Plutonium for Energy?

Explaining the Global Decline of MOX

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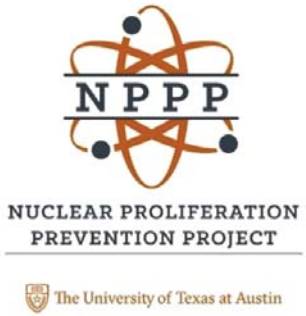

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MOX in the Netherlands: Plutonium as a Liability

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This chapter assesses the Netherlands' belated introduction of plutonium for energy – initiating commercial use of thermal mixed-oxide (MOX) fuel in 2014 – when most other global users were phasing it out due to economic and other concerns. Interviews were conducted in the Netherlands in 2018 with officials from the regulatory agency, the utility, the waste facility operator, and non-governmental organizations. The chapter finds that for the first 45 years of Dutch nuclear energy, based on traditional low-enriched uranium (LEU), the spent fuel was exported for reprocessing but Dutch utilities then paid other countries to take the separated plutonium off their hands. In 2006, France changed its environmental law to require that reprocessing contracts specify in advance the disposition of the plutonium to be separated, but foreign utilities were no longer interested in being paid to take Dutch plutonium because they were phasing out MOX fuel or already had large surpluses of plutonium. The Dutch utility EPZ, operator of the country's sole remaining power reactor, considered halting the foreign reprocessing and instead directly disposing of its spent fuel as waste. Ultimately, however, it opted to continue the reprocessing and to begin recycling the separated plutonium in MOX fuel. Licensing documents claim that this decision was made on economic grounds, but the utility did not actually engage in price negotiations over the alternative of direct disposal of its spent fuel. By signing long-term contracts for foreign reprocessing and MOX fabrication, and for domestic disposal of the repatriated waste from those activities – all of which carry severe financial penalties for cancellation – the utility effectively discouraged the government from closing the reactor prior to its scheduled shutdown in 2033, despite the power plant being uneconomical. Contrary to the utility's hopes, MOX fuel has proved to be substantially more expensive than LEU fuel, especially as uranium prices have plummeted by 80 percent. The Netherlands was the first country in a quarter-century to decide to initiate commercial use of MOX fuel in thermal reactors, and it may well prove to be the last.

The belated introduction of mixed-oxide (MOX) fuel in the Netherlands is puzzling, because the country only started using such plutonium-based fuel in 2014, after several other countries already had abandoned it on multiple grounds including economics. Of the five countries that historically had used MOX fuel commercially in thermal reactors, three of them – Belgium, Germany, and Switzerland – already had chosen not to renew contracts for reprocessing their spent nuclear fuel (SNF) and so were implementing schedules to irradiate their final MOX fuel assemblies. In addition, the United Kingdom, which historically had fabricated MOX fuel in two commercial facilities for export, closed both of them and chose not to initiate domestic commercial use of MOX fuel. Despite this, the Dutch utility EPZ, operator of the Netherlands' sole active nuclear power plant, at Borssele, chose in 2012 to sign a contract with the French company Areva (now Orano) to reprocess its SNF and recycle the separated plutonium in MOX fuel until the reactor's scheduled shutdown in 2033.

The Netherlands' recent embrace of MOX fuel might appear to call into question the lessons from the other case studies in this book, which illustrate the costs and dangers of recycling plutonium for energy. In fact, however, the Dutch case underscores these lessons. EPZ had never seriously considered using MOX fuel until foreign utilities ceased being willing to be paid to take its plutonium because they were abandoning the use of MOX fuel. EPZ was left with two options if it wanted to continue operating the reactor: start using MOX fuel, or halt reprocessing and instead dispose of SNF directly as waste. The Dutch utility considered both options but for a variety of reasons chose the former. In retrospect, in light of the subsequent decline of uranium prices, and persistently high MOX fabrication costs, that choice appears to have been a bad bet, underscoring the economic downside of using plutonium for energy.

This chapter's next section explains its research methods. Following that comes a brief overview of the Netherlands' nuclear energy program. The chapter then details the Dutch decision to initiate MOX use. After that, it analyzes the relatively brief Dutch experience so far with MOX fuel – including economics, security, safety/environment, performance, and public opinion. The chapter

concludes with lessons from the Dutch case for other countries considering processing SNF to recycle plutonium for energy.

Methods

Primary and secondary documentation was supplemented by field research in the Netherlands in March 2018. Interviewees included officials from the regulatory agency, the utility, the waste facility operator, and non-governmental organizations (NGOs). Several Dutch politicians declined to be interviewed for this study.

Small Nuclear Program

Although the Netherlands is home to a major nuclear research reactor at Petten that helps produce a significant share of the world's medical isotopes, its historical nuclear energy program has been relatively tiny, comprising just two small nuclear power reactors.[1] The first, in the center of the country, was the demonstration Dodewaard boiling water reactor (BWR), rated at only 55 MWe, which is about five percent of the output of modern nuclear plants. It produced power for three decades from 1968 to 1997,[2] when for economic reasons it closed seven years earlier than planned, leaving a lifetime total of only about 64 tonnes of SNF, an amount that modern reactors produce in less than three years. All of its SNF was exported for reprocessing, and the resulting high-level waste was returned to the Netherlands, but the separated plutonium was not.

A fraction of Dodewaard's SNF, about 8.5 tonnes, was reprocessed at the Eurochemic plant in Belgium between 1974 and 1981, and the resulting separated plutonium apparently was used to make MOX fuel for non-Dutch reactors. But the bulk of Dodewaard's SNF, about 55.5 tons, was reprocessed at BNFL's Sellafield facility in the United Kingdom.[3] In modern light-water reactors, the SNF contains about 0.9-percent plutonium, but the Dodewaard SNF had low burn-up resulting in only 0.7-percent, totaling 351 kg, of separated plutonium.[4] BNFL originally intended to fabricate this plutonium into MOX fuel for non-Dutch customers, but its Sellafield MOX Plant never functioned properly and then shut down prematurely in 2011 (see Chapter 4). As a result, in 2013, the UK government announced that under commercial arrangements it was "taking ownership of around 350 kg of material previously owned by Dutch utilities."[5]

The Netherlands' second nuclear power plant, at Borssele in the country's southwest, is a relatively small pressurized water reactor (PWR) rated at 485 MWe (net) – about half the output of modern PWRs. The Borssele reactor began operation in 1973, is now expected to continue until 2033, and currently produces three percent of the country's electricity.[6] The operator had no plan for the back-end of the fuel cycle when the reactor started, but in 1978 it signed a contract with France's Cogema (later Areva) to reprocess the reactor's first 30 years of spent fuel. This covered SNF exports to France through 2004, allowing two years for low-enriched uranium (LEU) SNF to cool in the reactor's pool. EPZ thus joined Cogema's founding foreign partners of the La Hague UP2 facility's oxide reprocessing capability, which started in 1976 (see Chapter 3).

Under French law, the plutonium and major radioactive waste separated from the SNF had to be removed from France.[7] In practice, the SNF from multiple customers was comingled at La Hague, so that each utility was assigned a *pro rata* share of the plutonium and waste. EPZ's contract specified that the disposition of its share of the plutonium would be determined in concert with the other foreign partners of the facility, meaning that EPZ could make financial arrangements for another country's utility to take the plutonium back in fresh fuel. From the reprocessing of Borssele's SNF arising until 1989, the separated plutonium was used to make fuel for demonstration fast reactors in France and Germany.[8]

For the plutonium separated from Borselle's next batch of SNF, the Dutch utility eventually paid Cogema to arrange for Swiss and German utilities to accept it in the form of fabricated thermal MOX fuel.[9] The price that EPZ paid was estimated by the leading Dutch nuclear institute, in 1997, to be about $15,000 per kg.[10] However, according to EPZ's chief financial officer, in a March 2018 interview, the price to get rid of plutonium is higher now than it used to be.[11]

In 2004, EPZ renewed with Areva for another 10 years, meaning the Dutch utility could continue to export SNF to France until about 2016 without specifying in advance the disposition of the plutonium to be separated by reprocessing. An EPZ

spokesperson declared in 2004 that the separated plutonium would *not* be recycled as MOX in the Borssele reactor, "because our plant is too small."[12] Thus, the operators of both Dutch nuclear power plants chose for over 45 years to have their spent fuel reprocessed abroad, but they did not take back the three tons of separated plutonium as MOX fuel or otherwise, and they instead paid others to take it.[13]

The repatriated radioactive waste from foreign reprocessing is stored on an interim basis for up to 100 years at a facility in the southwest of the Netherlands adjacent to Borssele. The site is run by a state-owned company called the *Centrale Organisatie Voor Radioactief Afval* (COVRA), or the Central Organization For Radioactive Waste, which EPZ pays to take ownership of the waste. At COVRA, high-level waste is held in a building known as *Hoogradioactief Afval Behandelings- en OpslagGebouw* (HABOG) in vaults, which are a series of above-ground cavities that enable monitored and retrievable storage. The building is designed to provide safety and security from intentional or accidental disruption. HABOG also stores unreprocessed research-reactor SNF, which is much smaller physically than power reactor SNF and is under IAEA safeguards. In a neighboring building, the returned long-lasting intermediate level waste from reprocessing is stored in a less robust fashion.

Vault storage is also possible for power-reactor SNF, and Spain is reportedly constructing such a facility based on the COVRA design. HABOG required €125 million and four years to construct, took five years to license, opened in 2003, and accepted its first waste in 2004. The building is modular, and an extension (adding two vaults to the existing three) is projected to be completed in 2020.[14] In light of this long-term interim storage capacity, the Netherlands has deferred decisions about permanent geological disposal of nuclear waste.

Why Switch to MOX?

The Dutch utility's decision to change past practice in 2012, by signing a combined reprocessing and MOX fabrication contract with Areva to initiate use of plutonium for energy at Borssele, is especially puzzling because the contract required EPZ to pay for a large amount of MOX fuel fabrication, which is notoriously expensive. Borssele typically had produced around 10 tonnes of spent LEU fuel annually, containing about 93 kg of plutonium. The renewed Areva contract covers 20 years of fuel discharges from 2015 to 2034, which using LEU fuel would include about 1,860 kg of plutonium. Each MOX assembly for Borssele contains about 27.5 kg plutonium, so one might assume that EPZ was required to pay to fabricate 68 MOX fuel assemblies – i.e., 1,860 divided by 27.5.

However, that is not how the Areva contract works. When EPZ sends its plutonium-laden spent MOX back to France, the Dutch utility is required to take back an equivalent amount of plutonium in still more fresh MOX. Given that MOX SNF contains several times as much plutonium as LEU SNF, this provision more than doubles – to 144 assemblies – the amount of MOX that EPZ must pay to fabricate under the contract.[15] If EPZ had not initiated MOX but continued to have its LEU SNF reprocessed, it would have had to pay for disposition of only 1,860 kg of plutonium. By contrast, under the Areva contract, it must pay for disposition of 3,960 kg of plutonium, more than twice as much, by having it fabricated into about 50 tonnes of MOX fuel.

A number of competing explanations have been offered for EPZ's belated adoption of MOX fuel, but some are more credible than others. First, the utility itself, in licensing documents, claims the switch was motivated by a desire to diversify fuel sources to hedge against potential increases in the price of uranium. Second, government documents and a licensing official say the move was actually motivated by two different factors: a change in French law that required reprocessing contracts to include up-front arrangements for plutonium disposition, and the absence of any foreign utility willing to be paid to take Borssele's plutonium. Third, a non-governmental watchdog hypothesizes that EPZ may have signed the long-term MOX contract, which imposes stiff financial penalties for cancellation, to deter the Dutch government from potentially shutting the reactor prematurely.[16]

The Dutch utility's chief financial officer, Bram-Paul Jobse, offers a fourth, more nuanced explanation. He says the change in French policy, combined with the absence of foreign utilities willing to be paid to take separated plutonium, left EPZ with two choices if

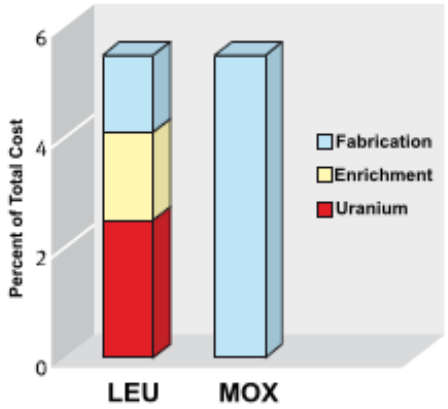
it wanted to continue operating the reactor. The Dutch utility either could initiate the use of MOX fuel in Borssele, or it could halt reprocessing and instead pay COVRA to store the SNF on an interim basis in preparation for its geological disposal as waste. In the 1990s, EPZ had rejected MOX recycle on economic grounds, in part due to uncertainty about whether the reactor's life would be extended, but in 2006 the government granted an extension until 2033. Jobse claims that EPZ then conducted a new study, which found that the expected price for each option – MOX recycle or interim storage of SNF – was approximately the same, but the Dutch utility chose the recycling option as less risky.[17] A fifth explanation, inferred from a government report, is that interim storage was not feasible because COVRA could not have constructed a new facility quickly enough. Each of these hypotheses is interrogated below.

Is MOX Cheaper?

Perhaps least persuasive is the explanation offered by EPZ in licensing documents, that the utility opted for MOX to diversify its fuel supply and reduce financial risk from potential uranium price increases. By all other accounts, this was not the original impetus. Although the utility may have viewed cost control as a potential benefit after other factors compelled it to explore MOX, in reality the recycling of plutonium significantly increased its fuel costs, especially after uranium prices plummeted, which was a foreseeable risk.

In its July 2010 environmental submission under the licensing process, the utility stated that, "EPZ sees a limited use of MOX elements as a cost control option."[18] The company conceded that fabrication costs were much higher for MOX than LEU. However, it argued that all the potential costs for MOX fuel were fixed – "free" plutonium, virtually free depleted uranium, and fabrication under long-term contracts – whereas the cost of LEU fuel was susceptible to the volatile price of uranium and the steadily rising price of enrichment.[19] Moreover, EPZ reportedly had a long-term contract for a modest amount of uranium at a low price, so that by initiating partial MOX use it could stretch out its existing uranium supply and thereby reduce its exposure to uranium price increases.[20] In a notional chart (see Figure 1), EPZ argued that the high price of uranium already had made the costs of LEU fuel and MOX fuel equivalent, so that if the price of uranium increased further, MOX fuel would actually be cheaper. According to the utility, this would compensate for the limited extra costs that MOX fuel would impose on its equipment for handling, measurement, and reactor control. The licensing submission concluded, "From the point of view of cost control, it is therefore attractive for EPZ to bet on MOX fuel."[21]

Figure 1
Cost Comparison in EPZ's 2010 Environmental Impact Assessment



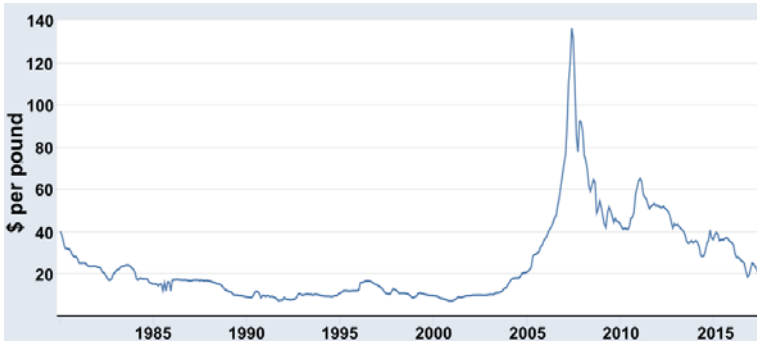
Source: Adapted from EPZ, "Milieueffectrapportage Brandstofdiversificatie," July 2010, Figure 2.9.1.
Note: "Total Cost" – to produce electricity – includes the amortization of reactor construction.

However, this argument is misleading in at least four respects. First, EPZ's chart suggests that in 2010, the price of MOX fuel was the same as LEU fuel, but that has never been true. Estimates from all five of the other countries that have used MOX commercially in thermal reactors indicate that MOX fuel has cost three to nine times as much as LEU fuel, and the highest estimates come from the countries that had to import MOX fuel, as EPZ proposed to do. Second, EPZ's submission suggests that the price risk of uranium was entirely on the up side. In reality, in 2010, the

price of uranium was about four times its historical norm, but less than one-third of its recent high (Figure 2). Thus, there was risk of the price either increasing or decreasing, and history suggested that it was more likely to fall, as in fact soon did occur.

Third, EPZ claimed that MOX unlike LEU could avoid price risk, but this was misleading in two more ways. In reality, uranium can be purchased on the futures market, which also eliminates price risk. Moreover, it is irrational to eliminate price risk by overpaying for a substitute. For example, if the price of red apples fluctuates from $0.10 to $1 per pound, it would be irrational to eliminate such price risk by purchasing green apples for a fixed price of $2 per pound. But that is essentially what EPZ advocated in its submission, and what it has done in practice by purchasing MOX fuel to replace LEU fuel. Overall, the economic argument in EPZ's submission is contradicted by the facts and makes little economic sense, so it is unlikely the main reason that the utility opted for MOX fuel.

Figure 2
Historical Price of Uranium



Source: Federal Reserve Bank of St. Louis, based on International Monetary Fund, https://fred.stlouisfed.org/series/PURANUSDM.
Note: Price is in current dollars, not adjusted for inflation.

In a 2018 interview, the utility's CFO Jobse offered a slightly different economic argument. He conceded that MOX fuel was more expensive than LEU fuel, but claimed that the price difference was less than the amount that EPZ would have had to pay to get rid of its separated plutonium, especially because Areva was the only potential taker and thus could have dictated the price.[22] Moreover, Areva had an economic incentive to inflate its requested price for taking ownership of EPZ's plutonium, to persuade the utility instead to purchase MOX fabrication services.

If this is really why EPZ opted for MOX, it would indicate that the negative market value of plutonium must be substantially higher than the $15,000 per kilogram reported in the late-1990s. Assuming, conservatively, that MOX fuel costs $1,500 more per kilogram than LEU fuel (see Chapter 7), then EPZ's purchase of about 50 tonnes of MOX fuel incurred a price penalty of at least $75 million. If that was cheaper than the price that EPZ would have had to pay to get rid of 1,860 kg of plutonium, then the negative market price of plutonium must have been over $40,000 per kilogram. Such a high negative market price for energy-rich plutonium would reflect both the low worldwide demand for, and the high fabrication cost of, MOX fuel.

New French Law?

A major impetus for Dutch MOX was France's 2006 change in environmental law. Cogema had always required that when it reprocessed foreign SNF, the customer was responsible for the resulting plutonium and major radioactive waste, but the specifics did not need to be worked out in advance. However, according to a 2017 Dutch government report, "In July 2006, new French legislation entered into force, which prescribes that a return-scheme for the radioactive waste has to be formalized at the moment the spent fuel is sent to France."[23] This posed a problem for EPZ if it wanted to renew its reprocessing contract with Areva for SNF arising after 2016, since foreign utilities no longer were willing to take plutonium even for a price, because the few countries that previously had used MOX were now phasing it out or, in the cases of Japan and France, already had enormous plutonium surpluses.

According to CFO Jobse, EPZ in 2006 engaged in talks with colleagues in Germany, Switzerland, France, and the UK, [24] presumably about paying them to take plutonium in the future, but apparently without success. As EPZ explained in a July 2010 press

release, by initiating MOX at Borssele, the utility avoided the challenge of trying to find a foreign MOX-licensed reactor whose operator was willing to be paid to take the plutonium.[25] A Dutch nuclear regulatory official, Gert Jan Auwerda, suggested in an interview that, "If France had not changed the law, EPZ would not have started using MOX."[26]

Jobse contends that even without the new French environmental law, EPZ would have conducted a cost assessment of the MOX option after the Borssele reactor received its life extension to 2033.[27] EPZ's fuel cycle manager, Jan Wieman, concurs that the extension was "a real game changer: it meant that EPZ could optimize its fuel strategy for Borssele's final 20 years of operation."[28] However, if not for the French legal change, Jobse concedes that considerations of risk minimization probably would have led EPZ to avoid the uncertain licensing of MOX fuel by continuing to pay Areva to arrange alternative end-users for the separated plutonium.[29]

Better than Direct Disposal?

The new French law and the lack of global demand for separated plutonium did not by themselves necessitate that EPZ initiate MOX use. The utility had the alternative of not renewing its reprocessing contracts and instead disposing of its SNF directly as waste. Three explanations have been offered as to why EPZ did not embrace this option – timing, economics, and risk – but none is fully supported by the facts.

In a 2011 report, the Dutch government claimed that constructing a building for interim storage of SNF would take too long, citing the history of the HABOG facility for high-level waste. In that earlier instance, according to the report, "a period of more than ten years prior to submitting the preliminary memorandum was required to find a suitable location. From that moment on, the total turnaround time to arrive at a definitive license was about seven years. The HABOG was then built and commissioned in five years." The report estimated that 10 years would be required to finish a new interim storage facility for SNF, given that the waste site already existed, but it characterized that as too long. Published in 2011, the report concluded that, "If a scenario is chosen for the direct storage of the fuel elements, a facility for this must be available by 2016 at the latest. This is not feasible, given the expected 10-year turnaround time for the realization of such a building."[30]

However, this asserted deadline of 2016 for an interim storage facility was artificial. If EPZ had opted not to renew its reprocessing contract, the temporary domestic buildup of SNF could have been accommodated by either increasing the capacity of the reactor's pool or resorting to dry-cask storage. Such steps might have required additional authorization but are commonplace around the world and would have provided additional time if necessary to complete an interim SNF storage facility. By ignoring these options, the Dutch government report appears intended to justify renewal of the reprocessing contract, rather than to assess rigorously the alternative of direct disposal.

Regarding the cost of interim storage of SNF, Jobse claims that the utility compared this to plutonium recycling in a 2006 study, including by discussing with COVRA the potential price of such a facility. Jobse and Wieman say the study found that the cost of interim storage was roughly the same as that for reprocessing plus MOX fabrication,[31] and Dutch regulator Auwerda confirms that EPZ conducted such a study.[32] Jobse also claims that "confidential" pricing information showed that the back-end was cheaper with reprocessing and MOX recycling, compared to direct disposal, thereby compensating for the extra cost of MOX fuel. Accordingly, he insists it is "incorrect to conclude that long term contracts for reprocessing and fabrication of MOX significantly increased the costs of EPZ."[33]

However, COVRA's Deputy Director, Ewoud Verhoef, says the waste company never conducted a detailed cost study for interim storage of SNF.[34] When Jobse was confronted with this fact, he replied that EPZ's assessment of direct disposal was conducted "using other European utilities (not COVRA) as a reference."[35] However, these foreign entities use entirely different waste storage concepts than COVRA. Evidently, EPZ concluded that direct disposal had the same cost as the MOX recycling option without ever negotiating the domestic price of direct disposal. This suggests that cost was not the determining factor in the utility's

embrace of MOX over direct disposal.

Indeed, Jobse says that the decisive factor for EPZ was that MOX had less "risk," in that it required less change than the direct-disposal option. He acknowledges that introducing MOX fuel did entail some risk, mainly from licensing the new fuel and developing new casks for fresh and spent MOX. Yet other parts of the fuel cycle would be unaffected, including exporting spent fuel to France and receiving back radioactive waste in the same form already stored at HABOG, whose capacity could be expanded by two modules to accommodate the additional volume of waste arising from future reprocessing and MOX fabrication. By contrast, he says, direct disposal would have required new laws, new regulations, a newly designed vault facility for interim storage of SNF, and perhaps a new cask for dry storage while that facility was being constructed.[36] A 2012 EPZ presentation highlighted these concerns, claiming that "the development of an alternative back-end process could risk the continued plant operation of Borssele."[37]

Deterring Premature Closure?

It is unquestionable that by signing a long-term contract in 2012 with Areva for reprocessing of SNF and fabrication of MOX fuel, EPZ effectively inhibited the Dutch government from prematurely shutting down the Borssele reactor prior to the 2033 expiration of its safety report, given the financial penalties that would result. The only question is whether this was one of the motives, or even the primary motive, for EPZ opting for MOX.

A 2016 study commissioned by the government (the "Holtkamp report") says that EPZ estimated the costs of closing the reactor and terminating the Areva contract as up to "€1 to €1.3 billion."[38] Although some of this cost would stem from lost payments to the decommissioning fund, a significant portion would represent the consequences of canceling the Areva contract. As the report states, "The costs related to the buyout of contracts and the entering into new contracts for fuel supply and disposal are estimated to be high in this scenario, in the hundreds of millions [of Euros]." Such costs would include the following: disposing of plutonium already separated under the contract, either domestically as waste or more likely by paying someone else to take it; paying COVRA for lost income and the unnecessary expansion of HABOG; and returning to France some MOX assemblies that were unirradiated yet slightly contaminated by having been stored in Borssele's spent fuel pool, potentially requiring the licensing of a new transport cask.[39]

According to Dutch regulator Auwerda, if a premature government shutdown of the reactor imposed such costs on EPZ, the utility could sue the government,[40] making it potentially liable for hundreds of millions of euros. Thus, EPZ's 2012 contract for reprocessing and MOX fabrication had the effect of strongly discouraging the Dutch government from contemplating the premature shutdown of the Borssele reactor, which otherwise might have been a serious prospect, given that the Green Party was in the governing coalition and that the reactor was cost inefficient (see below). It is possible that EPZ considered this as it weighed the two options of direct disposal versus MOX recycling, especially in light of the utility's strong emphasis on risk minimization. However, the company's CFO Jobse insists that, "The contractual penalties of all EPZ contracts are limited," and "EPZ formally denies that this was the strategy behind the choice for the continued closed fuel cycle."[41]

Implementing MOX

In 2008, EPZ applied for authorization to load up to a 40-percent core of MOX fuel in Borssele. Licensing of nuclear activities in the Netherlands has historically been divided between two ministries: economics and infrastructure. (The names of these ministries have changed over time.) When EPZ submitted its MOX application, overall responsibility fell to the Department of Nuclear Safety, Security, and Safeguards (KFD), within the Inspectorate of the Ministry of Housing, Spatial Planning, and the Environment (VROM Inspectorate). In 2015, the nuclear regulatory functions were separated from promotional activities and combined into a single institution, the Authority for Nuclear Safety and Radiation Protection (ANVS), which is responsible for assessing Borssele's nuclear safety and radiation protection. Due to the limited size of the Dutch regulatory apparatus, a German organization, *Gesellschaft fur Anlagen und Reacktorsicherheit* (GRS), has assisted both KFD and ANVS on safety assessments, including of potential

MOX fuel use at Borssele.[42]

Pre-Cycling

In light of the unusual circumstances of Borssele's proposed use of MOX fuel – EPZ having only a single reactor, not already having a surplus of separated plutonium, and being required to use a large amount of plutonium in MOX over a short time before the reactor's scheduled shutdown in 2033 – Areva devised a special arrangement called "pre-cycling." At the start, EPZ would borrow plutonium from Areva so that the French company could fabricate MOX fuel for Borssele, and then EPZ would pay back the plutonium in SNF. Ultimately EPZ would receive fresh MOX fuel containing the same amount of plutonium that EPZ would send to Areva in SNF (LEU and MOX) under the contract.

Considering that spent MOX requires two extra years of cooling before it can be removed from the reactor's spent fuel pool and exported for reprocessing, the last MOX fuel would be removed from the reactor's core two years prior to its shutdown, meaning it would be loaded six years prior to shutdown.[43] Under this arrangement, the reactor would "consume a sufficient quantity of plutonium early in its operational life to fully compensate for the plutonium arising later, including treatment of the final core."[44] According to EPZ, this led to "an ambitious scheme of MOX loading," comprising 144 MOX assemblies over 13 years from 2014 to 2026.[45] In most years, 12 MOX assemblies would be loaded, for a steady state loading of 48 MOX assemblies out of 121 total assemblies, or just under 40 percent, although the first loading in 2014 would be limited to eight MOX assemblies. On average, the MOX would contain about 7.8-percent plutonium,[46] including 5.41-percent fissile plutonium, providing equivalent burnup to the reactor's 4.4-percent enriched LEU fuel.[47] According to EPZ's Wieman in 2015, "This means that the reactor will have about 20 percent more plutonium in the core than any other commercial light water reactor," which may refer to the plutonium as a percentage of the core's heavy metal.[48]

Safety and Licensing

The introduction of MOX fuel raised several safety issues identified in EPZ's licensing submissions.[49] Perhaps most significant was that MOX fuel reduced the effectiveness of boron as a neutron poison in emergency cooling and control systems, due to the increased thermal-neutron capture cross-section of plutonium. Accordingly, EPZ switched from natural boron to enriched boron, raising the atomic percentage of Boron-10 from 20 to 32 percent, which required a license change.[50] MOX fuel also caused a harder neutron spectrum, which required a new safety analysis report on worst-case accident scenarios and embrittlement of the reactor pressure vessel. Using plutonium-based fuel also reduced the percentage of delayed neutrons, so EPZ needed to modify its reactor-control system.[51]

Due to the higher radioactivity of MOX than LEU in both fresh and spent fuel, EPZ also had to procure two new types of shipping casks for importing and exporting MOX fuel. According to EPZ's environmental submission, the more robust casks not only provided greater shielding from radiation but also extra protection against transportation accidents and security threats.[52] Nevertheless, the environmental report warned of an expected "higher [radiation] dose load for the EPZ employees who are deployed to receive the" MOX fuel.[53] The report also noted that MOX fuel rods could be more prone to radioactive release in an accident scenario, due to increased pressure from fission gases and decreased thermal conductivity of plutonium oxide particles.[54]

The regulatory process required both safety and environmental reviews.[55] KFD approved the safety review,[56] and the ministry for environment, after a public consultation on EPZ's submission, approved the environmental review. Based on both findings, on June 27, 2011, KFD granted "final" approval for EPZ to use MOX.[57] However, environmental groups then launched a two-year judicial challenge, which ultimately proved unsuccessful. In 2013, EPZ received "irrevocable" approval, and in 2014 the first MOX assemblies were loaded at Borssele.[58] The regulators required a gradual ramp-up of MOX fuel, which is why only eight assemblies initially were loaded. ANVS also required a post-hoc evaluation to assess if MOX fuel was behaving as predicted. That study, prepared

by Arcadis and delivered in 2017, reported that MOX fuel was performing within safety margins and that the worker dose actually was reduced due to the new casks and procedures for handling MOX fuel.[59]

Economics

It is difficult to evaluate the precise economic impact of introducing MOX fuel at Borssele because the prices in contracts are withheld as proprietary. However, it is known that after 2008, the price of uranium dropped precipitously from $140 to $20 per pound (Figure 1), a reduction of about 85 percent. If EPZ's assumption in its environmental submission that MOX and LEU fuel had the same total cost (Figure 2) was based on uranium at $140 per pound, then today's uranium price would result in MOX fuel costing twice as much as LEU fuel. Accordingly, a 40-percent MOX core would increase total fuel costs by about 40 percent. However, the actual increase in fuel costs would depend on many factors, including EPZ's contracted prices for uranium, enrichment, and fabrication of LEU and MOX fuel. Moreover, most experts would dispute the assumption in EPZ's environmental submission that MOX fuel ever cost as little as LEU fuel. If that assumption was overoptimistic, then for EPZ today the price of MOX fuel could be several times that of LEU fuel, as has been the case for every other country that has commercially utilized thermal MOX fuel. If so, EPZ's initiation of MOX fuel has increased its overall fuel costs by much more than 40 percent.

The good news for EPZ is that, under a long-term contract, it is paid above market price for the electricity it produces. EPZ sells its electricity for a fixed price of €43 per MWh to PZEM, which is owned by local governments and resells to customers at the market price, which in 2016 was only €31.50 per MWh. As a result, the local governments lose money whenever the Borssele reactor delivers electricity.[60] Not surprisingly, this has raised public calls to shut the plant. One result was the Holtkamp report, which highlighted that shutting the reactor prematurely would incur financial penalties from terminating EPZ's contracts for reprocessing, MOX recycle, and disposal of resulting waste. Whether intentional or not, EPZ's long-term contracts for MOX now function as a poison pill, deterring premature shutdown of a reactor that is producing electricity uneconomically.

Security

Although the introduction of nuclear weapons-usable plutonium in unirradiated MOX fuel in the Netherlands created unprecedented security challenges, it is unclear how the government evaluated them. The safety assessment for MOX states merely that, "The KFD also assessed the changes in security and safeguards due to the transport and storage of fresh MOX fuel assemblies. No further announcements can be made about this."[61] Only after the MOX license was issued did the Dutch government assess and accept EPZ's security plan and grant a separate transport license for MOX fuel.[62] The government declines to discuss the details of any upgraded security measures for MOX, but a few steps have been reported. First, the schedule for delivery of fresh MOX is less predictable than when only LEU fuel was delivered.[63] Second, fresh MOX fuel is transported by a "security vehicle," utilizing an MX6-type cask that provides some physical protection.

Beyond that, however, Jobse says that EPZ protects fresh MOX as it does LEU SNF, which if true would be inadequate.[64] Although both fresh MOX and LEU SNF contain plutonium, spent LEU is highly radioactive and thus deemed "self-protecting" against terrorist theft and processing to separate plutonium for nuclear weapons. By contrast, fresh MOX lacks sufficiently high radiation to prevent terrorists from stealing it to obtain plutonium.

Each of Borssele's MOX assemblies contains 27.5 kg of plutonium, sufficient for multiple nuclear weapons. The ground route for fresh MOX fuel from France's MELOX fabrication facility to Borssele is over 1,000 km (620 miles). Greenpeace noted in a 2011 report that it had provided evidence to the French military that "plutonium and MOX fuel transports could be identified, tracked, and in one case blocked and seized by Greenpeace activists." Accordingly, the report concluded, "A decision by EPZ and the Dutch state to use fresh MOX fuel increases the targets for nuclear terrorism."[65]

Public Opinion

Dutch environmental organizations – including the Laka Foundation, Greenpeace-Netherlands, and the Zeeland Environmental Federation – have opposed both continued operation of the Borssele reactor and its introduction of MOX fuel. The reactor is relatively old, having operated for 45 years, and is located within 120 miles of the Dutch cities of Amsterdam, Utrecht, and Rotterdam, and even closer to the Belgian cities of Antwerp, Brussels, and Ghent.[66] Domestic environmental groups demand further research on the safety risks arising from MOX fuel in accident scenarios and the potential need to modify emergency plans and evacuation zones.[67] A few demonstrations were organized against shipments of SNF from Borssele to France, but they failed to arouse the intense opposition to nuclear recycling that had emerged in other countries such as Germany in the 1990s.

Dutch environmentalists offer several explanations for this lack of popular resistance to MOX fuel in the Netherlands.[68] The country now has only a single power reactor, so the number of shipments of SNF, MOX fuel, and high-level waste is relatively small. Moreover, Borssele and COVRA are adjacent to Belgium, which is the route to and from France, so that ground transport through the Netherlands is quite brief – only about 35 km (20 miles) – and in sparsely populated territory that circumbscribes the directly affected population. The domestic political process is also less participatory than that of countries such as Germany, which reduces the opportunity for grassroots engagement. Finally, EPZ signed a single contract for the entire 13 years of planned MOX use, which deprived domestic anti-nuclear NGOs and politicians of the opportunity to mobilize public opposition to a potential contract renewal, as had proved effective in other countries. Possibly for these reasons, the introduction of MOX fuel in the Netherlands has failed to arouse substantial public opposition, parliamentary debate, or judicial intervention.

Summary of Findings

For 45 years, the operators of both of the Netherlands' nuclear power plants exported their spent LEU fuel for reprocessing, and while the radioactive waste was repatriated, the separated plutonium remained abroad. Dutch operators paid for other countries to take title to the plutonium, which was then kept in storage or used as fuel in fast or thermal reactors. In 2006, however, France changed its environmental law, requiring that reprocessing contracts specify in advance the disposition of the plutonium to be separated. Foreign utilities were no longer interested in being paid to take Dutch plutonium because they were phasing out MOX fuel or had large surpluses of plutonium. This left EPZ, operator of the sole remaining Dutch nuclear plant, with three choices: shut the reactor, stop reprocessing and instead dispose of SNF directly, or recycle future separated plutonium in MOX fuel.

In 2006, after the government agreed to extend the lifetime of the reactor by 20 years to 2033,[69] the Dutch utility EPZ conducted a comparative assessment of the latter two options, and chose to initiate use of MOX fuel. This decision does not appear to have been driven primarily by economics, because EPZ did not engage in negotiations over the price of interim storage of SNF with the Dutch government-owned company responsible for radioactive waste disposal. EPZ says its choice was driven mainly by the perception that MOX recycling was the less risky option, in that the only significant hurdle was obtaining a license to irradiate MOX, whereas direct disposal would have required several major changes on the back-end of the fuel cycle.

EPZ's licensing submission claims that the initiation of MOX fuel was driven by an economic desire to diversify fuel sources, but there is little evidence of that. MOX fuel was always likely to increase EPZ's fuel costs, especially given that the Areva contract required EPZ to pay for an unusually large amount of MOX fabrication, which even EPZ's submission acknowledges costs about five times as much as fabricating traditional LEU fuel. During most of the 13 years from 2014 to 2026, EPZ plans to use nearly 40-percent MOX fuel in the reactor's core. The sharp decline of uranium prices since 2008, by more than 80 percent, has likely increased substantially the financial penalty that EPZ will pay for substituting MOX for LEU.

EPZ is able to absorb this cost in part because the local-government owners of the reactor pay EPZ a fixed price, well above market rate, for the electricity produced. Thus, local governments

lose money whenever the Borssele reactor delivers energy, but EPZ has a financial interest in ensuring that the reactor is not shut prematurely. Notably, EPZ's contract for recycling of plutonium in MOX fuel, if terminated prematurely, would result in hundreds of millions of Euros in penalty fees, which the utility likely would seek to recover from the government. Thus, EPZ's decision to initiate MOX fuel has had the effect of deterring the Dutch government from shutting the reactor prematurely, although it is unclear if EPZ was motivated by such calculus.

In light of EPZ's unique circumstances – only one reactor, no surplus plutonium to start, and the need to recycle by 2033 all of the plutonium it would produce by then – Areva devised a "pre-cycling" scheme. The French company initially loaned plutonium to EPZ in fresh MOX fuel and subsequently accepted repayment in SNF. The major reactor modification was switching from natural to enriched boron in emergency cooling and control systems, which raised the percentage of Boron-10 from 20 to 32 percent. Two new cask designs were also developed for fresh and spent MOX fuel. In 2017, although the reactor's core had yet to reach full MOX capacity, a safety assessment reported that the new fuel was performing safely.

Security procedures for fresh MOX fuel, compared to LEU fuel, are only marginally more rigorous and reportedly equivalent to those for SNF. This appears inadequate for fresh MOX, which contains nuclear weapons-usable plutonium and is insufficiently radioactive to deter terrorist theft. Domestic environmental groups opposed the introduction of MOX fuel on safety and security grounds, but they had little impact on Dutch residents, legislators, or courts. This may be because few Dutch citizens are directly affected by shipments for the reactor and waste site, both of which lie near the border with Belgium, which is the transit route.

Conclusion

The Netherlands initiated commercial use of MOX fuel in thermal reactors in 2014, after most other countries using such fuel already had decided to phase it out. This might appear to signal a revival of global use of plutonium for energy. However, the details of the case reveal exactly the opposite. The Dutch utility's preference was

not to recycle plutonium in its reactor but to pay someone else to take it. Only when it could not find a taker, because MOX is so unpopular globally, did the utility seriously explore using such fuel itself. The Dutch experience also underscores two financial insights about the closed fuel cycle: MOX is much more expensive than LEU, and direct disposal of SNF offers an economically competitive alternative to reprocessing. This was true even before the 2008 collapse of uranium prices, which has made it only more so. Nevertheless, due to unique domestic political considerations, EPZ chose to sign long-term contracts for SNF reprocessing and MOX fuel fabrication, which appear to have significantly increased its costs. The Netherlands was the first country in a quarter-century to decide to initiate commercial use of MOX fuel in thermal reactors, and it may well prove to be the last.

Endnotes

[1] The author gratefully acknowledges research assistance by Ms. Yeo-Ri Kim.

[2] World Nuclear Association, "Nuclear Power in the Netherlands," April 2018, http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/netherlands.aspx.

[3] Ann MacLachlan, "UK returns reprocessing waste from shutdown Dutch reactor," *NuclearFuel*, March 22, 2010. Ministry of Economic Affairs and the Environment, "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 for the Sixth Review Meeting, October 2017, 81, https://zoek.officielebekendmakingen.nl/blg-820682.pdf. Martin Forwood, Cumbrians Opposed to a Radioactive Environment (CORE), email to author, February 27, 2018.

[4] Martin Forwood, Cumbrians Opposed to a Radioactive Environment (CORE), email to author, March 1, 2018. Ministry of Economic Affairs and the Environment, "Joint Convention," 16. Xavier Coeytaux and Yves Marignac, "Extension of Dutch Reprocessing: Upholding the Plutonium Industry at Dutch Society's Expenses?" WISE-Paris, June 2004, 2, https://www.laka.org/docu/catalogue/publication/1.01.4.40/10_extension-of-dutch-reprocessing-upholding-the-plu. The fuel burnup was 24,823 megawatt-days per tonne of uranium.

[5] UK Department of Energy & Climate Change, "Plutonium deal brings security benefits," press release, April 23, 2013, https://www.gov.uk/government/news/plutonium-deal-brings-security-benefits. See also, Ministry of Economic Affairs and the Environment, "Joint Convention," 27-28.

[6] World Nuclear Association, "Nuclear Power in the Netherlands."

[7] R.J.M. Konings and D.H. Dodd, "Nader onderzoek naar de verwerking van gebruikte splijtstof uit Nederlandse kerncentrales [Further research into the processing of spent nuclear fuel from Dutch nuclear power plants]," Nuclear Research & Consultancy Group (NRG), Report No. 21483/99.24187/p, commissioned by the Ministry of Economic Affairs, Petten, Netherlands, March 24, 1999, Section 4.2, says the amount of "fissile" plutonium in the SNF must be returned under the reprocessing contract.
https://www.laka.org/docu/catalogue/publication/1.01.4.40/08_nader-onderzoek-naar-de-verwerking-van-gebruikte-s.

[8] Peter Breitenstein and Jan Wieman, "Pre-cycling within plant lifetime," paper presented at the Top Fuel 2012 conference, Manchester, United Kingdom, September 2-6, 2012, 318. The two fast reactors were Germany's Kalkar and France's SuperPhenix.

[9] Drs. A.P. (Bram-Paul) Jobse RA, Chief Financial Officer, N.V. Elektriciteits-Produktiemaatschappij Zuid-Nederland (EPZ), interview with author, March 8, 2018. Breitenstein and Wieman, "Pre-cycling within plant lifetime," 318, 321. Ministry of Economic Affairs and the Environment, "Joint Convention," 27-28.

[10] D.H. Dodd, R.J.S. Harry, J.L. Kloosterman, R.J.M. Konings, A.M. Versteegh, "Opwerking van Nederlandse Splijtstof," Energy Research Centre of the Netherlands (ECN), Report No. ECN-C--97-031, 1997, https://www.ecn.nl/publicaties/ECN-C--97-031, 34, states that, "The increasing global surplus of plutonium and the high costs associated with the manufacture of MOX fuel mean that separated plutonium currently has a negative market value. It is assumed here that EPZ will have to pay 30 NLG/gPu for someone to take it (ECN estimate)" [author's translation]. See also, Konings and Dodd, "Nader onderzoek naar de verwerking," Section 3.5.

[11] Jobse, interview, March 8, 2018.

[12] Ann MacLachlan, "Dutch utility announces renewal of reprocessing with Cogema," *NuclearFuel*, March 15, 2004.

[13] Breitenstein and Wieman, "Pre-cycling," 321.

[14] Dr. Ir. Ewoud V. Verhoef, Deputy Director, COVRA NV, interview with author, March 8, 2018.

[15] EPZ, "Milieueffectrapportage Brandstofdiversificatie," July 2010. https://www.laka.org/docu/catalogue/publication/1.01.8.23/33_milieueffectrapportage-brandstofdiversificatie. Jobse, interview, March 8, 2018.

[16] Dirk Bannink, Laka Foundation, interview with author, March 7, 2018.

[17] Jobse, interview, March 8, 2018.

[18] EPZ, "Milieueffectrapportage Brandstofdiversificatie."

[19] The cost of enrichment was highlighted in another submission. See, EPZ, "Aanvraag tot wijziging van de kernenergiewetvergunning Brandstofdiversificatie," July 2010, 12.

[20] Jobse, interview, March 8, 2018.

[21] EPZ, "Milieueffectrapportage Brandstofdiversificatie," 14, states that, "Vanuit het oogpunt van kostenbeheersing is het daarom voor EPZ aantrekkelijk om MOXsplijtstof te kunnen inzetten."

[22] Jobse, interview, March 8, 2018.

[23] Ministry of Economic Affairs and the Environment, "Joint Convention," 27-28.

[24] Jobse, interview, March 8, 2018.

[25] EPZ, "EPZ applies for a permit for re-use of fuels at the nuclear power plant," Press release, July 8, 2010. The statement also says that the "price

of natural uranium has risen sharply in recent years," although in fact the price had plummeted in the preceding two years.

[26] Gert Jan Auwerda, ANVS, interview with author, March 7, 2018.

[27] Jobse, interview, March 8, 2018.

[28] Jan Wieman, "Borssele Moves to MOX," *Nuclear Engineering International*, March 11, 2015, http://www.neimagazine.com/features/featureborssele-moves-to-mox-4530062/.

[29] Jobse, interview, March 8, 2018.

[30] Minister for Economic Affairs, Agriculture and Innovation, "Reprocessing of radioactive material," letter to the President of the House of Representatives of the States General, Parliamentary paper 25422, no. 87, The Hague, January 17, 2011, author's translation, https://zoek.officielebekendmakingen.nl/kst-25422-87.html. COVRA's Deputy Director, Ewoud Verhoef, email to author, August 13, 2018, says that HABOG actually took four years to construct (1999-2003), following a five-year licensing phase (1994-1999), which implies that the entire process for a new facility might have required nine years.

[31] Jobse, interview, March 8, 2018. Wieman, "Borssele Moves to MOX," reports similarly that, "EPZ assessments found that the cost of continuing fuel recycling would not be much different from the expected cost of direct fuel disposal."

[32] Auwerda, interview, March 7, 2018.

[33] Drs. A.P. (Bram-Paul) Jobse, email to author, August 23, 2018.

[34] Verhoef, interview, March 8, 2018. He estimates that such a facility would have cost at least as much as the original HABOG, which was €125 million.

[35] Jobse, email to author, August 23, 2018.

[36] Jobse, interview, March 8, 2018. See also, Wieman, "Borssele Moves to MOX."

[37] Breitenstein and Wieman, "Pre-cycling," 321.

[38] Mr. A.B. Holtkamp, Drs. W.J. Laman RA, and Dr. H.A. Selling, "Rapport betreffende de validatie van de onderliggende aannames m.b.t. de operationele kosten en kosten van mogelijke sluitingsscenarios van de kerncentrale Borssele" [Report on the validation of the underlying assumptions regarding the operational costs and costs of possible closure scenarios of the Borssele nuclear power plant], September 15, 2016, 11-13, https://www.rijksoverheid.nl/documenten/rapporten/2016/09/15/rapport-betreffende-de-validatie-van-de-onderliggende-aannames-m-b-t-de-operationele-kosten-en-kosten-van-mogelijke-sluitingsscenarios-van-de-kerncentrale-borssele.

[39] Holtkamp, et al., "Rapport betreffende de validatie," 11-13.

[40] Auwerda, interview, March 7, 2018.

[41] Jobse, email to author, August 23, 2018.

[42] GRS, "GRS assists Dutch regulatory authority KFD," July 26, 2010, https://www.grs.de/en/content/kfd.

[43] EPZ, "Milieueffectrapportage Brandstofdiversificatie," states that LEU SNF requires one to two years of cooling in the pool, but that MOX SNF requires an extra one to two years.

[44] Breitenstein and Wieman, "Pre-cycling," 320.

[45] Wieman, "Borssele Moves to MOX." Breitenstein and Wieman, "Pre-cycling," 316.

[46] Shaun Burnie and Frank Barnaby, "Safety Implications of MOX Fuel Use in The Borssele Nuclear Power Plant – Lessons from Fukushima," Greenpeace, August 3, 2011, 2, http://www.greenpeace.nl/Global/nederland/image/2011/PDF/moxfuelus e_borssele.pdf.

[47] Breitenstein and Wieman, "Pre-cycling," 322.

[48] Wieman, "Borssele Moves to MOX."

[49] This includes the environmental impact assessment, dated July 2010, and submitted in autumn 2010. EPZ, "Milieueffectrapportage Brandstofdiversificatie." Wieman, "Borssele Moves to MOX."

[50] EPZ, "Milieueffectrapportage Brandstofdiversificatie," 28.

[51] Auwerda, interview, March 7, 2018. EPZ, "Milieueffectrapportage Brandstofdiversificatie."

[52] EPZ, "Milieueffectrapportage Brandstofdiversificatie," 29, 70-72.

[53] EPZ, "Milieueffectrapportage Brandstofdiversificatie."

[54] EPZ, "Milieueffectrapportage Brandstofdiversificatie," 58.

[55] Jan Haverkamp, Greenpeace-Netherlands, interview with author, March 5, 2018.

[56] Ministry of Infrastructure and the Environment, "Brandstofdiversificatie KCB – beoordelingsrapport veiligheidstechnische onderbouwing," VROM Inspectorate, April 29, 2011.

[57] *Government Gazette 2011*, No. 11565, June 29, 2011.

[58] Wieman, "Borssele Moves to MOX."

[59] Auwerda, interview, March 7, 2018. ARCADIS, "Evaluatie Mer Brandstofdiversificatie EPZ: Gebruik van Mixed-Oxide splijtstof in de Kerncentrale Borssele," May 2017.

[60] WISE-Nederland, "Borssele maakt winst... hoe zit dat?" July 11, 2017, https://wisenederland.nl/borssele-maakt-winst-hoe-zit-dat. PZEM is 100-percent owned by the Zeeland municipalities and the Province of Zeeland.

[61] Ministry of Infrastructure and the Environment, "Brandstofdiversificatie KCB," 13.

[62] Auwerda, interview, March 7, 2018. Jobse, interview, March 8, 2018.

[63] Haverkamp, interview, March 5, 2018.

[64] Jobse, interview, March 8, 2018.

[65] Burnie and Barnaby, "Safety Implications of MOX," 17-20.

[66] Burnie and Barnaby, "Safety Implications of MOX," 13.

[67] "EPZ mag plutonium gaan gebruiken," *Omroep Zeeland*, February 13, 2013, https://www.omroepzeeland.nl/nieuws/63064/EPZ-mag-plutonium-gaan-gebruiken.

[68] Bannink, interview, March 7, 2018. Shaun Burnie, phone interview with author, February 23, 2018. Haverkamp, interview, March 5, 2018.

[69] "Borssele Nuclear Power Plant Convenant," June 2006, https://laka.org/docu/boeken/pdf/1-01-8-20-45.pdf#page=2**.** The actual license change was granted later. See, Minister of Economic Affairs, "Amendment of the Nuclear Energy Act Licence Granted To NV EPZ for the Extension of the Design Lifetime of the Borssele Nuclear Power Plant," March 20, 2013, https://www.unece.org/fileadmin/DAM/env/pp/compliance/C2014-104/Correspondence_with_Party_concerned/frPartyC104_03.02.2015/Appendix_6_-_Borssele_NPP_LTO_license_final.pdf**.**