Diversification of the VVER Fuel Market in Eastern Europe and Ukraine

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Background Following the fall of the *Berlin Wall* and the dissolution of the Soviet Union, the newly independent countries of Eastern Europe hosted fleets of reactors of Russian design. The technology ranged from older RBMK's to more modern VVER-1000 reactors. Efforts by the international community resulted in immediate safety upgrades of the RBMK reactors and soon after their permanent shutdown, increased safety to allow longer term operation on the smaller VVER-440 reactors which could meet international standards and later upgrades to the VVER-1000 fleet.

Today, there are 33 VVER active reactors (see **Table 1**) in the EU and Ukraine, accounting for the largest percentage of the total electricity supply in the countries operating these units. The reactors are operating effectively and safely, generating low cost energy to the benefit of these countries. However, they are exposed to the legacy of the past with a monopoly fuel supply from Russian state-owned companies. This dependency presents a large risk for these countries and indeed for neighboring EU countries, which often import their energy.

Country	Name of station & reactor unit	Type of unit	
Bulgaria	Kozloduy 5-6		VVER-1000
Czech Republic	Dukovany 1-4	VVER-440	
	Temelin 1-2		VVER-1000
Finland	Loviisa 1-2	VVER-440	
Hungary	Paks 1-4	VVER-440	
Slovakia	Bohunice 3-4	VVER-440	
	Mochovce 1-2	VVER-440	
Ukraine	Khmelnytskyi 1-2		VVER-1000
	Rivne 1-2	VVER-440	
	Rivne 3-4		VVER-1000
	South Ukraine 1-3		VVER-1000
	Zaporizhzhia 1-6		VVER-1000

Tab. 1.
VVER units in Europe and the Ukraine.

Typically in other nuclear markets, there are at a minimum two qualified nuclear fuel suppliers. This is important for not only security of supply, but also to ensure competition which drives both cost and technology improvements. Nuclear fuel is a highly engineered product which must go through rigorous design and testing before independent regulatory approval allows their use in nuclear reactors. The mixed core situation requires certain analyses to ensure compatibility between the different designs, but as long as the necessary data is exchanged the needed analyses can be performed. Since a large number of utilities have operated with mixed core conditions there is also an extensive experience, showing that these cores can operate safely and efficiently utilizing fuel simultaneously from two vendors.

VVER-1000 fuel

Westinghouse Electric Company is the only nuclear fuel producer outside Russia, which has taken the steps to test, qualify and license VVER fuel – both for VVER-440 and VVER-1000 reactors. The beginning of this effort was again the result of the rapid changes following the dissolution of the Soviet Union. The Czech Republic decided in the mid-1990s to complete the VVER-1000 *Temelin* Nuclear Power Plant which had been partially built prior to independence. An international tender was initiated which required that the plant must meet European and International safety standards and subsequently won by *Westinghouse.* As part of the successful completion, the fuel was also produced by *Westinghouse,* consistent with the VVER core parameters which required a hexagonal rather than square shaped fuel assembly. The fuel assemblies operated successfully for 2 to 3 years but experienced "bowing" which resulted in a redesign to operate at specification. As this was the first ever attempt to produce Russian-designed fuel, a learning curve was not entirely unexpected. Eventually, the *Westinghouse* fuel design was proven to work reliably, but the utility, ČEZ, in the interim decided to procure from the Russian supplier for the next contract.

In parallel of these efforts in the Czech Republic, the Ukrainian and US Governments began discussing energy cooperation and security which resulted in a competitive tender for a program to design a VVER-1000 fuel assembly which would be "compatible" and licensable in Ukraine for mixed core use. *Westinghouse* was selected and spent the next several years modifying its *Temelin* fuel design from lessons learned and to for the first time prove it could be loaded adjacent to operating Russian supplied assemblies. The normal industry practice is that the existing fuel supplier and/or the plant operator provide technical specifications of its fuel to allow a second supplier to design its fuel to ensure full compatibility. The most obvious aspect of compatibility is the geometrical, but also other areas such as thermal hydraulics and neutronics have to be analyzed over the life time of the fuel. *Westinghouse* provided this information to the Russian supplier in the case of *Temelin*, but the corresponding information was not provided to *Westinghouse* in Ukraine. This presented an additional challenge and caused a several year delay as the initial testing proved to not meet necessary parameters.

Lead Test Assemblies (LTA´s) were delivered and inserted for operation in the *South Ukraine* unit 2 in 2005. The fuel was successfully operated until end-of-life and the anticipated

Fig. 1.
Location of the nuclear power plants in Ukraine.

behavior was confirmed by extensive inspection campaigns. Following the LTA´s, *Westinghouse* delivered the first two reloads, for *South Ukraine* unit 2 and 3, in 2011. The fuel performed very well during operation, but at the annual reloading the following year unexpected issues were discovered. The large lateral stiffness and distortion of the co-resident fuel assemblies caused difficulties to load the *Westinghouse* fuel assemblies into the core. Inspections showed several scratches and rub marks clearly indicating mechanical interaction with the neighboring fuel during the core shuffling. Some of the fuel assemblies also showed damage to the fuel assembly grids.

To resolve the issue *Westinghouse* investigated different alternatives to avoid mechanical interaction during the unloading and loading of the core. A new loading sequence was created, limiting the risk for mechanical interaction when shuffling the core (e.g. by the use of as many open-water positions as possible) and using special designed loading devices that would ease and aid the loading and unloading of fuel assemblies. It was also decided to make mechanical modifications, such as tapered bottom nozzles and redesign of the spacer grid, to the fuel assembly to protect against mechanical interaction with the neighboring assemblies during the shuffling. The improvements made also required significant testing to verify the functionality and effectiveness.

To date, the new loading sequence has been successfully used during two reloading campaigns as measured by the mechanical forces during the loading of the fuel. Inspections of the fuel have also confirmed the absence of harmful mechanical interference. The first reload of the modified fuel design has been delivered and is planned to be inserted in *South Ukraine* unit 3 during the spring of 2015. The new design is expected to reduce the risk for damage in case of mechanical interference.

The general performance of the *Westinghouse* fuel has been very good and with the solutions to the mechanical interference as described above, the fuel is qualified to be working to specification which results in the potential to deliver to all similar 13 VVER-1000 plants in Ukraine (plant locations see **Figure 1**). A contract was subsequently signed on December 30, 2014 which expands the supply of *Westinghouse* nuclear fuel, providing Ukraine for the first time in its history a fully qualified and licensed alternative. Ukraine now depends on nuclear energy for roughly 60 percent of its total power production and therefore these long and difficult steps represent a tremendous lever in energy security for the new government of Ukraine.

VVER-440 fuel

The countries operating the VVER-440 units within Europe and Ukraine have also announced a growing interest in qualifying a second supplier. Already in 1998 *BNFL (British Fuel Nuclear Limited)* delivered five LTA's to the *Loviisa* unit 2 in Finland. The assemblies were manufactured in the fuel facility in Springfields, UK and the purpose of the program was to qualify a second supplier for the Loviisa plant as well as for the *Paks* units in Hungary. Following a successful operation of the LTA`s, *BNFL* was awarded a contract in December 1999 to supply reload deliveries to Loviisa and a total of seven reloads were delivered in 2001 to 2007. Shortly before the contract award, Springfields was incorporated in the *Westinghouse* fuel operations following the acquisition of *Westinghouse* by *BNFL*. (As a result of these changes it was decided that the reload fuel was to be assembled by *ENUSA* in Spain instead of Springfields.)

Following some unsuccessful fuel tenders in 2006 and 2007, *Westinghouse* decided to exit the VVER-440 business. Lately, the increased importance of diversification has resulted in discussions with different utilities about upgrading the fuel design to include more advanced materials as well as improved mechanical features.

Conclusion

A significant effort has been invested to develop and qualify reliable fuel designs for the VVER plants in Eastern Europe and Ukraine. Fundamentally, the technical challenges are similar to those encountered in Western designed light water reactors, but sometime harder to overcome due to the difficulties to get access to required technical data and information. With the increased knowledge and experiences built, *Westinghouse* has established a stable foundation for developing, manufacturing and delivering competitive products to the VVER utilities, which will foster the diversification in the region.

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