in France for both plutonium and fresh MOX fuel transports. See, Security Assessment Report for Plutonium Transport in FrancePrepared By Ronald E. Timm certified protection professional, Greenpeace International March 2005, and Potential radiological impact and consequences arising from incidents involving a consignment of plutonium dioxide under transit from Cogema la Hague to Marcoule/Cadarache Large&Associates, Greenpeace International report ref no r3108-a6, March 2004. As observed in 2011 by Greenpeace, there have been no major changes in the security arrangements for plutonium/fresh MOX fuel since these reports were drafted, with even greater quantities of fissile material now transported annually within France.

51 Opposition to MOX fuel in Japan continued through the last ten years, with 460,000 signing a petition to stop MOX fuel loading in the Genkai reactor in southern Kyushu. See, Defective MOX fuel pellets, Nuke Info Tokyo No. 132 (September/October 2009 - http://cnic.jp/english/newsletter/nit132/nit132articles/nw132.html#mox

52 There remain no overall international agreed standards for MOX fuel production. The ISO has guidelines for quality

inspect production but rely on assurances from the customer that they are meeting the specification agreed with the producer. This is wholly unacceptable position persists to this day. In the case of Borssele, EPZ will likely commission KEMA to oversee the production of its MOX fuel, including agreement on quality control and assurance standards.[53] While we have no experience of KEMA nor reason to question their competence, AREVA, as with its relationship with its much larger Japanese customers remains defiant when it comes to its production standards and any question that they are problematic.

The original BNFL MOX scandal exposed the larger reality of MOX fuel production standards, of which quality control is only one. The fundamental issue is that it is not possible to produce MOX fuel of a consistently high standard to ensure reliable performance.[54] Sufficient evidence exists to show that AREVA's MOX production technique based on the MIMAS process produces an inferior product to the much troubled UK Sellafield MOX Plant. This includes the larger concentrations of plutonium particles, so called hot spots, which have direct implications for reactor safety.[55]

One important issue to understand is that the safety of MOX fuel has been scrutinized at a public level in Japan unlike any other nation. Thus, utilities are highly sensitive to issues around safety. The Fukushima-daiichi accident has already increased public scrutiny of utility MOX fuel plans in Japan, and it is bound to grow further. While this in no way provides assurance that utilities can apply standards that would guarantee the safety of MOX fuel, it does mean that in their relations with MOX producers, specifically AREVA, they are more exacting. Japan has been and continues to be AREVA's most important overseas nuclear fuel services client but even this relative strength does not permit Japanese utilities access to vital safety data. This should be factored in when considering the likely relationship between EPZ and AREVA, the former a utility that in terms of commerce with the French atomic giant barely registers.[56]

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control of plutonium oxide powder, oxygen to metal ratio for MOX, and carbon content in sintered pellets. See, Nuclear-grade plutonium dioxide powder for fabrication of light water reactor MOX fuel — Guidelines to help in the definition of a product specification, INTERNATIONAL ISO STANDARD 13463 First edition September 1999, and Nuclear fuel technology, Determination of the O/M ratio in MOX pellets, Gravimetric method, ISO 21484:2008, November 2008; Determination of carbon content of UO2, (U, Gd)O2 and (U, Pu)O2 powders and sintered pellets -- Combustion in a high-frequency induction furnace -- Infrared absorption spectrometry,ISO November 2008, ISO 21614:2008.

53 http://www.kema.com/about/history.aspx

54 Fundamental deficiencies in the quality control of mixed-oxide nuclear fuel Dr Frank Barnaby/Shaun Burnie Greenpeace International Fukushima City, Japan, March 27th 2000.

55 See, NUPEC, Report on Fuel Assembly Credibility Substantiation Examination - Mixed Oxide Fuel Irradiation Compilation March 12th 2000.

56 A client that AREVA still seeks to defy is the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission. A range of safety and quality control issues have arisen during the much troubled manufacture of the AREVA designed MOX plant at Savannah River Site. Currently, quality control issues are a factor in the uncompleted AREVA MOX plant at SRS. Three structural components were procured and installed by the prime contractor at Savannah River during construction of the MOX Facility that did not meet the technical specifications for items relied on for safety. These substandard items necessitated costly and time consuming remedial action to, among other things, ensure that nonconforming materials and equipment would function within safety For example, as of October 2008, the MOX Facility had incurred costs of more than $680,000 due to problems associated with the procurement of $11 million of nonconforming safety-class reinforcing steel. In general, the internal control weaknesses we discovered could have permitted, without detection, the procurement and installation of safety critical components that did not meet quality assurance standards. In a worst case scenario, undetected, nonconforming components could fail and injure workers or the public. The Department's Office of Environmental Management (EM) supported the conclusions and the recommendations reached and told us that it had identified similar quality weaknesses at Savannah River. While the NRC stated that these were of the lowest level of severity, the Auditor General concluded, "however, we do not agree that the problems were of low significance.Unless and until the Department resolves the internal control weaknesses that permitted the failures NRC identified at MOX, it is possible that non-conforming parts or components that do not meet safety standards could continue to be procured and installed in critical nuclear facilities." see, Safety Reviewers Raise Questions about Construction of New Nuclear Fuel Plant MOX Fuel Fabrication Facility on November 19, 2007 (National Nuclear Security

Spent MOX fuel issues

Although warranting a separate detailed report of its own, final mention should be made of the implications of MOX fuel use in Borssele for nuclear waste management in the Netherlands.

In Japan the safety implications of MOX use have included public debate and opposition due to the hazards of MOX fuel once it is removed from the reactor, so-called spent MOX fuel. In its 2005 Framework for Nuclear Energy Policy, the Japanese government stated that it will commence an assessment on managing spent MOX fuel in "around 2010". But the Atomic Energy Commission has failed to keep to this timetable, with no prospect of it being assessed anytime soon. This the same Energy Policy that commits the nation to multiple reactors loaded with MOX fuel (hundreds of tons over the coming decades), the operation of the world's most advanced (and expensive) reprocessing plant at Rokkasho-mura, and a long term commitment to the commercial deployment of fast breeder reactors. Clearly with such a program, assessing options for spent MOX fuel, including its reprocessing, and the 'recycling' of the separated plutonium in FBR's would be entirely consistent with national policy ? But no such assessment has been conducted.The reality is that a debate on what to do with spent MOX fuel would be wholly counterproductive to the successful implementation of Japanese nuclear policy. It would reveal that there are no real long term plans for the management of spent MOX fuel – other than indefinite storage. As with the UP2800 and UP3 plants at la Hague, Rokkasho will almost certainly never reprocess spent MOX fuel. No geological repository exists in Japan and will not do so for decades if ever. So a nation with formally the most ambitious plans for plutonium use of any nation, has no formal position on the management of one its principal and most hazardous of waste forms spent MOX. What does that say about the prospects for long term management of spent MOX fuel in the Netherlands?

The French plan for managing its 1000 tons of spent MOX fuel as of 2010, due to rise to over 2000 tons by 2020, has at least been declared. The nuclear waste agency ANDRA reports that sometime between 2025 and 2035 some of this will be reprocessed, perhaps in a modified la Hague plant.[57] This is on the basis that a commercial fast breeder program unfolds in France (or anywhere for that matter). On the basis that this won't happen, the option of disposal arises. But there are significant problems. In 2000 a critically important report was presented to the French government. The Charpin-Dessus-Pellat Report to the Prime Minister on the past and future economics of nuclear power in France, exposed many myths about the French nuclear program.[58] One of which was the challenge posed by spent MOX fuel. It revealed EDF's own conclusion that spent MOX fuel would have to cool on the surface for 150 years, compared to 50 years for spent LEU fuel or vitrified waste.

According to EDF, the thermal load of spent MOX fuel is about three times as high as that of spent uranium fuel. Accordingly, it is estimated that spent MOX fuel will have to be cooled at least 100 years longer than spent LEU fuel or it would need to be placed in four or five times as many disposal casks as the equivalent amount of spent LEU fuel.[59]

The national waste policy of the Netherlands is that after 100 years there will be established a

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Administration) Donna Deedy, special to ProPublica with Michael Grabell, ProPublica May 5, 2011 and See, http://www.gao.gov/products/GAO-09-406T.

57 See, ASN, *Plan National de Gestion des Déchets Radioactifs 2010-2012, page 86.* http://www.asn.fr/index.php/S-informer/Actualites/2010/Plan-National-de-Gestion-des-Matieres-et-des-Dechets-Radioactifs

58 *See, Economic Forecast Study of the Nuclear Power Option*, Report to the Prime Minister, July 2000, CDP 2000: Jean-Michel Charpin, Benjamin Dessus, René Pellat, http://lesrapports.ladocumentationfrancaise.fr/cgi-bin/brp/telestats.cgi?brp_ref=004001472&brp_file=0000.pdf English translation: http://fire.pppl.gov/eu_fr_fission_plan.pdf, as cited in Spent Nuclear Fuel Reprocessing in France, Mycle Schneider and Yves Marignac, 2008, www.fissilematerials.org

59 Ibid, Schneider and Marignac, citing Cour des Comptes, Le démantèlement des installations nucléaires et la gestion des déchets radioactifs" in Rapport Annuel 2005, www.ccomptes.fr/CC/documents/RPA/InstallationsNucleaires.pdf.

national geological repository, or that an international solution will have been found, or that the option exists to extend storage for a further 100 years. In its submission to the 2008 Spent Fuel Convention, the government concluded that there are advantages to storing for 100 years, including,

"the heat-generating waste will cool down to a situation where cooling is no longer required."[60]

This of course is incorrect when it comes to any future Borssele spent MOX fuel. A government sanctioned decision to continue reprocessing and in particular use of plutonium MOX fuel is a decision that will impact many future generations well into the 22nd century. It appears that not only is the Dutch state technically not able to assess the safety implications of using MOX fuel, it also has little understanding of the long term implications for the management of the resulting nuclear waste. On this evidence it is of little surprise therefore that a decision to license Borssele to use MOX fuel was granted when one of the worlds MOX reactors at Fukushima-daiichi, along with two others had just melted their entire cores.

As already cited, the issue of hydrogen generation and nuclear fuel cladding, including from spent fuel, has been raised as an urgent matter by the IAEA following the explosions and meltdowns at Fukushima-daiichi. The issue is therefore directly relevant to the safety case for spent MOX fuel storage at the Borssele reactor, and interim storage at COVRA. The safety implications are clear – extended storage of spent plutonium MOX fuel with a significantly higher thermal load and radiological inventory increases the risk that in the event of accident, including loss of cooling capabilities, the human health impact of a major release would be considerably higher than for conventional uranium fuel. Given the lack of technical competence in the Netherlands, this matter should be immediately addressed by the GRS, fully taking into account the lessons of Fukushima.

MOX FUEL, NUCLEAR TERRORISM AND PROLIFERATION

MOX fuel is at its most vulnerable during transportation and risks of sabotage or hijacking must be considered. Having obtained a quantity of fresh unirradiated MOX fuel by diversion or theft, a terrorist group would have little difficulty in making a dirty bomb and/or a crude atomic bomb.

It would require only a few MOX fuel pellets to make a so called "dirty bomb" - each pellet is cylindrical in shape, 1cm by 1cm, weighing around 8 grams.[61] The pellets will contain in the proposed Borssele/AREVA MOX fuel around 7.8% plutonium. A typical batch of AREVA MOX fuel of 4 assemblies would contain around 500,000 pellets.

Deaths and injuries caused by the blast effects of the conventional explosives and long-term cancers from radiation exposure would be minimal if a few pellets of MOX fuel were involved. The true impact of a dirty bomb would be the enormous social, psychological and economic disruption caused by radioactive contamination.

The potential for dispersal of respirable plutonium, from fresh MOX fuel and separated plutonium oxide plutonium transport, was made public amidst major controversy in France during the 2002-2004 period. It was at this time that AREVA was seeking to expand production at the MELOX plant. In briefings to senior French military personnel, Greenpeace provided evidence that showed the ease with which plutonium and MOX fuel transports could be identified, tracked and in one case blocked and seized by Greenpeace activists.[62] In one report it was shown that from the point of

60 See, 3rd National Report of the Netherlands, prepared in October 2008, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management National Report of the Kingdom of the Netherlands Third Review Conference (May 2009) Ministry of Housing, Spatial Planning and the Environment Ministry of Social Affairs and Employment Ministry of Economic Affairs Ministry of Foreign Affairs, page 16/132.

61 Dirty Bombs and Primitive Nuclear Weapons, Dr. Frank Barnaby, 2005.

62 For details on routes, containers and vehicles, including registration plates, photos and video see

interception by an armed group, an AREVA plutonium transport, containing around 160kg of plutonium, could be seized and destroyed within minutes. Plutonium oxide dispersal into the atmosphere would contaminate large areas in the vicinity.[63]

Over a period of 12 months Greenpeace monitored the regular movements of plutonium between la Hague in Normandy and the MELOX plant in Provence. The weekly schedule of plutonium transports were so predictable that at any point along the 1000 km route it was possible to know where the trucks would be to an accuracy of minutes.[64]

On the security arrangements for plutonium and MOX fuel, AREVA has opted for minimal and therefore wholly inadequate provision. Greenpeace having already tracked and blocked one plutonium transport in Chalon in 2003, consulted a senior security analyst who had provided risks assessments and run force on plant exercises at US Department of Energy facilities. His conclusion on assessing AREVA and French state security arrangements was that there was effectively no security.[65]

Fresh AREVA MOX fuel transport as documented by Greenpeace France, January 27th 2011.
credit: Yannick Rousselet

The level of security in France is no different for plutonium as it is for MOX fuel. The fundamental problem is that France has turned a nuclear weapons material into a commodity. Except plutonium, as EPZ and the government of the Netherlands must surely realize, is not a commodity. The decision to license Borssele will bring the 'commodity' of plutonium on to the public highways of the Netherlands.

Nuclear weapons use

To fabricate a nuclear weapon more than a few pellets would be required. A Borselle/AREVA MOX fuel assembly would contain around 27 kg of plutonium. This would be sufficient for several nuclear weapons, more depending on the degree of sophistication available.

The necessary steps of chemically separating the plutonium dioxide from uranium dioxide, converting the dioxide into plutonium metal, and assembling the metal or plutonium dioxide together with conventional explosive to produce a nuclear explosion are not technologically demanding and do not require materials from specialist suppliers. The information required to carry

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http://www.greenpeace.fr/stop-plutonium/index.php3

63 Potential radiological impact and consequences arising from incidents involving a consignment of plutonium dioxide under transit from COGEMA la Hague to Marcoule/Cadarache Large&Associates, Greenpeace International report ref no r3108-a6, March 2004.

64 See, for video of plutonium trucks - http://www.greenpeace.fr/stop-plutonium/img/video_passage_convoi_D901.MPG

65 Security Assessment Report for Plutonium Transport in FrancePrepared By Ronald E. Timm, Certified Protection Professional for Greenpeace International March 2005.

out these operations is freely available in the open literature.

AREVA and the nuclear industry have spent decades denying the proliferation risks of reactor grade commercial plutonium. But this is driven by commercial and political interests not the laws of physics. In the mid 1970's the Carter Administration briefed governments, including the UK, France and Japan, on the weapons utility of commercial plutonium. This was aimed at preventing the commerce in reprocessed plutonium. As Robert W. Selden at the US Department of Energy's Los Alamos National Laboratory reported in November 1976,

"A militarily useful "low technology" nuclear explosive using reactor grade plutonium could be designed to produce nuclear yield in the kiloton range."

Since when over the years definitive statements have been issued on the security and proliferation risks of commercial plutonium.

Nuclear weapons and commercial reactor grade plutonium

"Although plutonium of any isotopic composition is inherently difficult to handle, only a marginal increase in difficulty is involved in handling reactor-grade plutonium in the fabrication of nuclear weapons."

U.S. Department of State "Guidance on the Use of Reactor Grade Plutonium for Weapons Fabrication," November 1976

"The difficulties of developing an effective design of the most straightforward type are not appreciably greater with reactor-grade plutonium than those that have to be met for the use of weapons-grade plutonium."

J. Carson Mark, former Director, Theoretical Division at Los Alamos Nation al Laboratory, 1993

"In short, it would be quite possible for a potential proliferator to make a nuclear explosive from reactor-grade plutonium using a simple design that would be assured of having a yield in the range of one to a few kilotons, and using an advanced design. Theft of separated plutonium, whether weapons-grade or reactor-grade, would pose a grave security risk."

Committee on International Security and Arms Control of the U.S. National Academy of Sciences, 1994

"We are aware that a number of well-qualified scientists in countries that have not developed nuclear weapons question the weapons-usability of reactor-grade plutonium. While recognizing that explosives have been produced from this material, many believe that this is a feat that can be accomplished only by an advanced nuclear-weapon state such as the United States. This is not the case. Any nation or group capable of making a nuclear explosive from weapons-grade plutonium must be considered capable of making one from reactor-grade plutonium."

American Nuclear Society, "Protection and Management of Plutonium," August 1995

The explosion of a primitive nuclear weapon would use only a small fraction of the plutonium in it; the rest would not be fissioned and would be released into the atmosphere and dispersed. Even if the device, when detonated, did not produce a significant nuclear explosion, the explosion of the chemical high explosives would disperse the plutonium widely. If an incendiary material, such as an aluminium-iron oxide (thermite), were mixed with the high explosives, the explosion would be accompanied by a fierce fire.

The un-fissioned plutonium would be dispersed by the explosion or volatilised by the fierce heat. When plutonium burns it is mostly dispersed as small particles of plutonium dioxide. These would be taken up into the atmosphere in the fire-ball and scattered far and wide downwind. A large fraction of the particles are likely to be smaller than three microns (millionths of a metre) in diameter, and could, therefore, be breathed into, and retained by, the lung. Here they would be very likely to cause lung cancer by irradiating the surrounding tissue with alpha-particles.

Once dispersed into the environment, plutonium dioxide is insoluble in rainwater and would remain in surface dusts and soils for a very protracted period indeed. The half-life of the plutonium isotope plutonium-239, the predominant isotope in civilian plutonium, is 24,400 years.

These factors would combine to render a large area uninhabitable until decontaminated, a procedure which could take many months or years. The threat of dispersion of many kilograms of plutonium makes a crude nuclear explosive device a particularly attractive weapon for a terrorist group,

The storage and fabrication of MOX fuel assemblies, their transportation and storage at a conventional nuclear power stations on a scale envisaged by the nuclear industry will be extremely difficult to safeguard. EPZ, if acquires sufficient plutonium for a 40% MOX core at Borssele will over the years impose a major security threat on the Netherlands, and transit states, through the importation of many thousands of kilograms of plutonium. Security at the Borssele reactor will require the equivalent of that for nuclear weapons – the so called stored weapons standard.

Even with this and what that means in terms of threat to society including civil liberties, the risk will remain of diversion or theft of fuel pellets or whole fuel assemblies by personnel within the industry or by armed and organised terrorist groups is a clear possibility.

A decision by EPZ and the Dutch state to use fresh MOX fuel increases the targets for nuclear terrorism, increases the availability of MOX fuel, and increases the availability of reactor-grade plutonium. Nuclear facilities and nuclear materials may be tightly controlled but the risks of nuclear terrorism are simply too great.

Proliferation

A decision by the Government of the Netherlands to license MOX use in the Borssele reactor runs directly counter to claims that it supports effective nuclear non-proliferation. The commercial use of a nuclear weapons material has long been controversial within the nuclear non-proliferation community.

"I would like to see a civilian cycle completely free from weapons-useable material if possible," *Mohamed El Baradei,* Director General of the International Atomic Energy Agency, IAEA, March 19th, 2004[66]

Attempts to negotiate an international treaty that would prevent the production of fissile material for nuclear weapons have stalled since 1995.[67] If ever a treaty is negotiated if is to be effective the commercial use of plutonium would also have to be prohibited. The decision by the Netherlands to pursue a MOX program undermines efforts to deter other countries from embarking on a nuclear program based on the production, reprocessing and use of nuclear weapons material. On this issue alone plans for MOX fuel use at Borssele should be abandoned.

CONCLUSION

To conclude, our assessment of the safety implications of the Fukushima-daiichi accident for plans to use MOX fuel in Borssele is that the Government of the Netherlands has made an poorly informed decision that has major safety, security environmental and public health implications for the nation, and its neighbours. Fundamentally important issues are likely to have been poorly understood, discarded or ignored. The declared commitment of the Dutch state to its people when it comes to its nuclear program appear to us to be utter deception,

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66 UN atomic energy chief warns that terrorists could go nuclear, Vienna (AFP), March 19th 2004.

67 See, Sixty years on – time for a comprehensive fissile material treaty, , Shaun Burnie/Tom Clements, Greenpeace International Briefing Washington DC, May 2004. In 2006 Greenpeace International presented to delegates to the Conference on Disarmament in Geneva a draft Comprehensive Treaty on Fissile Materials, see, http://www.greenpeace.org/international/Global/international/planet-2/report/2006/4/comprehensive-fissile-material.pdf

"Transparency of nuclear activities and communication to the public are the cornerstones of the chosen solution: to build confidence in the regulator and the safety of radioactive waste management; to enable a dialogue among stakeholders and/or public debate on the final disposal."

The catastrophic events of Fukushima-daiichi should lead to a realization that business-as usual and public relations generated spin is not acceptable when it comes to nuclear power. A decision to revoke the MOX fuel license for EPZ's Borssele would be an indication that safety of nuclear power is being taken seriously by the elected representatives of the Dutch people.

Recommendations following the Fukushima-daiichi accident:

Immediate suspension and withdrawal of MOX license granted to EPZ for Borssele;

Release of all documents related to the safety case for Borssele MOX fuel use, including correspondence between Dutch authorities, EZP and the GRS;

Disclosure of plutonium ownership and transactions including quantities between EPZ, EDF and AREVA;

Disclosure of standard AREVA MOX fuel quality control data, specifications for production, including quality assurance system and inspection to be applied at MELOX.

Disclosure of Netherlands nuclear security and non-proliferation assessment of the implications of MOX fuel use, including assessment of French security arrangements.

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Appendix 1

ASSESSMENTS OF THE RADIOLOGICAL CONSEQUENCES OF RELEASES FROM EXISTING AND PROPOSED EPR/PWR NUCLEAR POWER PLANTS IN FRANCE, Large and Associates, commissioned by GREENPEACE FRANCE, 2007

		Number of Health Effects Fractile		
NPP Site	Health Effect/Countermeasures	Maximum	Mean	50th
Flamanville EPR 100% LEU core Target 65GWed/tU Fuel Burn-Up	Early Death	381	81	42
	Late Fatal Cancer	26,430	6,212	5,623
	Thyroid Cancer DEATHS	1,454	309	263
	Land Area (ideally) Evacuated km²	16,950	7,214	6,475
	Area (ideally) Iodine Prophylaxis km²	1,541	361	257
	Numbers Persons (ideally) evacuated	1,246,000	313,00	259,900
	Persons (ideally) I-131 Prophylaxis	68,050	14,570	11,750
Flamanville Existing 1330MWe PWR 100% LEU core	Early Death	179	41	23
	Late Fatal Cancer	15,020	3,748	3,311
	Thyroid Cancer DEATHS	824	184	158
	Land Area (ideally) Evacuated km²	13,320	4,796	4,365
	Area (ideally) Iodine Prophylaxis km²	1,445	318	2,512
	Numbers Persons (ideally) evacuated	725,300	176,800	151,400
	Persons (ideally) sheltered	869,500	125,800	35,480
	Persons (ideally) I-131 Prophylaxis	65,380	12,990	10,470
Flamanville EPR 100% MOX core	Early Death	650	147	85
	Late Fatal Cancer	60,760	8,055	7,586
	Thyroid Cancer DEATHS	1,307	161	110
	Land Area (ideally) Evacuated km²	44,810	13,300	11,750
	Area (ideally) Iodine Prophylaxis km²	7,3214	2,360	2,138
	Numbers Persons (ideally) evacuated	3,319,000	662,200	569,500
	Persons (ideally) I-131 Prophylaxis	376,000	69,260	33,110
Flamanville EPR 30% MOX core Thyroid Prophylaxis limited to 10km	Early Death	322	67	34
	Late Fatal Cancer	29,260	6,295	5,754
	Thyroid Cancer DEATHS	984	212	186
	Thyroid Cancer Incidence	9,630	2,116	1,862
	Land Area (ideally) Evacuated km²	36,540	11,660	10,000
	Area (enforced) Iodine Prophylaxis km²	314	78	63
	Numbers Persons (ideally) evacuated	3,246,000	567,600	537,000
	Persons (enf'd) I-131 Prophylaxis	13,070	3,228	2,570

http://www.largeassociates.com/3150%20Flamanville/r3150-final-summary.pdf