Expanding on the VVER Fuel Market

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Abstract

Entering a new fuel market is not only about signing a fuel contract. Entering a fuel market that has no previous experience of mixed cores is even more challenging.

Westinghouse has previously presented the work performed in the UNFQP program, where personnel from the CRCD were trained in core engineering and design at Westinghouse facilities in the US. The program provided Energoatom with an independent partner for licensing and core engineering activities in Ukraine.

In addition to development and license a compatible fuel design, there are many other factors that need to be addressed in order to be able to load and operate fuel from a new vendor.

A common licensing approach for mixed cores in most European countries is that the new vendor demonstrates, by tests and analysis, that their fuel design meets the criteria of the existing safety evaluation. Hence, a new full safety evaluation is not required when fuel from a new vendor is loaded.

Transport containers have to be licensed and tested to ensure compatibility for each transport route and at each site.

Inspection and repair equipment need to be flexible to allow for various fuel designs.

Core monitoring system is another area to consider. The system needs to be able to model different fuel designs. If the core monitoring system has the capability to model different fuel designs, the utilities or its independent partners should have the competence to set up the models.

Westinghouse experience with all of these various aspects related to expanding on the VVER fuel market will be further developed in this paper.

1. Introduction

Within the Ukraine Nuclear Fuel Qualification Program (UNFQP), a full qualification of a new fuel design in a mixed core was completed in South Ukraine NPP. The qualification was performed by Westinghouse and the United States Department of Energy, through the Pacific Northwest National Laboratory (PNNL). In addition to design development, the program started with training of engineers from Ukraine of the Westinghouse codes and methods. This was followed by licensing and introduction of Lead Tests Assemblies (LTAs) as well as licensing of new transport containers, a new core monitoring system and an inspection and repair equipment. The program was concluded with reload licensing and delivery, and the subsequent inspection campaign after each cycle until the fuel was removed from the core after the planned four cycles of operation.

Unforeseen issues with first time introduction can be resolved more easily in a small scale LTA program than in a reload delivery on critical path for the outage schedule. The purpose of an LTA program is hence not only to show the operational experience of the new fuel design, it is also to get experience on a smaller scale (as compared to a reload) of the applicable licensing requirements and approach with a new regulator, of the licensing of transport container as well as establishing the manufacturing capabilities, the transport routes and the fuel handling routines. In addition, a core monitoring system and fuel inspections/repair equipment capable of handling fuel assemblies of different designs need to be installed and fully operational at site for full reloads.

Westinghouse experiences of expanding on the VVER fuel market with focus on the different aspects, shown in the Figure below, will be further discussed in this paper.
2. Compatible design - westinghouse VVER-1000 fuel assembly design development

Significantly different from the Westinghouse VV6 Temelin fuel assembly design, the WFA (Westinghouse VVER-1000 Fuel Assembly) and later the RWFA (Robust WFA), were designed to be 100% compatible with resident fuel design of other VVER-1000 reactors, and, very importantly, to perform safely in mixed core transitions and to excel reliably and economically in equilibrium core operations.

The development of the WFA LTA- and Region designs have earlier been presented in the 7th and 9th International Conferences on WWER Fuel Performance, Modelling and Experimental Support in 2009 and 2011, respectively, see References 1 and 2. A separate paper for the Enhanced Westinghouse VVER-1000 Fuel Design for Ukraine Reactors, the RWFA, was presented at the 11th International Conferences on WWER Fuel Performance, Modelling and Experimental Support, 2015, see Reference 3.

Currently, Westinghouse is developing a fuel design based on the RWFA design that will be compatible with the resident fuel in Temelin NPP.

3. Licensing

A common licensing approach for mixed cores in most European countries is that new vendors show, by tests and analyses, that their fuel design meets the criteria of the existing safety evaluation. Hence, a new full safety evaluation should not be required when fuel from a new vendor is loaded.

When a new fuel design is introduced, a review of the plant analysis of record (AOR), usually FSAR (Fuel Safety Analysis Report) and other relevant documents is performed to identify which analyses are fuel-dependent and need to be part of the licensing analyses. The main source of the reference safety analysis is the plant FSAR Chapter 4, 6 and 15. From the identified analyses it is also determined which are one-time analyses, and therefore only needed to be verified for the introduction of the fuel the first time, and which are cycle-dependent and need to be verified each subsequent reload.

As a result of the evaluation each analysis should fall into one of the following categories:

- Affected by the introduction of a new fuel design, and is potentially limiting requiring that the event is verified for each reload.
- Affected by the introduction of a new fuel design, but not by different reloads with that design requiring that the analysis is verified for the introduction of the new fuel design, but not for subsequent reloads.
- Potentially affected by a new fuel design, but is bound by a more limiting event of the same frequency category.
- Not affected by the introduction of a different fuel type.

It is necessary to demonstrate compliance with the applicable safety requirements for both mixed and homogenous cores.

Other areas of concern are the qualification of methods and methodologies needed to license a new fuel design. The European approach is usually not to “license” a code or a methodology but it is necessary to present a sufficient verification and validation basis for regulatory approval.

3.1. Exchange of third party data and split scope

Establishing and mutually agreeing on the initial inputs and assumptions list is a critical initial task in a fuel licensing project. The level of details in the data to be exchanged between fuel suppliers must be agreed very early in the fuel licensing process because the licensing analyses will not be able to start until this data is made available.

One approach that will limit the amount of proprietary information exchange between fuel suppliers is to agree on a split scope, where the utility or a third party supplier carries out parts of the analyses work. This approach has been very successful during the introduction of Westinghouse fuel in Ukraine. The CRCD as an independent Ukrainian supplier has the capabilities to carry out the major part of a licensing scope where proprietary fuel data is needed.

3.2. Licensing of LTAs

Since an LTA batch typically only contains six fuel assemblies in a VVER core the fuel licensing for an LTA program can be limited in scope. Through fuel rod design, thermal-hydraulic and nuclear design calculations in combination with evaluations of design basis events, it can be demonstrated that the LTAs can meet the applicable acceptance criteria for design basis events, are not limiting, do not significantly impact the core characteristics (such as the range of reactivity coefficients) and...
do not adversely impact the resident fuel.

A typical approach when licensing LTAs is to model a reference cycle in order to define the LTA composition and core design model with LTAs. The typical reference cycle model will be generated using the resident fuel assemblies only. It is then assumed that six resident fuel assemblies in the typical reference cycle design model are replaced with six LTAs without any additionally assembly or core design modifications. The LTAs will be placed in the typical reference cycle core model in non-limiting core power locations, potentially with a power peaking penalty, and the key safety parameters for the core will be confirmed.

Compliance with the present design basis shall be demonstrated and the existing safety analyses of record for the NPP (Transient Analyses, large break LOCA analyses, small break LOCA analyses) will remain applicable as-is. Margins for mixed core situations must be specifically studied and quantified as part of the licensing. Due to hydraulic mismatch between the different fuel designs, a power peaking penalty will need to be assigned to the fuel design having the highest pressure drop.

The non-LOCA and LOCA safety evaluation for the insertion of the LTAs relies on the nuclear and thermal-hydraulic design calculations demonstrating that certain key design characteristics apply to the core with the LTAs inserted. Since these characteristics will be confirmed for a core with LTAs, the existing licensing basis analyses remain valid. The key design characteristics are as follows:

- The presence of the LTAs does not adversely alter (design limit are not being reached) the overall response of the core to the current licensing basis design transients.
- The presence of the LTAs does not adversely impact the resident fuel.
- The LTAs themselves are in non-limiting locations, which means that all the rods in the LTAs will produce less power than the hot rods of the core. The margin in peak power between the LTAs and the resident fuel must be sufficient to offset any transition core effects that may reduce relative flow to the LTAs and fuel feature differences that introduce LOCA Peak Clad Temperature (PCT) penalties.
- The LTAs can meet the same nuclear and thermal-hydraulic safety limits as the resident fuel.

Individual assessments for all design basis events shall be documented. Each evaluation will explain why the applicable safety analysis limits for the event being considered will continue to be met with the LTAs in the core. As a result of these assessments it could be necessary to perform certain calculations to verify compliance with the safety criteria.

3.3. Reload licensing

A utility can choose either to go with LTA licensing with limited scope as described above or directly perform a licensing for reload quantities. Licensing of codes, methods and fuel rod design are the same for LTA and reload licensing.

The main differences between a reload licensing and an LTA licensing are the increased scope of nuclear and core calculations and potential re-calculations of certain design basis events. Also an extended radiological evaluation might be required for reload quantities of a new fuel design.

The nuclear design of the fuel and the core shall confirm that key safety parameters such as reactivity coefficients are met and therefore it is necessary to model typical transition and equilibrium cores for the introduction of new fuel. Due to hydraulic mismatch between different fuel designs a power peaking penalty will be assigned to the design having the highest pressure drop.

After the review of the plant AOR it should be identified which analyses are fuel-dependent and need to be part of the licensing analyses. From the identified analyses it is also determined which are one-time analyses, and therefore only needed to be verified for the introduction of the fuel the first time, and which are cycle-dependent and need to be verified each subsequent reload.

4. Transport and fuel handling

Each fuel vendor has their own qualified transport container that is licensed for a specific fuel design in the countries currently used for transport. Hence, when expanding on a new market the transport container needs to be licensed and certified with the regulator on this market. In addition, a transport route needs to be established including the approval for transport through various countries along the route.

To complete the fuel delivery, the procedures and training of personnel for transport container and fuel handing at site need to be implemented.

Furthermore, training and procedures for fuel handling during outages for core unloading, loading and inspections should be established.
5. Inspection and repair equipment

For full evaluation of the operational performance and for potential repair of a new fuel design, fuel inspection and repair equipment should be available at each site. This equipment should be sufficiently flexible to allow for different fuel design. One example is the fuel inspection and repair equipment at the Temelin site that was designed and installed with a full core of Westinghouse fuel design, but has been functional also for inspections of the current resident fuel.

The fuel inspection and repair equipment used at South Ukraine and Zaporizhzhya NPPs supports full scope visual inspections as well as measurements of oxide, bow, twist, fuel assembly length, grid width and RCCA drag forces. In addition, equipment for detecting leaking fuel rods as well as for fuel reconstitution is included. The results from the latest inspection in Ukraine will be presented in a separate paper “Performance of the Westinghouse WWER-1000 fuel design, 2017 Update” at the 12th International Conferences on WWER Fuel Performance, Modelling and Experimental Support, 2017, see Reference 4.

6. Core monitoring

To support a fuel transition and different mixed core situations, the core monitoring system must be able to model different fuel designs. To avoid exchange of proprietary data between fuel vendors and for independence reasons, a utility or its independent partners should have the competence to set up the models for the core monitoring system.

The Westinghouse BEACON™ system meets all these requirements and supports plant operations with core monitoring, core measurement evaluation, core analysis and tracking, and core predictions. The BEACON system uses measurement data from the plant together with a three dimensional analytical nodal model to yield a continuously measured three-dimensional power distribution. This allows BEACON to offer a variety of core support functions.

BEACON has demonstrated its capability to model different fuel design in numerous plants around the world. Examples of VVER implementations are in Temelin NPP, South Ukraine 3 and Zaporizhzhya 5.

In Temelin, the BEACON system was primarily implemented to monitor homogenous cores with Westinghouse VVANTAGE6 fuel design. After ČEZ decision to transition to TVSA-T fuel there was no need to change the core monitoring system and the monitoring continued with BEACON for homogenous cores of TVSA-T. ČEZ had also obtained the necessary tools and training to independently create and implement BEACON models so there was no dependence on Westinghouse to continue using BEACON.

In South Ukraine 3 and Zaporizhzhya 5, BEACON has been used to monitor mixed core with Westinghouse WFA/RWFA fuel designs and the TVSA fuel. CRCD has all the time had the capability to create BEACON models and just recently ZNPP obtained the necessary tools and training to independently create and implement BEACON models.

7. Manufacturing capacity

In order to expand on a new market, the manufacturing capacity has to be ensured. The fuel supplier has to be able to show qualified processes with increased capacity.

Westinghouse has made substantial investments to obtain increased capacity to manufacture the VVER fuel designs.

The spacer grid manufacturing at the Westinghouse site in Columbia South Carolina, USA has been expanded. The fuel assembly manufacturing at the Westinghouse site in Västerås, Sweden has been up-graded with a new fuel-rod-loading equipment as well as an expanded fuel assembly storage area, facilitating the increased number of VVER fuel assemblies being produced.

8. Conclusions

- Unforeseen issues with first time introduction of a new fuel design can be resolved more easily in a small scale LTA program than with a reload delivery on critical path for the outage schedule.
- A full safety evaluation should not be required when fuel from a new vendor is loaded, instead it is shown that the new fuel design meets the criteria of the existing safety evaluation
- To limit the amount of proprietary information exchange between fuel suppliers a split scope can be agreed upon where the utility or a third party supplier carries out parts of the analyses work.
- When expanding on a new market the transport container needs to be licensed and certi-
fied with the regulators in affected countries.

- To support a fuel transition and different mixed core situations the core monitoring system must be able to model different fuel designs.
- Each utility should be able to independently create and implement models for the core monitoring system.

References


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