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40 YEARS OF LOGISTICAL SUPPORT FOR A CLOSED FUEL CYCLE

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Abstract

The 500 MWe Borssele Nuclear Power Plant in The Netherlands is owned and operated by Elektriciteits-Produktiemaatschappij Zuid-Nederland N.V. (EPZ). Because the plant was designed with a minimal storage capacity for fresh and irradiated fuel, reactor operation is highly dependent on “just in time” fuel deliveries and removals. The logistical processes for the fuel cycle – supply of fresh uranium and MOX fuel, shipment of used fuel, of reprocessing waste – are described. A variety of transport casks are being used, mainly the ANF-18 for fresh fuel, the MX-6 for MOX, the TN17/2 for used fuel and the TN28VT for radioactive residues.

At several moments in the 40-years history of the Borssele plant, the fuel decay pool has been critically overcrowded because of mismatches between deliveries and removals. Repeated rack compaction, to increase capacity of the fuel pool storage racks, has added operational flexibility. It appears that the shipment of used fuel to France, for reprocessing in La Hague, is the logistical process most vulnerable to legal and political interference. AREVA and EPZ have sought to increase logistical robustness by making the used fuel shipments as efficient as practicable. As a result, the original transport procedure of 3 assemblies at one time will be replaced by shipments of 27 fuel assemblies at one time, after introduction of a fleet of newly designed TN17MAX casks in the near future.

Introduction

The Netherlands has a medium-sized economy with an annual electricity consumption of 110 TWh. Of this, about 3,3% is produced by the Borssele Nuclear Power Plant (500 MWe rating) which is the only commercial nuclear unit in the country. Most electrical power in The Netherlands is produced by domestic natural gas and imported hard coal.

Photo 1: the Borssele Nuclear Power Plant

Borssele NPP is a KWU (now AREVA) designed PWR plant running at base load with an annual refueling cycle. It started commercial operations in October 1973 and is scheduled to be shut down after 60 years, by 2034. The Borssele reactor core is fueled by 15*15 assemblies of 265 cm active length, containing 4.4% enriched uranium fuel or MOX with 5.4% Pu-fiss content.

The design of the power plant is based on quick removal of the used fuel. There is no wet or dry storage capacity, only a decay pool in the reactor building. The pool racks also keep the fresh fuel for reactor loading. Originally, in 1973, the capacity of the racks in the decay pool was very limited and based on the assumption that used fuel would be removed for reprocessing within one year.

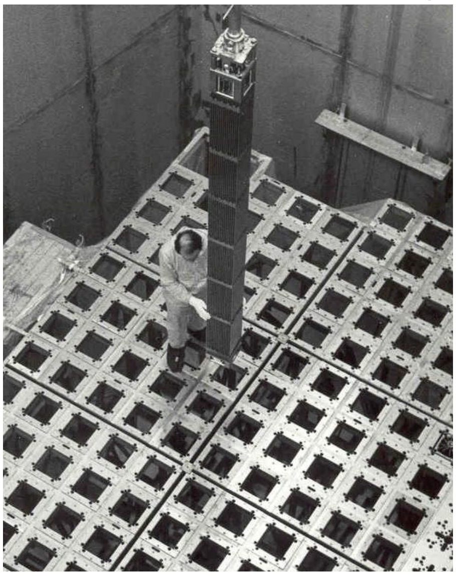

Photo 2: commissioning of the racks in 1973

Because of the limited on-site storage capacity, the reliability of logistical processes for fuel going to and going from the power plant is fundamental to reactor operations. Front-end deliveries are essential because the plant cannot hold a significant stockpile of fresh fuel. Back-end shipments must avoid overfilling of the decay pool with used fuel.

Balancing Front- and Backend shipments

From 1973 onwards, about 600 tons fuel have been shipped to and from the Borssele plant, as illustrated in figure 1. The graph in figure 1 shows interruptions in the used fuel shipments that will be discussed below. The difference between the mass of fuel shipped to and from the reactor site is the on-site inventory which is kept in the pool racks, and is set out in figure 2 and compared with the pool storage capacity.

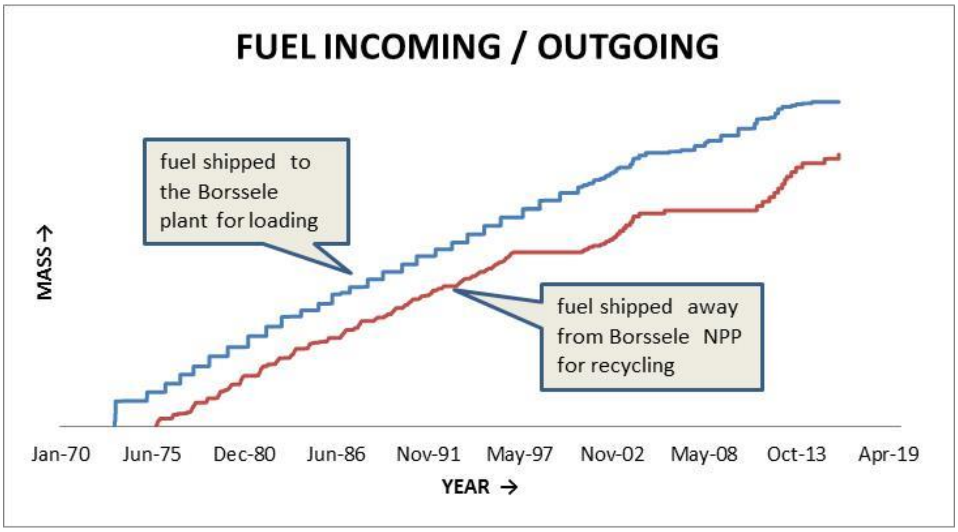

Figure 1: cumulative quantity of fuel shipped to Borssele NPP compared with the quantity removed since 1973

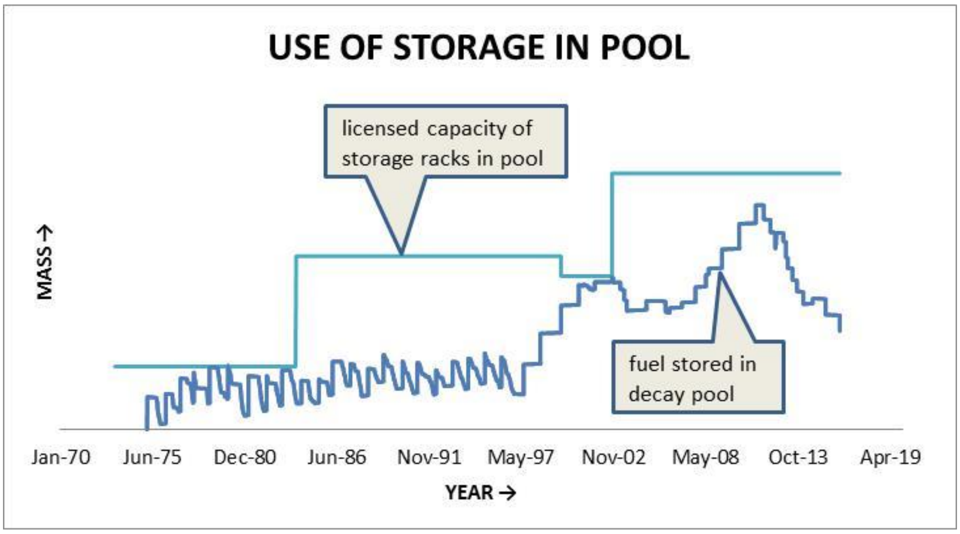

Figure 2: in-pool fuel inventory in relation to rack storage capacity

As shown in figure 2, during the first 25 years of plant operations, the shipments of fresh fuel and of used fuel were more or less in balance. However, in some years, the full available rack capacity was in use with no spare room left. In 1983 the storage racks were compacted by partially replacing the racks with borated steel to allow for a greater capacity; in 1998 regulatory restrictions (related to higher fuel enrichment) made the available capacity smaller again. In 2002, a second compaction project increased the storage capacity of the decay pool to 500 fuel assemblies.

Four logistical processes for the fuel cycle

The Borssele NPP has a closed fuel cycle. AREVA NP is the exclusive designer and manufacturer of new fuel. This includes fuel made from Enriched Natural Uranium (ENU), Enriched Reprocessed Uranium (ERU) and Mixed-Oxide (MOX). For the recycling of its used fuel, EPZ has a long standing contractual relation with AREVA NC (previously Cogéma). From the very first core, all used fuel has been treated in the La Hague reprocessing plant. AREVA NC is also responsible for conditioning radioactive reprocessing residues into manageable waste packages for repatriation to The Netherlands. The government-owned COVRA, located near the Borssele site, receives the radioactive waste for intermediate storage.

This closed fuel cycle involves four essential logistical processes:

- fresh uranium fuel (ENU and ERU) with the ANF-18 cask for road transport, occasionally maritime transport
- fresh MOX fuel, with the MX-6 cask for road transport
- used uranium fuel, with the TN17/2 cask for rail transport; in the near future to be replaced by the TN17MAX cask which will also accommodate used MOX fuel
- radioactive residues, with the TN28VT or TN24DH cask for rail transport to COVRA.

Uranium fuel (ENU and ERU)

EPZ has contracted the services of AREVA NP as the exclusive designer and manufacturer of fuel. Manufacturing is done in the ANF Lingen facility in Germany. ANF has subcontracted the shipment of the freshly fabricated fuel to DAHER Nuclear Technologies. The workhorses for these transports are the shipping casks of the ANF-18 model provided by AREVA TN.

The ANF-18 was designed to comply with the 1996 IAEA standard TS-R-1 and saw first service in 2002. From Lingen, where each cask is loaded with two ENU fuel assemblies, transport over the German-Dutch border is performed by road in standard trucks, each vehicle carrying up to four ANF-18 casks. These casks are easily manipulated in the power plant, either closed or with the lid off, horizontally or vertically. The security regime of these transports (Class III) is relatively light. Essentially these shipments have over the years been running very smoothly.

Photo 3: the arrival of ANF-18 casks in Borssele NPP

With intervals, EPZ contracts AREVA NP to fabricate fuel from reprocessed uranium (ERU). Such fabrication involves the services of another AREVA subcontractor, MSZ, for uranium enrichment, pellet fabrication and for final fuel assembly. MSZ has its manufacturing plant in Elektrostal, in the Russian Federation. In such ERU campaigns, the logistics involve more steps. The ANF-18 casks, loaded by MSZ, are shipped by rail from Elektrostal to St. Petersburg harbor, from St. Petersburg by ship to a local Borssele harbor, and from that local harbor again by truck to the reactor site.

Photo 4: the unloading of ANF-18 from the Russian cargo ship Bugulma

These transport procedures multiple cask transfers, including the mobile crane shown in Photo 4. Such multiple handlings naturally increase the risk of mechanical incidents. The ANF-18 casks are fitted with acceleration detectors that will signal to the Borssele operators, upon opening of the cask in the reactor building, any rough handling that could have jeopardized the design limits of the fuel; e.g. by overloading the springs in the spacer grids. During all the years of shipping fuel to Borssele by ANF-18 or its predecessor casks, never a fuel assembly was rejected upon receipt.

For the plant operating personnel, the collective dose received in the framework of fuel transports is being closely monitored. Both for ERU or ENU fuel it is less than 0,2 mSv per campaign, which is low for receiving a batch of 28 or 32 assemblies.

MOX transports

The other front-end flow of nuclear fuel to Borssele NPP concerns the MOX assemblies that are being fabricated in the AREVA MELOX plant in Southern France under contract with AREVA NP. This is a more recent process, since the first MOX was loaded in 2014. For these transports, the pre-existing MX6 cask was adapted for the Borssele fuel design. The MX6 is a cylindrical type B cask specifically designed by AREVA TN for the transport of MOX fuel, with a payload capacity of 6 fuel assemblies. The introduction of this cask was managed by a working group of AREVA and EPZ specialists and involved

- design and licensing of a modified basket for the MX6 dedicated to the Borssele 15*15 fuel
- fabrication of that basket
- modification of the interfaces at Borssele NPP for receiving the MX6
- blank testing of the transport process.

A commercial contract covering these activities was signed in July 2011 and a successful test run of receiving the MX6 with dummy fuel was performed in July 2013. Early 2014, the first MOX was delivered for loading in the reactor.

Photo 5: handling the MX6 cask in Borssele

The MOX transports are performed by road in a dedicated “security vehicle” which contains a security “caisson” protecting the shipping cask (figure 3). These transports take place under the most severe security classification (Class I). They require intensive co-ordination between the authorities in the concerned countries, France, Belgium and The Netherlands.

All transports have been performed on schedule. Public or political interest in MOX or the MOX transports, meanwhile, has been very low to non-existent.

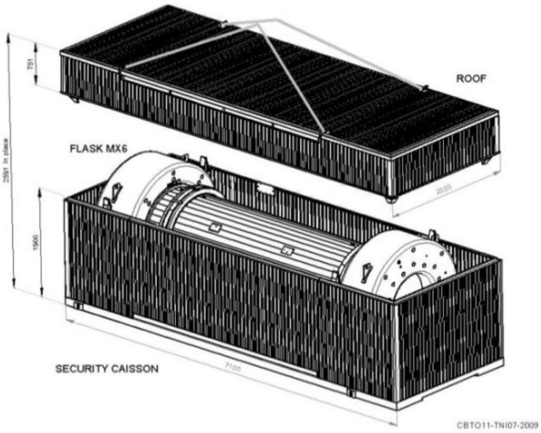

Figure 3: Security caisson

Unirradiated MOX fuel is significantly more radioactive than uranium fuel, and its radiation field includes neutron radiation. For that reason, the procedure for unloading the MX6 cask in the reactor building of Borssele NPP involves specific measures to minimize personnel exposure. The MX6 cask is placed in vertical position and, after removal of the main lid, a neutron-shielding polyethylene cover is applied with openings which allow MOX assemblies to be removed one by one while keeping neutron shielding intact.

Photo 6: removing MOX assembly through the protective cover

Because of the heat generated by decay of plutonium isotopes, the temperature of the fuel during transport becomes elevated and the MOX assemblies must be cooled before insertion into the pool water. This cooling is done by placing the MOX assemblies first in a dry underwater box (for shielding) with forced air circulation. The net result of all radiation management measures is that the receipt of a reload of 12 MOX fuel assemblies takes a collective dose for the operators and surveillance personnel of less than 1 mSv.

Used Fuel transports

Originally, used fuel was shipped off-site with the NTL8 series cask, using road transport from the nuclear power plant right into the La Hague treatment plant in France. The NTL8 had a payload of 3 fuel assemblies and required some 12 - 14 casks to be individually shipped each year. Because at those days, the authorized transport route included several border stops in small villages at the Dutch/Belgian and Belgian/French borders, the fuel transports were highly visible and raised safety concerns and political opposition from the Dutch and Belgian municipalities concerned.

In 1998, cases of external contamination of spent fuel casks were reported by the French authorities to several other European countries, including The Netherlands. In all of these countries, the authorities decided to temporary suspend used fuel transports until the root cause would be known and corrective actions taken. In fact, as far transports with the NTL8 from Borssele to La Hague were concerned, there had never been any reportable case of contamination. But under political pressure from nuclear opponents, the Dutch government allowed transports to resume only in 2002; while in other countries, the suspensions lasted much shorter. By this time, as can be seen from figure 2, the storage condition in the Borssele decay pool had become critical – just one storage position of 350 was left unused. Two developments timely reversed this critical condition: first the resumption of shipments to France, and second a re-racking of the fuel pool to increase the capacity from 350 to 500 positions.

In 2006, the used fuel shipments were interrupted again. This time, the cause was a legal development. A change in the French environmental law, introduced in June 2006 and taking immediate effect, made the import of used fuel onto French territory subject to a specific intergovernmental agreement. In The Netherlands, the procedure to enter into such an intergovernmental agreement was slowed down for years for political reasons. Only in 2011 the transports of used fuel to France could be resumed.

Since it appeared so imperative that used fuel transports, when possible, should be implemented in the most efficient manner, AREVA and EPZ agreed by 2000 to develop the optimum logistical process within the technical restraints of the Borssele plant. For instance, the air lock of the reactor building limits a transport cask to a diameter of 198 cm. Many available shipping casks are too big. The TN17/2 cask, which was selected, has a diameter of 195 cm. Three TN17/2 casks have been configured for Borssele fuel and are being shipped by train in a single “tridem” transport. The payload of one TN17/2 is 7 PWR fuel assemblies. A tridem transport thus carries 21 fuel assemblies, which is a sevenfold increase in efficiency compared with the previous transports with the NTL8.

Photo 7a and 7b : handling the TN17/2 cask outside and inside Borssele NPP

Because the Borssele reactor is not connected to a railway track, and neither is the La Hague treatment plant, the shipments by TN17/2 casks involve transfers from and onto road vehicles. The cask leaves the Borssele site by road truck for a 2-kilometer stretch to the COVRA site, which has a train terminal. At COVRA, a mobile crane is used to transfer the casks onto railway carriages.

Photo 8: cask transfer at COVRA by mobile crane

Upon arrival in France, the train terminates at the Valogne platform, where the casks are being transferred on road trucks for the last 30 kilometer stretch to La Hague.

In The Netherlands, used fuel transports are classified as IIa (intermediate between II and I) and there is a significant security regime; a shipment takes 3 locomotives, 3 'nuclear' carriages and at least one wagon for the police escort. This procedure has worked quite well since its first implementation in 2002. Although anti nuclear NGO's have occasionally organized some protest along the railway route, generally the transports have gone smoothly. Because of its efficiency, typically one used fuel transport per year is sufficient to evacuate the annual reactor unloadings.

From a work safety viewpoint, the used fuel transports are being carefully managed to minimize personnel exposure. A tridem used fuel transport results in a collective dose to Borssele plant operators, AREVA staff and surveillance personnel of only about 5 mSv, which is a good performance considering all the worker activities in proximity of loaded casks.

New cask for used fuel

The TN17/2 cask was designed in accordance with the IAEA rules of 1985; this means that after the issuing of new design rules by the IAEA, this cask came under progressive restrictions from the licensing authorities. First, it became impossible to approve it for new types of fuel (such as irradiated MOX). In the near future, it may no longer be approved for continued use even with the existing range of fuels.

So back in 2008, EPZ and AREVA agreed to initiate feasibility studies for a new model of cask, compliant with the current IAEA design rules (TS-R-1, 2005 edition). This new cask is member of the "Generation 3" under development by AREVA TN and is called TN17MAX. Its capacity will be increased to 9 fuel assemblies, including used MOX. So when these TN17MAX casks become operational by 2019, the efficiency of a tridem transport will be increased to 27 fuel assemblies. (Note that the process to replace the existing model of used fuel transport cask by a complete new design takes more than 10 years).

After final plant shutdown in 2034, the efficiency of the TN17MAX will be helpful to evacuate all remaining fuel from the Borssele site in preparation of the dismantling project. Any delay in removing used fuel from site would significantly increase the cost of decommissioning Borssele NPP. The estimated cost saving in this defueling period was a major factor in EPZ's decision to select the TN17MAX cask in preference of competing designs of lesser efficiency.

Returns of radioactive residues

As a result of recycling its nuclear fuels, EPZ has a legal and contractual obligation to return the resulting waste to The Netherlands. The AREVA NC plant in La Hague produces two types of conditioned waste from treating EPZ's fuel: vitrified fission products in standard 180 liter canisters (CSD-V) and compacted hulls&end-pieces in the same standard canisters (CSD-C). Over the 60 years lifetime of its Borssele NPP, EPZ will have to return about 1000 of these two types of canisters. In The Netherlands, the waste management organization COVRA has an interim storage building (HABOG) to receive and store the radioactive residues for a minimum of 100 years before geological disposal.

The cask used for these waste transports is the TN28VT. It was designed for transport of 28 CSD-V, but is also used for CSD-C. Because the mass of metallic CSD-C is higher compared with CSD-V, the payload of the TN28VT is limited to 20 CSD-C.

Photo 9: Transport with the TN28VT near the Valognes terminal

The shipments of the vitrified residues to The Netherlands started in 2004; in 2009 the first metallic waste was repatriated. To accelerate the CSD-C transport program, two high efficiency TN24DH casks were deployed for a few years (two times 24 CSD-C payload in one transport).

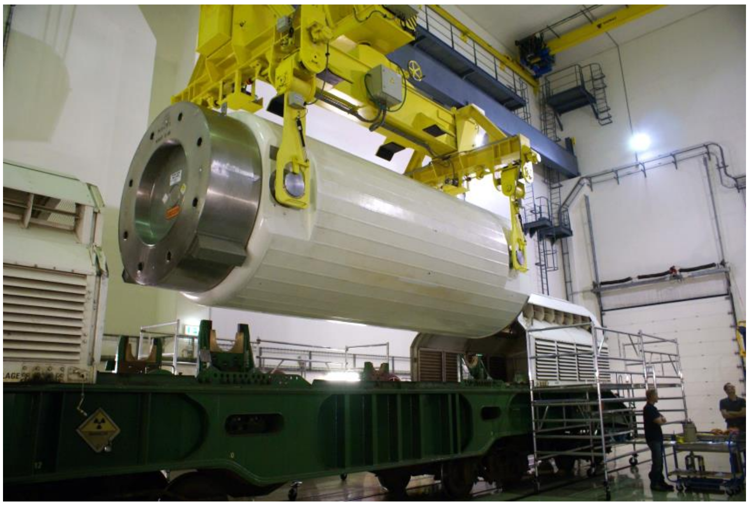

Photo 10: handling the TN28VT at COVRA

At present, 196 CSD-V and 282 CSD-C have been repatriated from France to The Netherlands, about half the lifetime quantities of Borssele's fuel cycle. New residues transports are being implemented in phase with the production of waste from additional fuel recycling campaigns; the historical waste backlog has been removed. The residues transports to The Netherlands have been executed without legal or political difficulties and in full compliance with pertinent agreements made between the governments of France and The Netherlands.

Conclusion

EPZ's Borssele Nuclear Power Plant is per design completely dependent on timely front- and backend fuel transports, because of severe restrictions for on-site fuel storage. Over the years, the used fuel transports have proven to be most complicated and most vulnerable to political and legal interferences. As the best way forward, AREVA and EPZ have intensely co-operated to develop the most efficient procedure of used fuel transport, minimizing the number and the political visibility of the shipments. Used fuel transports originally required more than 12 shipments per year, today just one is sufficient to balance the fuel arriving in the plant. The new TN17MAX cask under development will increase this efficiency of used fuel transports even further.