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The International VVER Fuels Market

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1 The State of the Western Fuel Fabrication Market

Never before in the history of the Western nuclear fuel fabrication industry has there been a period of such intense competition among vendors. And this is occurring in what is truly an international market for nuclear fuel supply.

In the early years of nuclear power, utilities typically purchased fuel from their reactor vendors who were often located in their own country. Today, however, vendors in every nation are actively pursuing (and winning) contracts in other countries and for the reactors of other manufacturers. Even in Japan, which has always relied on domestic fabrication supply, consideration is being given to purchasing fuel from foreign vendors.

Because the international growth of nuclear power has lagged well behind the rates anticipated a decade or so ago, existing fabrication capacity in the West far exceeds the current and anticipated demand. In fact, current demand is not much more than half of the capacity available to supply it.

This has led to the aggressive competition noted earlier, especially in the USA where prices have fallen substantially, even as new and improved fuel designs are being brought to market.

2 The View to the East

Facing a heavily oversupplied market with no prospects for growth in the foreseeable future, and with the dramatic political changes in Eastern Europe during the past several years, Western vendors have turned eastward in an attempt to fill their fabrication plants. And the potential market they have seen there has brought broad smiles to the faces of marketing managers, production supervisors, financial executives and the stockholders of the Western vendors.

Focusing solely on pressurized water reactors, and excluding the plants in the Russian Federation, there is a possible long-term market of up to 44 units in Bulgaria, the Czech Republic, Finland, Hungary, Slovakia and Ukraine. These include:

- 20 VVER-440 reactors in operation, with an additional 4 units under construction
- 12 VVER-1000 units operating and 8 under construction.

As these markets have opened, Western vendors have aggressively pursued them, some independently, others in joint ventures. Even with the prospect that some of the older VVER units may be shut down, and even if some of the units currently under construction are not completed, this is certainly a market which could profitably support multiple suppliers.

3 The Benefits of Competition

Competition in the VVER fuel market promises significant benefits for the operators of these reactors. This will be especially true during the next several years when the marketplace will determine the identity and number of Western vendors that will participate in the market with the current Russian VVER fuel supplier and the market share of each one.

Among the principal benefits of this competition are:

- Lower cost - the most obvious benefit - the current U.S. market is the best example of the result of many vendors vying for a limited amount of business.
- More favorable contract terms and improved vendor cooperation with the customer in such areas as response to problems, sharing of information, etc.
- Accelerated technological development as vendors attempt to make their products more attractive through design improvements which enhance safety, improve fuel performance, expand operational flexibility and reduce fuel cycle costs.

There is also an indirect benefit to the utility's country in that most of the Western vendors have been seeking local subcontractors to provide fuel components and testing and analytical services in association with the supply of VVER fuel. Should any Western vendor obtain a sufficient number of contracts, there is a strong possibility that a VVER fuel fabrication plant might be built somewhere in Eastern Europe.

4 Active and Prospective Participants in the VVER Fuel Market

The current VVER fuel suppliers are TVEL and Westinghouse Electric Corporation (W). Other Western PWR fuel vendors who have bid but not yet secured fuel supply contracts for VVER plants, include Asea Brown Boveri Atom (ABBA), British Nuclear Fuels (BNFL), and European VVER Fuels GmbH (EVF). Their relationship to the international PWR fuels industry is shown on Fig. 1 and discussed below.

TVEL

All of the VVER fuel to date has been supplied by TVEL, an organization within the Russian

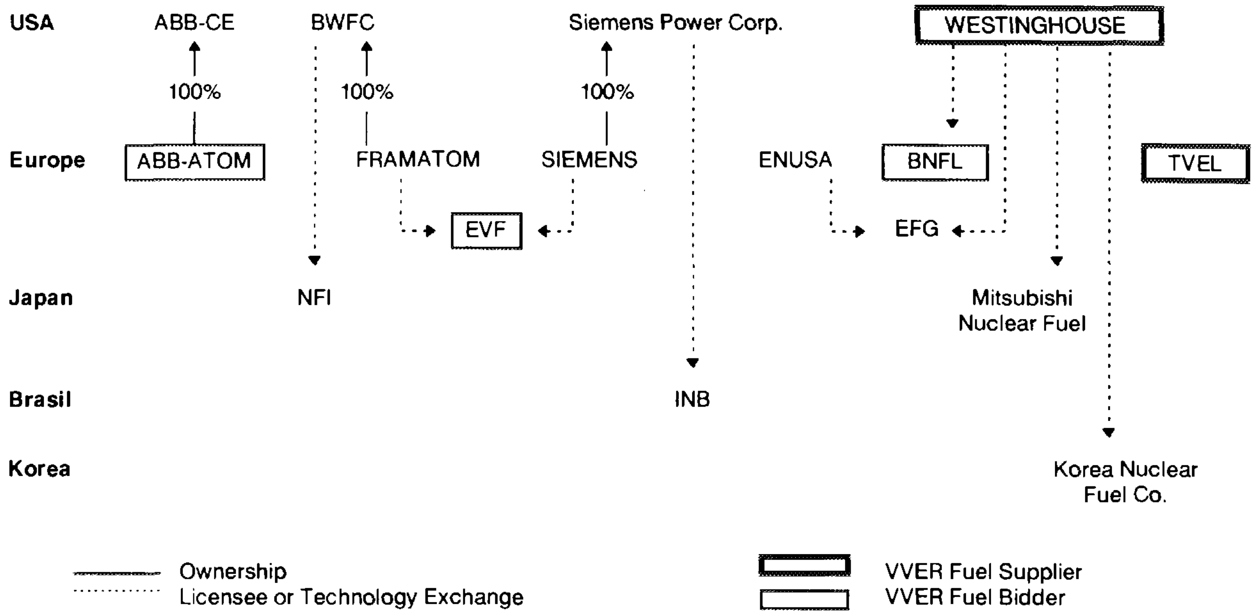

Figure 1 The PWR fuel fabricators

Ministry of Atomic Energy (Minatom), through its marketing and sales organization TENEX. TVEL coordinates the laboratories, design organizations, and fabrication plants to produce fuel for its customers. Within Russia, its customers are also a part of Minatom, and in other countries, the customers are independent utilities resembling Western utilities. The main contributors to the Russian fuels industry are the extensive facilities of the All-Russian Scientific and Research Institute of Inorganic Materials, Moscow; the Kurchatov Institute, Moscow; and Gydropress in Podolsk for design and development work. The fabrication plants and their products are:

⇨ Machinostroitelniy Zavod, Elektrostal
  - UO_2 pellets from UF_6
  - VVER 440 fuel assemblies

⇨ Chemical Concentrates Plant, Novosibirsk
  - VVER 1000 fuel assemblies

⇨ Ulba Metallurgical Plant, Ust-Kamenogorsk (Kazakhstan)
  - UO_2 pellets from UF_6

⇨ Chepetsky Mechanical Plant, Glazov
  - Zirconium alloy tubing, sheet, and rod from ore

The size and the capacity of these facilities exceed those of any Western vendor. All of these organizations are currently part of Minatom, but consideration is being given to restructuring this organization. TVEL and its facilities are expected to continue to be the dominant VVER fuel supplier for at least the near future.

ABB ATOM

ABBA, a privately owned stock company, was primarily a supplier of BWR fuels until it purchased Combustion Engineering (CE), a U.S. firm that designs and builds PWRs and supplies PWR fuel. CE's fuel market is principally for reloads to its own NSSS in the U.S. With the help of CE's expertise in PWRs, ABBA established a PWR reload business in Europe and successfully sold fuel for W reactors in Belgium, Sweden and Switzerland, Framatome reactors in France and Siemens reactors in Germany.

The ABBA fuel design, development and production facilities are in Våsterås, Sweden. The CE design and metal component fabrication facilities are in Windsor, Connecticut and fabrication facilities in Hematite, Missouri - both in the USA.

BNFL

BNFL is a government owned corporation that provides all of the fuel to the UK's gas cooled Magnox and AGCR reactors. They have extensive experience in the production of these fuel assemblies as well as the production of UO_2 pellets from UF_6 for LWRs. Their entry into the PWR fuel fabrication field is relatively recent. Earlier this year, under a W license, they fabricated the first core of fuel for Sizewell B, the first PWR in the UK. They are a member of the European Fuels Group (EFG) which is a consortium of W and two of its licensees, ENUSA in Spain and BNFL, to supply PWR fuel to the West European market.

BNFL's fuel fabrication plant has the capability of providing complete assemblies with metal components provided by W. The plant is located in Springfields, England.

EVF

EVF GmbH, a German corporation located in Offenbach, was created in 1993 specifically for the supply of VVER fuel and is a partnership of 50% Siemens and 50% FRAMATOME and COGEMA of France. EVF represents the two largest PWR fuel vendors in Western Europe. Their facilities are extensive as listed in Table 1 and include

Table 1 Uranium fuel fabrication facilities - PWR/BWR fuel

Region	Owner/Operator	Plant Name&Location	Capacity, *t U/Year*
United States	B&W Fuel Co.	Lynchburg, VA	400
	ABB-CE[1]	Hematite, MO Windsor, CT	300
	Siemens Power Corp.[1]	Richland, WA	700 (to 1,200)
	General Electric[2]	Wilmington, NC	1,000
	Westinghouse	Columbia, SC	1,700
			4,100 (4,600)
Europe	ABB Atom[1]	Vasteras, Sweden	400
	ANF (Siemens)[1]	Lingen, Germany	400
	ENUSA[1]	Juzbado, Spain	200
	FBFC (Framatome)	Dessel, Belgium Romans, France Pierrelatte, France	400 800 250
	Siemens[1]	Hanau, Germany Karlstein, Germany	800 400
			3,250
	VVER Fuel: TVEL	Elektrostal	700
		Novosibirsk (assemblies only)	1,000
		Ust-Kamenogorsk (pellets only)	(2,650)
			1,700
Far East	Japan Nuclear Fuels[2]	Yokasuka City, Japan	750
	Korea Nuclear Fuel Co.	Taejeon, S.Korea	200
	Mitsubishi Nucl. Fuel	Tokai Mura, Japan	440
	Nuclear Fuels Ind.[1]	Kumatori, Japan Tokai Mura, Japan	265 200
			1,855

[1] BWR and PWR Fuel
[2] BWR Fuel Only

zirconium semi-finished product fabrication in France at CEZUS, zirconium alloy tube production in France at Zircotube and in Germany at Nuklear-rohr. FRAMATOME fuel design, development and fabrication facilities are distributed throughout France; and Siemens facilities are located in both Germany and the USA.

In the non-VVER fuel market FRAMATOME and Siemens still compete with each other.

WESTINGHOUSE

W is the largest PWR fuel supplier in the USA and, in addition, has agreements in Europe with EFG, and in Japan and Korea as shown in Fig. 1. The design and development facilities are located in the Pittsburgh, Pennsylvania area and its fuel plant is in Columbia, South Carolina. W contracts include reloads for CE and Babcock and Wilcox NSSS.

In addition, W owns Western Zirconium a producer of semi-finished zirconium alloy products in Ogden, Utah and a zirconium alloy tubing plant in Blairsville, Pennsylvania. In addition to its customers in the U.S., W has supplied fuel assemblies to reactors in Europe and Taiwan. Extensive component supply flows from the USA to its licensees.

Status of New Suppliers in the VVER Market

VVER-1000

The first request for competitive VVER fuel supply bids was issued in 1991 by Ceské Energetické Závody (CEZ) for the first cores and reload fuel for Temelín 1 and 2, a twin unit of 1000*MWe* VVERs under construction in the Czech Republic. W won the contract in 1993 in a competition that included ABBA, FRAMATOME, Siemens and TENEX. The independent technical evaluation of the bids was performed by the Stoller Corporation.

An extensive design and development program is currently in progress to complete and qualify the final design in 1995. The major objectives of the program are to produce a design that meets or exceeds initial performance goals, to assure that the fuel is compatible with the Russian design plant, and to license the core to Czech and U.S. regulatory standards. Some of the advanced features are described in the next section.

The program is carried out in W's facilities in the USA with the exception of cooperative work with Skoda, primarily in the areas of hydraulic testing and plant compatibility. Production of the fuel will be in the USA and the completed assemblies will be shipped directly from Columbia, to Temelín.

VVER-440

The first invitation by VVER 440 owners for competitive fuel supply bids was issued in 1992 by CEZ and Slovenský Energetický Podnik (SEP). It requested reload fuel for CEZ's four Dukovany Units and two of SEP's Bohunice Units, as well as first cores and reloads for SEP's four Mohovce Units. The bidders in this case included ABBA, BNFL, EVF, W and TVEL. The bid evaluation process narrowed the list to EVF, W and TVEL and the current negotiations are expected to identify the winner(s) in 1995. The initial bid evaluation was a joint CEZ-SEP effort, but each utility is negotiating its final contract individually. The Stoller Corporation assisted the utilities in the preparation of the bid specification, the technical, economic and commercial evaluation of the bids and is currently assisting in the contract negotiations.

5 Principal Differences Between Western and VVER Fuels

Physical Features and Related Design Considerations

The most obvious physical difference between Western and VVER Fuels is the square vs. hexagonal lattice geometry. To appropriately evaluate the nuclear behavior of hexagonal lattices, Western vendors have had to modify their existing nuclear codes, and subsequently qualify the calculational capability of the modifications. Existing thermal-hydraulic (e.g., subchannel analyses), mechanical design (e.g., fuel performance, seismic analysis), and safety/LOCA analyses methods are generally directly applicable to hexagonal assemblies with little or no modification. Perhaps the one unique modeling development required by Western vendors to appropriately analyze the spectrum of Condition III and IV events is related to the horizontal steam generator in VVER plants vs. the vertical generators in Western PWRs.

Regarding assembly mechanical design, the design concept of the VVER spacer grids is different from their Western counterparts. The VVER grids act primarily as springs without tight restraint of the fuel rods; the grids are closely spaced to control vibration. The Western grids have a more rigid structure and rod restraint with springs and hard stops and, as a result, fewer grids are needed. If the Western grid concept is to be introduced into VVER fuel, detailed testing and modeling are required to assure the adequate hydraulic, thermal, and mechanical performance of the assembly. There are also significant differences in the designs of the top and bottom nozzles.

Of necessity, all Western fuel assembly mechanical designs must be compatible with the core internals, fuel handling equipment, spent fuel storage, and shipping containers. If reload fuel is being supplied, it must also be compatible with the residual Russian fuel.

Considering thermal and hydraulic parameters, VVER-1000 cores are quite similar to those of Western PWRs, falling somewhere in between Western 3 and 4 loop plants. The VVER-1000 assembly has a somewhat lower water-to-fuel ratio then its Western counterparts which has important nuclear related implications. In neither the VVER-1000 or Western PWRs are assembly shrouds employed; additionally, control rod geometric designs are similar.

On the other hand, the VVER-440s have fuel assembly and core features quite different from either the VVER-1000 or Western PWRs. These include, but are not limited to, shrouded assemblies (which eliminates cross-flow modeling in thermal-hydraulic analyses), and control assemblies which have fuel assembly followers. These raise a potential pellet-clad interaction issue associated with the movement of the fueled portion of the control assembly into the core.

There are also basic material differences between VVER and Western PWRs. All the VVER reactors operate with Zr-1% Nb cladding in a KOH and NH_3 water chemistry, while all Western reactors operate with Zircaloy 4 cladding in a LiOH water chemistry. Both, of course, use boric acid for reactivity control. Since Zircaloy 4 can operate satisfactorily in the more corrosive LiOH atmosphere, its introduction into VVERs should pose no problem, but confirmation is desirable.

The greater hydrogen pickup potential of Zircaloy 4 compared to Zr-1%Nb also needs to be monitored, as would be the greater oxygen sensitivity of Zr-1%Nb if it were to be introduced in Western plants.

The LOCA performance of Zircaloy 4 in VVERs should be satisfactory, based on Western safety testing.

Previously, we alluded to the necessity for mechanical compatibility. For transitional cores (mixed cores containing VVER and Western fuel) there are also nuclear and thermal-hydraulic compatibility issues. The most important of these is pressure drop compatibility to prevent flow starvation of any assemblies.

Operational Considerations

VVERs are currently operated on annual fuel cycles with discharge burnups generally in the low 30*GWd/tU* range. In contrast, current Western PWRs operate annual, eighteen month and two-year fuel cycles with significantly higher discharge burnup levels (mid-40 to low 50*GWd/tU*) leading to longer in-core residence time for fuel assemblies. Annual cycles are prevalent in Western European PWRs, and eighteen month cycles dominate in U.S. PWRs. In the West, the selections of cycle length

Table 2 Principal advanced VVER fuel features offered or under development

FEATURE	MAJOR ADVANTAGES					UNDER DEVELOPMENT BY	
	Reduced Fuel Cycle Costs	Reduced O&M Costs	Pressure Vessel Protection	Improved Fuel Reliability	Improved Operatiing Flexibility	W for Temelin	TVEL
Zirconium Alloy Grids	o	o				✓	✓
Zirconium Alloy Guide Tubes	o	o					✓
Advanced Zirconium Alloys	o	o					
Burnable Absorbers: IFBA	o					✓	
Gd_2O_3	o						✓
Axial Blankets	o					✓	
Optimized Fuel Rod Diameter	o					✓	
Water Rods	o						
Extended Discharge Burnups	o					✓	✓
Advanced In-Core Fuel Management	o		o			✓	✓
Debris Resistance: Filter, Long End Plug				o		✓	
Removable Top Nozzle	o			o		✓	✓
High Performance Spacer Grids	o				o	✓	
Longer Lived Control Rods (VVER-1000)		o				✓	

and discharge burnup are based upon cost/benefit analyses (including fuel costs, O&M costs), operating and system factors (especially cycle length influence on plant availability), and regulatory concerns (including number of interactions with regulators and need for a mid-cycle maintenance outage). In the West, a modest experience base exists for fuel assemblies irradiated in the 45 - 55*GWd/tU* range.

6 Advanced Features Offered by Vendors

The recent competition in the VVER fuels market has been the incentive for the development of advanced design features for the improved reliability, economy and operational flexibility of the fuel. Major advanced design features and their vendors are summarized in Table 2.

The two currently active suppliers, TVEL and W, are developing advanced features that will be, or can be, implemented in the near future. Those under development by W for TemelHn are indicated by a single asterisk on Table 2, and those under development by TVEL by a double asterisk. Given sufficient time and development funds, it is Stoller's belief that both TVEL and all Western vendors can provide the entire range of features shown on Table 2. Comments on Table 2 follow.

Zircaloy 4 grids and guide tubes are part of the W Temelín fuel design and are also offered by other Western vendors. TVEL has Zr-1%Nb grids under irradiation in LTAs and offers these as an option.

All of the vendors offer designs that have the nuclear and mechanical capability to achieve higher burnups. Advanced fuel management cores, low leakage fuel management for example, are also offered. Low leakage fuel management and perhaps longer and higher burnup fuel cycles increase the demand for burnable absorbers. For such applications, fuel suppliers are moving away from so-called discrete burnable absorbers which occupy guide thimbles, to integral burnable absorbers which are mixed with or are on the surface of the UO_2 fuel. Typical among these are gadolinia mixed with the UO_2, and ZrB_2 deposited upon the cylindrical fuel pellet surfaces. The former is used by all vendors except W, the latter is being provided by W to Temelín, and is in commercial use in Western fuel. Advantages of the integral burnable absorbers include better power distribution and moderator temperature coefficient control, lower end-of-cycle residual reactivity penalties and elimination of separate handling and disposal.

Although debris has not been a problem in VVERs, debris resistant features are available. For example, long lower end plugs in fuel rods will be delivered to Temelín by W.

Removable top nozzles (RTN) to permit replacement of failed fuel rods, rather than replace the entire assembly, will be part of the design delivered by W to Temelín. TVEL has designed and built several LTAs with this feature and intends to irradiate them. Versions of RTNs for VVER fuel have also been designed by the other vendors. The application of RTNs necessitates repair stands for the spent fuel pool which are offered by the vendors as well. W is in the process of designing the first one for Temelín.

The current VVER 1000 control rods are life limited by B_4C swelling, irradiation assisted stress corrosion cracking (IASCC) of the steel clad, and B_4C washout. The W Temelín design, and those offered by other vendors, will use AgInCd alloy in their tips, the point of highest exposure, to extend the control rod life.

7 Entering the Competitive Marketplace

Most VVER reactor operators have not yet been involved in a competitive fuel procurement. For those contemplating such a procurement, we offer a few suggestions.

- ⇨ Become familiar with the various vendors and their products and services. Invite the vendors to visit your facilities to make presentations and hold discussions on how they can satisfy your requirements.
- ⇨ Involve all areas of your company in the process, including engineering, operations, purchasing, economics and finance.
- ⇨ Prepare well thought out, detailed bid specifications defining your technical, economic and commercial requirements.
- ⇨ Perform comprehensive evaluations of the technical, economic and commercial portions of the proposals with emphasis on development of VVER fuel designs and analytical methods and licensing the fuel and methods in your country.
- ⇨ At the conclusion of the evaluation, and to ensure that competition is maintained, develop a short list of no more than two or three vendors and negotiate the final contracts with each before making the award.

The political and market changes of the past several years have opened a new era in fuel procurement for VVER reactor operators. It is an era filled with challenges for the utilities and there will undoubtedly be some bumps in the road.

We are convinced, however, that the rewards of participating in the new VVER fuel market will far outweight the effort involved.