

OPTIMA3 - when flawless fuel performance becomes a reality

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Fuel failures and enhanced channel bow are the most challenging issues to a majority of all boiling water reactor (BWR) fuel operators. With SVEA-96 Optima3, Westinghouse has developed a fuel design that has the potential to operate flawlessly. The risk of debris failures has been effectively reduced through the combination of a new spacer design and the enhanced TripleWave+™ debris filter. To minimize channel distortion a new channel material, Low-Tin ZIRLO™, has been implemented and measurements show that the channel bow has been effectively reduced. More than 500 Optima3 fuel assemblies have already been delivered, and the operating experiences up to more than 50 MWd/kgU, as well as the performed inspections, confirm the anticipated behavior and function.

Los fallos de combustible y las mejoras en las deformaciones por arqueamiento del canal son los desafíos más importantes a las que se enfrentan la mayoría de operadores de BWR. Con SVEA-96 Optima3, Westinghouse ha desarrollado un diseño de combustible que posee el potencial de operar sin fallos. El riesgo de fallos por restos ha sido reducido eficientemente con la combinación de un nuevo diseño de espaciado y un optimizado filtro para restos TripleWave+™. Para minimizar la distorsión del canal de combustible un nuevo material, Low-Tin ZIRLO™, se ha implementado mostrando las medidas que el arqueamiento del canal se ha reducido. Más de 500 elementos combustible Optima3 han sido entregados, y la experiencia en operación de hasta más de 50 MWd/kgU, así como las inspecciones realizadas, han confirmado las expectativas en comportamiento y funcionalidad.

THE IMPORTANCE OF FUEL RELIABILITY

For many years and on many occasions Westinghouse has asked its customers about the key parameters to consider when developing new boiling water reactor (BWR) fuel designs. With almost no exception the answer has been: "reliability". This is understandable since not only does a fuel leak cause a lot of extra work and operational uncertainties, it can ultimately force a utility to an unplanned mid-cycle outage to unload the failed fuel assembly. Such disruptions often result in costs which far exceed the economic advantages of design features implemented to improve the neutron economy. This very clear message about priorities from the customers guided and inspired Westinghouse to develop its most recent fuel design, SVEA-96 Optima3 – or simply Optima3 when written without its family name.

1 + 1 = 0

Studying the operating data of Westinghouse 10x10 liner fuel with the current fuel cladding material, we could conclude that all determined

failures originate from debris fretting. In most cases the debris enters the fuel assembly with the coolant and can potentially get caught by a spacer grid on its way through the fuel assembly. Once captured by a spacer, the debris can be brought to very rapid oscillation by the coolant flow. If such debris is in contact with a fuel rod, the high frequency of the oscillations can rupture the cladding within a few days. Long and slender debris, such as small pieces of metal, are particularly harmful.

A common remedy, applied by all BWR fuel suppliers, is to equip the fuel assembly with a debris filter in the bottom where the coolant enters the assembly. This has been proven to be an effective measure, and operating experience shows that the most advanced filters can significantly reduce the number of failures. However, a filter must allow sufficient coolant to the fuel rods, also under anticipated events where massive amounts of smaller debris particles are released and may potentially clog the filter. Consequently, the filter must allow small debris to pass through. Larger



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debris that is captured by the filter tends to break up over time and the resulting smaller pieces can escape the filter and enter the assembly.

Debris which has passed through the assembly will follow the recirculation flow path and return at the bottom of the core after a few minutes. Each time the debris enters the fuel assembly there is a small probability that it will get caught at each spacer level. Considering the number of opportunities for the debris to get captured, the importance of the design of the spacer becomes evident.

The Optima3 design is equipped with the debris filter TripleWave+™, which has been proven to effectively capture debris exceeding 10 millimeters. Operating experience also clearly indicates a significant decrease of the debris-induced failures in fuel assemblies equipped with the TripleWave+ filter. However, due to the required margins to clogging and pressure drop limitations the debris filter could not be designed to capture smaller size debris.

To address smaller size debris Westinghouse realized that the design of the spacer had to be changed. The new spacer design of Optima3 resembles the shape of a honeycomb, consisting of almost identical thin straps that are formed into individual cells. The cells are placed side-by-side inside a frame and welded together. The manufacturing process has been completely automated, which has enabled excellent precision. The flexible walls of each spacer cell replace the dimple-spring concept used in traditional spacers, and thereby the contact points and openings with potential to catch debris have been eliminated. Moreover, each cell is curve-shaped to guide debris away from the fuel rod. The debris will immediately pass the spacer, or may rest at a safe location underneath the spacer where the curved cell provides efficient protection of the fuel rod. From that location, the debris is too short to reach a neighboring fuel rod (large debris will not pass the TripleWave+ filter).

What makes the Optima3 fuel assembly unique is the combination of the two features: the TripleWave+ debris filter and the new spacer design. By adding the functionality of the two it is believed that the ultimate goal of zero fuel failures can be achieved, in other words, one plus one equals zero.



Debris enters the bottom of the fuel assembly with the coolant flow. The recirculation of the flow gives the debris a very large number of attempts to get caught in a spacer during a cycle of operation.

MINIMIZED CHANNEL DISTORTION

The family name “SVEA” was introduced in 1980 in conjunction with the implementation of a water cross structure inside the fuel channel. The main purpose of the cruciform structure and its central water canal was to improve the moderation of the fuel assembly, but it was also found to provide excellent mechanical support. The SVEA channel has proven to have less bulge (since the free length of the wall is only half as long) and better flexibility (due to a thinner channel wall). The flexibility is important, since it means that the fuel channel will easier give way in case of mechanical contact with a control rod during maneuvering.

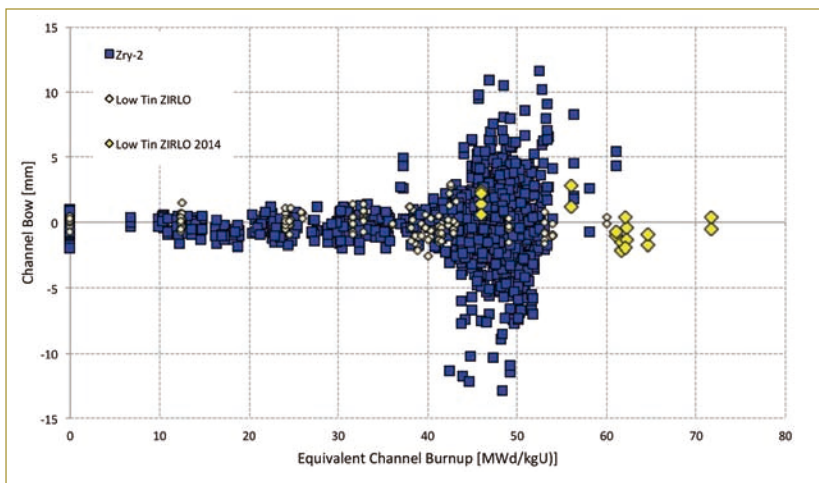


Optima3 retains the SVEA channel design, but incorporates Low-Tin ZIRLO material.

Today, many utilities are struggling with channel distortion issues as a result of higher average burnup and 24-month cycle operation with control rods inserted adjacent to fresh fuel. The most obvious consequence of excessive bow is mechanical interference with the control rods. Since a distortion changes the geometry of the core, there is also an impact on the power distribution, which leads to a less effective fuel utilization, as well as reduced dryout and thermal margins. The extra management of the channels due to distortion, and sometimes also premature replacement, cause the utilities significant costs.

The main distortion mode of the channel is caused by bowing. Bowing is a result of differential growth – meaning that one side of the channel grows faster than the opposite side, which forces the channel to bow. Differential growth is caused by the variation of the fast neutron flux in the core, for example, the channel wall facing the core periphery is usually exposed to a lower flux than the opposite wall facing the center of the core. Although there are means to reduce the effects from the gradients in the neutron flux, it is a difficult condition to control.

Following the transition, especially in the U.S., of many reactors from annual to 24-month cycle operation, some BWR units started to report observation of enhanced channel bow. This type of bow could not



The diagram shows the measured bow of regular Zry2 and Low-Tin ZIRLO fuel channels. The Low-Tin ZIRLO channels have successfully limited the channel bow to a level of 3 mm.

be explained by the regular (fluence gradient-driven) differential growth only. Instead, it was concluded to be caused by the presence of a control rod early in life of the fuel assembly, which is common for cores operating 24-month cycles. The control rod causes shadow corrosion to the two sides of the channel it is facing, which leads to hydrogen uptake of the channel. This early-life hydrogen pickup causes an enhanced irradiation growth later in life, that is, an increased differential growth and consequently an enhanced bow. The mechanisms are only partially understood, but the phenomenon was clearly demonstrated under the Nuclear Fuel Industry Research Program managed by the Electric Power Research Institute.

Westinghouse's solution to address channel bow, in particular the enhancement caused by early life shadow corrosion, was to introduce a new Low-Tin ZIRLO™ material, known from pressurized water reactor (PWR) experience to have very low rate of irradiation-induced growth and hydrogen pick-up. As shown in the next section, extensive operating experience, as well as channel growth and bow measurements, confirm the improved behavior. It can therefore be concluded that the Low-Tin ZIRLO channels of Optima3 has the properties needed to keep the channel distortion at a minimum.

OPERATING EXPERIENCE CONFIRMS THE ANTICIPATED BEHAVIOR

To date, more than 500 Optima3 fuel assemblies have been delivered to seven BWR units, with the leading fuel assemblies at an average bur-

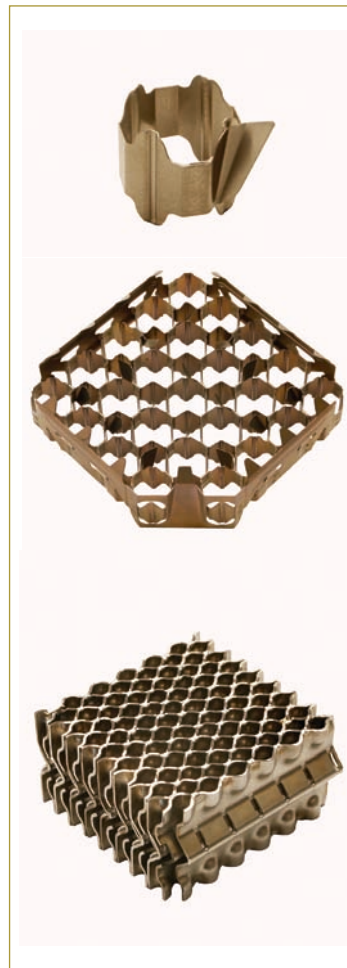
nup of between 50 and 55 MWd/kgU. Several inspections and measurements have been performed, verifying the expected behavior. Optima3 does include several new mechanical features, such as free-standing rods (resting on the bottom tie plate), replacement of the top tie plate with an additional spacer, a modified bottom

tie plate and most importantly, the new spacer design. The inspections of these components confirm the anticipated behavior and function.

The first full reload with Low-Tin ZIRLO channels was delivered in 2011, and the experience base now encompasses 670 channels. The Low-Tin ZIRLO channel material has been verified to very high burnup (more than 70 MWd/kgU), as well as full lives in 24-month cycle operation in locations with extensive control rod presence early in life. The diagram below shows that, despite the challenging operating conditions, the bow of the Low-Tin ZIRLO channels has been limited to a level of 3 mm.

FLAWLESS FUEL BECOMING A REALITY

A long-term ambition of the Westinghouse Electric Company has been to create a product that addresses the reliability concerns raised by the BWR utilities. With Optima3, a fuel design that has the potential to operate flawlessly both with regard to fuel failures and channel distortion has become a reality. ■



OPTIMA3 SPACER

The spacer sleeve is formed from thin sheets and shaped to provide four linear supports to the fuel rod. The simplified design improves reliability while retaining flexibility. The design

- is less prone to catching debris – flexible cell walls replace dimple-springs,
- has unmatched mechanical strength due to the elastic interaction between neighboring cells,
- provides lower two-phase pressure drop, which provides a better protection against core instabilities,
- uses less material and experiences less parasitic absorption,
- shows improved dry-out performance for better operating margins,
- has larger margins to grid-rod fretting – the new spacer sleeve design provides long linear contact rather than point contact with the rod.

TRIPLEWAVE+ DEBRIS FILTER

The TripleWave+ name refers to three successive barriers to debris passage: two perpendicular to the inlet and outlet flows and one parallel to the center.

Thinner, more closely spaced plates with a slightly different shape increases its catching abilities, further minimizing the risk of debris-induced fretting. In fact, testing confirms that it provides three times better catching efficiency than its predecessor.